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Prepared by Joint Venture of SMEC International Pty. Ltd., Rehman Habib Consultants Pvt. Ltd. and Engineering General Consultants, and in association with Asian Advisory Services

Punjab, Pakistan

For Punjab Irrigation Department

Asian Development Bank

Punjab Irrigation Department

ADB
ASIAN DEVELOPMENT BANK

JFPR
Japan Fund for Prosperous and Resilient Asia and the Pacific

From the People of Japan

CDTA 9255-PAK: Institutional Transformation of the Punjab Irrigation Department to a Water Resources Department

INDUS RIVER BASIN PLAN

December 2021

SUBMITTED BY JOINT VENTURE OF

SMEC
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RHC

Engineering General Consultants

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ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	Description
ADB	Asian Development Bank
AP	Affected person
AWDO	Asian Water Development Outlook
CDTA	Capacity Development Technical Assistance
the Consultant	SMEC International
DB	Design and build
DBB	Design, bid, build
DSS	Data Support System
DRM	Disaster Risk Management
DTW	Depth to Water
EIA	Environmental impact assessment
EMP	Environmental management plan
EOI	Expression of Interest
E-R Model	Entity Relationship Model
FGD	Focus group discussion
GoP	Government of Pakistan
GWP	Global Water Partnership
ICT	Information and Communication Technologies
IT	Information Technology
IEE	Initial environmental examination
IWRM	Integrated Water Resources Management
m	metre/s
MAR	Managed Aquifer Recharge
MOU	Memorandum of understanding
MOM	Management Operation and Maintenance
MPW	Ministry of Public Works
NGO	Non-government organisation
PMO	Project Management Office
PMU	Project Management Unit
PMIU	Project Monitoring and Implementation Unit
PIAIP	Punjab Irrigated Agriculture Investment Project
PIDA	Punjab Irrigation and Drainage Authority
PID	Punjab Irrigation Department
PPP	Public private partnership
PS	Provisional sum
PWA	Punjab Water Act
PWP	Punjab Water Policy
PWRC	Punjab Water Resources Commission
PWSRA	Punjab Water Services Regulatory Authority
QA	Quality assurance
RAP	Resettlement action plan
RBA	River Basin Authority

Abbreviation/ Acronym	Description
RBP	River Basin Planning
ROW	Right of way
RP	Resettlement plan
RPF	Resettlement policy framework
SDD	System Design Document
SDG	Sustainable Development Goals
SRD	System Requirement Document
SRS	System Requirement Specifications
TA	Technical assistance
TBA	To be advised
ToR	Terms of reference
WHO	World Health Organization
WRD	Water Resources Department
WRIS	Water Resources Information System
WRIMS	Water Resources Information Management System
WRMP	Water Resources Management Plan
WRRA	Water Resources Regulatory Authority

EXECUTIVE SUMMARY

Over the last 60 years most countries have developed their water resources with construction of large dams and other infrastructure to store and regulate water which has produced substantial economic and social benefits. In many countries there is little additional water to exploit and increasing competition between existing and new users for available water, as urban populations increase, priorities for water use change and climate change affects water availability. As a result, there has been a shift away from 'technical' and Master Planning approaches for basin planning, to more strategic Integrated Water Resources Management (IWRM) approaches.

An important part of this approach is the management of water resources at a basin scale, recognising the connection between all water resources in a basin and its uses. Resolution of competing interests over access to water, particularly in dry times, can only be addressed at the river basin scale.

The primary purpose of water resources and river basin management is:

- Equitable sharing of the river basin's connected water resources (quantity and quality, surface and groundwater) between the different and competing water using sectors, including the environment.
- Water resource protection (quantity and quality) to ensure access to acceptable water resources for present and future generations.
- Bulk water supply to all water users in a fair and equitable manner.
- Manage water in an integrated and balanced way, recognising all costs and benefits.

The River Basin Plan (RBP) (**Figure E1**) involves firstly making a detailed basin assessment (river basin profile), which provides a benchmark of water related issues in the basin, to map a way forward to improve economic, social and environmental outcomes. In due course the RBP comprises priority thematic plans that regulate water use in the basin and will result in the different water using sectors developing their own plans, consistent with the RBP requirements. The plan is also likely to identify hotspot locations (certain rivers, urban, irrigation areas, watersheds) in the basin which require urgent action to address local problems such as river conditions, water quality, salinity, water availability.

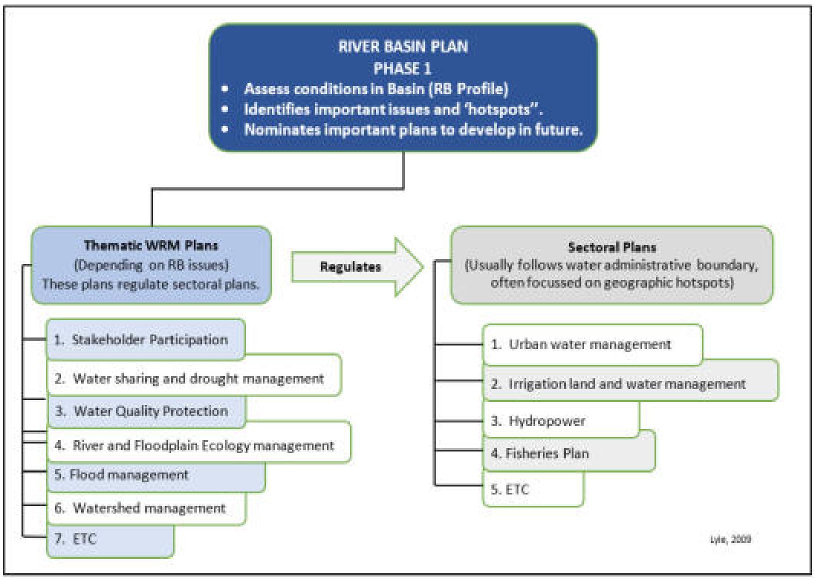


Figure E1: Structure of a River Basin Plan

The river basin planning process (**Figure E2**) is cyclical. Development of the first Plan will take several years and should then be revised regularly (eg. every 5 years).

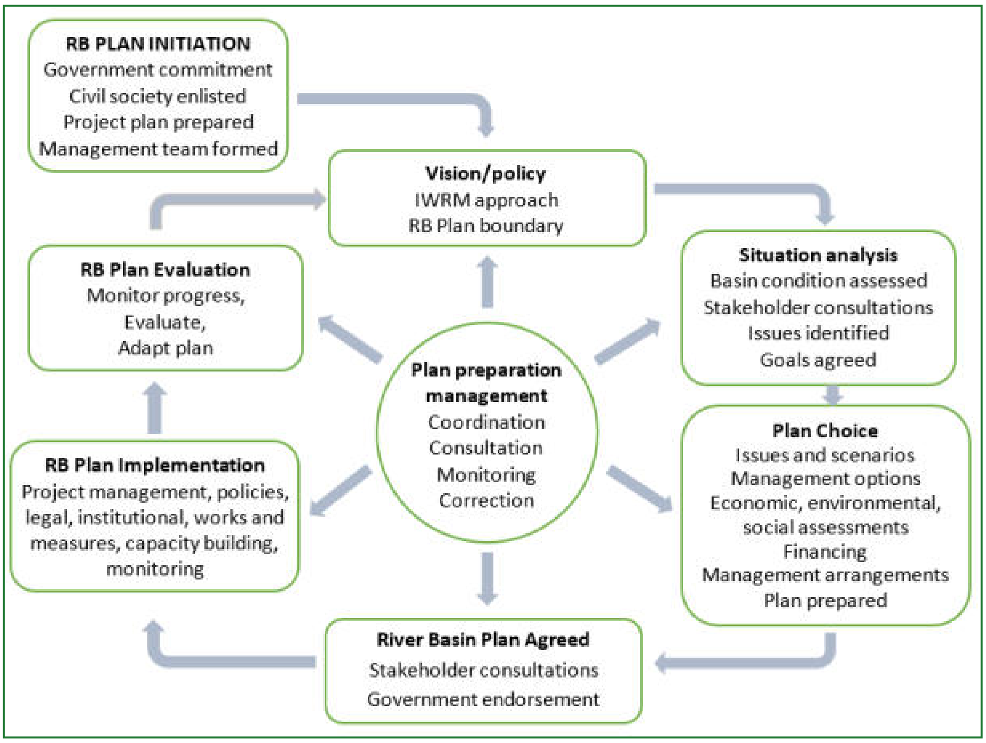


Figure E2: The River Basin Planning Process

Critical to the development and success of a RBP are:

(i) Strong and capable project management and technical specialists.

(ii) Information and information management/assessment tools such as GIS, remote sensing, monitoring data, surface and groundwater models, DSS tools. This capacity is developed continuously to improve successive plans.

(iii) Participation of water using sectors (government and non-government) as well as other members of civil society.

(iv) Involvement of leaders to that the plan receives final government endorsement.

(v) Links from the agreed Plan into government budget cycles.

This report on the Punjab Indus River Basin is in effect a River Basin Profile, or situation analysis, in the above diagram. It was developed without the usual extensive stakeholder consultation, which was prevented because of the covid 19 situation. This executive summary provides an overview of the findings. More detailed findings and recommendations are to be found in the respective chapters.

An Overview of Punjab River Basins

Punjab has a large population of 110 million (2017) and a very large irrigation system, which together place a high demand on the available water resources. Agriculture is important to the provincial economy, contributing 21% of the GDP and employing 47% of the work force. Half of the population of Punjab lives in rural areas, where poverty is as pervasive as it is in the slums of urban areas. About 31% of the Punjab population live below the poverty line, compared to 40% in Pakistan on an overall basis. About 45% of the rural population is landless and 44% of rural households derive their income

either directly or indirectly from agriculture. Government policy is pushing to restructure agriculture to improve productivity and to produce higher value crops to improve economic conditions.

Punjab has 4 seasons: (i) the hot-dry, pre-monsoon (April to June) (ii) the slightly less hot but humid monsoon season (July to September), (iii) the cooler / mild and mostly dry season (October to November) and (iv) the cold rain season (December to March). Annual temperatures typically range from -2°C to 45°C.

The geography of Punjab can be sub-divided into:

a) the extensive and flat alluvial plains of central Punjab. This area is transacted by five rivers the Indus, Jhelum, Chenab, Ravi and Sutlej. The land between each of these rivers is flat and referred to as Doabs. These plains comprise deep, fertile alluvial deposits with associated alluvial aquifers. Irrigation is extensive in this area.

b) the Pothohar area in the north of the Province, near Islamabad. Annual rainfall is about 750 mm and crops are mostly rainfed, although small tanks are becoming common.

c) the Piedmont deposits of the Sulieman range to the west of the Indus River, where annual rainfall is 125-130 mm. The hill torrent areas are located here, along with two smaller irrigated command areas KG Khan and CRBC.

d) the Cholistan desert to the south of Punjab.

The main rivers the Indus, Jhelum, Chenab, Ravi and Sutlej emanate from upstream countries. The latter four combine as the Chenab, which is the main tributary of the Indus River. It is of significance that the runoff upstream of Pakistan from the Ravi and Sutlej rivers is allocated to India under the Indus Waters Agreement. Smaller rivers, including the Haro and Soan, flow from the Pothohar plateau on the right bank of the Indus river. The Kabul river originates in Afghanistan and flows though Khyber Pakhtunkhwa Province (KPK), before entering Punjab and joining the Indus river.

In Punjab, surface water is mostly allocated for agriculture and groundwater is the property of the land holder. Groundwater is the main source of urban and rural drinking water. The dominant water user is agriculture. About 50% of the cultivated area in the province is irrigated and about 50% of the irrigation water is derived from groundwater. Other water users include cities, towns and a wide range of industries spread across the province.

The province has extensive irrigation water supply infrastructure with 13 barrages, 25 main canals with a combined length of 6,390 km, 13 inter-river link canals with a length of 845 km, 2,794 distributary canals with a length of 31,000km and 58,000 canal outlets within the five rivers (Indus, Jhelum, Chenab, Ravi and Sutlej). In addition, there are 57 small to medium sized dams, 9,795 km of surface drains and 3,360 km of flood embankments. The province uses 98 BCM of water for irrigation annually.

Two thirds of the total cropped area of Punjab is dedicated to three crops, namely wheat, cotton, and rice.

Water resources and river basin governance

River basin, river, and land management units

The logical water resources planning unit for Punjab province is the Punjab Indus River Basin. The Water Resource Plan should aim to share and protect of its water resources. Alternatively, the 5-rivers area, which forms the Panjnad as the tributary to the Indus river, could be treated as a river basin. However, since this area is connected to the Indus river via link canals the larger area is preferred.

The Doabs lend themselves to be land management units. Land and Water Management Plans or Groundwater Management Plans can be developed for Doabs to manage the surface water, groundwater and land resources sustainably.

Rivers are important natural resources management units. The health of rivers and floodplains is important as they provide many services including water supply (drinking, irrigation, industry), ecosystems, recreation, fisheries, tourism, flood management and navigation. River flow, water quality, bed and bank conditions, and sedimentation require management.

Stakeholders and Management Arrangements

Management arrangements for the Punjab Indus River Basin are complex, with shared responsibilities between federal and provincial agencies and with the usual multiplicity of sectoral water users (domestic and stock use, urban and recreation, flooding, irrigation, fisheries, hydropower, industry, environment, navigation, catchment and tourism uses). Significantly from an operational efficiency and effectiveness perspective, the O&M of river and link canal infrastructure is shared between different governments and agencies, which is unlikely to be optimal.

The main government departments, agencies and organisations involved in the administration of water resources include:

a) **National level**: The Ministry of Water Resources, Indus River System Authority (IRSA), the Water and Power Development Authority (WAPDA), the Planning and Flood Commission and the National Disaster Management Authority.

b) **Provincial level**: Punjab Water Resources Commission (WRC), the Water Services Regulatory Authority (WSRA), Irrigation Department (PID), Agriculture Department (PAD), Public Health Engineering Department (PHED) through Water and Sanitation Agencies (WASAs), Environment Protection Department (PEPD) and Environmental Protection Agency (PEPA), Department of Forestry, Wildlife and Fisheries (PFWFD). The Department of Local Government is involved with rural water supply and sanitation and the Department of Industry is involved with industrial water use. Khal Panchayat (KP) are farmer based tertiary canal level water managers.

In order to maintain independence and accountability in the management of water resources it is now internationally accepted that best practice separates the responsibilities for (i) regulator/standard setter; (ii) resource management, and (iii) operator/service provider. Sometimes the operator responsibilities for bulk and retail water supply are also separated. The introduction of WRC and WSRA provides strengthening (although incomplete) of the regulator role. Introducing a Water Resources Department would further strengthen this role. There are however some roles (within the Punjab Province) that remain absent or weak, such as: river management; bulk and retail water supply; and shared responsibility for the management of water assets (eg. of link canals). More in depth study is needed to see whether these short comings represent a serious issue or not.

As the Punjab Indus River Basin is the preferred water management unit, a river basin organisation is not considered necessary at this stage and that function could largely be carried out by the new Water Resources Commission (WRC) and Water Services Regulatory Authority (WSRA), supported by a Water Resources Department (WRD). The WRC could be strengthened by including a community advisory committee, with membership drawn from the community throughout the province, representing the different water users and interest groups.

Water Entitlements, Allocation and Water Sharing

Pakistan's Water Apportionment Accord (WAA) provides provincial water shares (entitlements), as well as the basis for making seasonal water allocations. Some aspects of the accord remain contentions[1]. The WAA does not address water quality and only addresses environmental flow requirements at Kotri Barrage, at the end of system. Analysis of deliveries to Punjab by Anwar and Bhatti found that the that supplied volumes were substantially less than the seasonal allocations. There are a number of potential causes for the discrepancies and it is important to investigate and resolve these discrepancies.

Currently entitlements are assessed using rudimentary water balance approaches and could be improved by downscaling the surface water and groundwater models developed for Pakistan's Indus Basin. This would provide a better tool for assessing the sharing of allocation between command areas and other water users (such as urban areas), and for assessing the implications of climate change, declining storage capacity in reservoirs and availability of groundwater.

Internationally a range of different mechanisms may be applied to adjust water entitlements between water users, such as: by decree which is usually politically difficult and unlikely to be optimal; water markets enabling trade between water users (however while likely to approach economic optimality this requires a well-developed water measurement and accounting system); and government, city or industry payment for infrastructure renewal in order to reduces losses and/or achieve water savings, with transfer of an agreed water entitlement in return. All require safeguards and feasibility assessment.

Once an allocation is made, water is supplied via a 7-10.5 day Warabandi system with minimal other water regulation. The Water Policy notes that the current approach assumes that there are no water conveyance losses in the earthen canals. This is clearly not true and results in reduced delivery volumes to users at the tail of the system. The Warabandi system is simple to apply but does not deliver a fair outcome.

Modern irrigation systems adopt technologies that enable water releases to be accurately controlled and measured and supplied on demand, ensuring compliance with water allocations. Precise measurement enables volumetric irrigation service fees to be adopted.

Water Availability, Use and Demands

The following conclusions are made from the water budget analysis:

i) There is insufficient water to meet all water demands at present. All sub-basins have shortfalls in water supply, except for DG Khan sub-basin, Pothohar and the Hill torrents

ii) Inflows and outflows have been estimated for each sub-basin including canal command areas, rain fed areas, hill torrent areas and the Pothohar region.

[1] eg. Anwar and Bhatti (2018),

iii) The water budget for the seven sub-basins indicates a water deficiency, which agrees with past studies. However, this doesn't give a true picture, as most of the water balance components are estimates and they have a high degree of uncertainty. This highlights the need to invest in improved analysis of the water budget for each sub-basin through the development of computer models.

iv) Water balances at basin and sub-basin levels do not identify issues such as 'tail end supply shortfalls', capacity constraints and water seeping to saline aquifers etc. A detailed canal level water balance is required to identify these issues.

v) Water supply sources are likely to decrease due to factors such as: climate change; siltation of dam storages and canals; and deteriorating irrigation asserts. These issues need to be considered in the water budget.

vi) A holistic approach towards water management and conservation needs to be implemented.

vii) Surface drainage outflows are not properly gauged and have been ignored in the water budget analysis.

viii) Models at the Doab scale are useful for the Irrigation Department to improve planning and management of surface and groundwater resources. This will require increased capacity for irrigation agencies, as well as institutional reform.

ix) Expansion of the irrigation area is desirable but is currently constrained by limited water resources. The sustainable and cost-effective option to facilitate expansion is to enhance water productivity. This requires enhancement of crop productivity and reductions in crop water use. This is possible by adoption of water efficient technologies, improved production practices, more productive and higher value crops and varieties, improved operation and maintenance of irrigation systems, and reduced non-beneficial losses of water.

x) The PID is an irrigation department with a focus on supply of water to irrigation command areas, although it has other responsibilities including flood control, operation and maintenance of river infrastructure and hill torrent management). A result of this focus is that information on water balances has been focused on command areas, rather than the overall water resources of the Province.

xi) A Water Resources Department would have a stronger recognition of rivers and their values and uses including environmental, recreational, heritage and cultural uses, as well as traditional irrigation, drinking water and industrial water uses.

River Water Quality

Water pollution in Punjab rivers, canals and nullahs derives from three major sources: i) entry of untreated domestic effluents and stormwater from the large urban towns; ii) untreated industrial effluents; and iii) return-flows from agricultural lands which may contain high levels of nutrients (from fertilisers), chemicals (pesticides and herbicides) and salinity (mainly from irrigation using brackish groundwater).

Major water pollutants include heavy metals, faecal coliforms, phosphorous, sodium, nitrogen, and sediments, as well as pathogenic bacteria and viruses. Low BOD and COD is common. Agriculture is a source of salinity, nutrients (fertilisers), highly toxic pesticides and persistent organic pollutants (POPs). Pollution is exacerbated by low river flows and hence low dilution.

As a result, water is often unfit for drinking. Agrochemicals in groundwater, especially pesticides, are a major source of human poisoning in Pakistan. Poor water quality also negatively impacts fish diversity and fish population numbers and affects other uses. Groundwater quality can be marginal for irrigation, due to over exploitation and this problem is worsening.

The available water quality data for most canals/drains show pollution levels that are well above the permissible limits provided by the Pakistan National Environmental Quality Standards (PNEQS). signifying significant impacts on the health of downstream water users and the health of the aquatic ecosystem. There are no national surface water quality standards for the disposal of treated wastewater into freshwater bodies.

The collection and treatment of urban and industrial effluents in Punjab is low, with the mostly untreated effluent discharged into canals, drains and rivers. Seepage of contaminated surface water into aquifers results in the aquifers becoming polluted and unfit for drinking. There is very little separation of municipal wastewater from industrial effluents, with both discharging directly into open drains before flowing into the nearby natural water bodies.

There is no established water monitoring programme for assessing the water quality of surface waters in Punjab province. While there have been studies of water quality in the rivers, these have been piecemeal and not part of a systematic monitoring approach.

Water quality in the rivers is variable and season specific. The Chenab River has very high heavy metal concentrations in both the water column and sediments, which significantly exceed PEDS standards. This is of concern as the river water is used for drinking. Of the few canals sampled, the Lower Jhelum canal was unfit for stock or irrigation purposes, with high E. coli levels at most sampling points due to faecal contamination. Ravi and Sutlej rivers have the poorest water quality Punjab. The Ravi River in particular is in a highly degraded state.

Departmental responsibilities for water quality monitoring should be reviewed to ensure all aspects are addressed. Suggested roles include: EPD and WRD lead the coordination and overview of surface water and groundwater quality management. EPD - pollution control and auditing of industry self-monitoring; industry- self-monitoring for point sources such as industrial effluent discharge and city wastewater disposal; PID- monitoring water quality in rivers, canals, drains, nullahs and groundwater, including assessment of nonpoint pollution from agriculture. WRD- Assess river flow needs (environmental flows) in the annual water allocation and river operations plans and designation of groundwater protection zones where land use is controlled.

A range of important recommendations are made including:

a) Development of an action plan to improve water quality.

b) Awareness raising education campaign for downstream water users on the risks from using polluted waters from drains and irrigation canals for human and livestock consumption.

c) Improved water quality monitoring, especially for nutrients and highly toxic agrochemicals that impact surface and groundwater quality.

d) Develop water quality standards.

e) Education of farmers on proper use of agrochemicals and enforcement of environmental regulations for urban wastewater discharge and industrial effluent discharge and agricultural practices.

f) Urgent implementation of measures to minimize pollution and to regulate levels, with systematic monitoring and evaluation of water quality in drains, canals and rivers.

g) Accelerated action with the installation of wastewater treatment plants for urban sewage and industrial effluent.

h) Review of responsibilities of regulatory and implementing agencies, their coordination and collaboration, and strengthening their capacity. Training and recruitment to improve staff capabilities and provide additional facilities/equipment where needed.

Groundwater Management

Groundwater has become a significant source of water in Punjab, providing 50% of irrigation water and 70% of drinking water. The contribution of groundwater to irrigation has increased from about 10% in the 1960's to more than 50% in 2018. Groundwater pumping by over one million farmer-owned tubewells has enabled an increase in cropping intensity from 67% to around 131%.

Increased groundwater use resulted from the conjunction of several factors including: (i) groundwater is the property of the landowner and as a result its use is not regulated; (ii) surface water supplied irrigation water contributed to a significant increase in groundwater recharge so that the groundwater resource grew rapidly, and, (iii) groundwater can be used flexibly by the farmer to meet crop demand, thereby offsetting lack of water resulting from the warabandi system or from drought.

Analysis of the water balance however shows that groundwater usage exceeds recharge in the 5 Doab areas of Bari, Rechna, Chaj, Thal and Bahawalpur. Only the 2 irrigation areas on the right bank of the Indus (DG Khan and CRBC) have recharge that is greater than abstractions. Excess abstractions for the Doab areas represents 1-2% of inflows (rainfall and canal supply) annually with groundwater level Doab declines of 0.1 - 0.2m/y. However, there are localities where depletion is more serious. The suitability of groundwater for irrigation (based on water quality) has declined significantly from 65% in 2006 to 30% 2019[2].

Groundwater levels are declining seriously in the vicinity of cities, for example in Rawalpindi groundwater levels are declining at 1.7 m/y and for Lahore groundwater is projected to decline to 70m in 2025 and 100m in 2040. As groundwater levels decline there is generally a corresponding decline in water quality, increasing pumping costs and a decline in water resource availability.

Groundwater levels and quality are monitored by both the SCARP Monitoring Organization (SMO) of WAPDA, and the Directorate of Land Reclamation (DLR) of the PID. Monitoring networks, systems, and data should be integrated with on-line and free data sharing.

Domestic, industrial and agricultural water demand is expected to increase by an additional 37 BCM (30% of the 2020 demand) by 2050, which places additional pressure on existing surface and groundwater sources. Reallocation of water from irrigation to meet increasing urban and industrial demands is inevitable, and has already started in some areas. This will require improved efficiency in agricultural water use.

It is important that future water resource planning recognises the connection between surface water and groundwater with the surface and groundwater resources to be managed conjunctively. Options for additional water are limited and places extra responsibility on departments to ensure sustainable management of all available water resources. However, there is a significant lack of capacity within existing institutions for monitoring, modelling and management of groundwater resources.

[2] Note that mixing poorer quality groundwater with better quality surface water allows groundwater to be utilized when the water quality is otherwise not suitable.

The immediate roadmap for improving groundwater management comprises:

Institutional and regulatory arrangements: Currently groundwater regulatory arrangements are very weak and there is little capacity within government. An effective GW regulatory framework and laws are required for Punjab and a dedicated GW management division should be established within WRD.

Groundwater Management Plans in priority Doabs. These are referred to as Land and Water Management Plans as they involve integrated management of land and surface and groundwater. Integrated plans are needed to identify the best management of surface and groundwater. Community participation is needed. The TRTA groundwater report provides guidance for development of these plans.

Managed Artificial Recharge has potential to use flood and excess drainage water to recharge the aquifer storage system. Suitable locations and configurations need to be identified and investigated. It is recommended that pilot studies be trialled for proof of concept prior to full implementation.

Conjunctive Water Use, aims to make best use of available water resources by planning water use and allocation for both surface water and groundwater accounting for both water availability and quality. For example, head reaches usually have the best quality groundwater, but mostly use canal water, while the reverse is the case in the tail end. A more effective arrangement would be for the head reaches to use more (good quality) groundwater allowing a greater volume of surface water to be available for tail reaches.

Strengthen GW Information and Knowledge Management: This involves (i) developing and implementing a comprehensive groundwater monitoring plan, and (ii) applying modern groundwater modelling approaches to develop better policy and better Groundwater Management Plans. This approach would be a major improvement on the current water balance and groundwater analytical approaches.

Community Awareness Raising and Participation is needed to consider water user and land holder needs, as well as to enlist their cooperation.

A standalone, detailed report on groundwater management in Punjab was prepared as part of this TRTA project.

Environmental Condition of the Rivers

The key elements of the environmental condition of rivers are captured in river health assessments including: (a) river hydrology; (b) water quality; (c) aquatic life (instream, birds and other wildlife); (d) river form including bed and bank condition; and (e) the condition of the streamside zone including wetlands, riparian vegetation, floodplains, land use and settlements.

Significant economic and social benefits result from good river environmental conditions including recreational values; fisheries; amenity and living conditions; groundwater recharge from wetlands; improved agricultural production (poor water quality leads to lower productivity), reduced water supply treatment cost, lower prevalence of water born disease.

Studies of the Indus River and its tributaries in Punjab show that environmental conditions have deteriorated and the deterioration is accelerating. Pollution and reduced river flows are profound problems. Low and unhealthy fish populations are a key indicator of ecological problems.

River ecosystems are degraded by many other factors including:

1. Water quality data clearly demonstrate the effect of point and non-point source pollution on the riverine ecosystem (presented in Chapter 6). Contaminants are responsible for an increase in occurrence of water-borne diseases within the human population, as well as a reduction in the biodiversity of flora and fauna. Pollution control is a fundamental requirement.

2. Flow in the basin's rivers is much reduced especially in the Ravi and Sutlej rivers. This negatively impacts the ecology and contributes to poor water quality due to the lack of dilution flows. The WAA has provisions for ensuring minimum environmental flow in the basin's rivers, but these provisions have not been actioned.
3. Riverbank erosion is significant along some Punjab rivers causing damage to agricultural land, settlements and local infrastructure, which impacts people's livelihoods. A bi-product of riverbank and water shed erosion is river sedimentation which badly affects the river ecology.
4. The construction of barrages and dams has created habitat fragmentation and provides barriers to fish migration. The loss of wetlands has impacted the ecology, reduced flood storage, reduced groundwater recharge and reduced nursery conditions for fish, aquatic birds and other aquatic life. This threatens survival of certain flora and fauna.

Water quality monitoring networks should be established to quantify key parameters (BOD5, COD, DO, NH3-N ,and TP) across the river basins and to identify key sources of pollution. Monitoring of the river condition should also be undertaken including flows; channel condition; condition of wetlands; number and diversity of fish, birds and other aquatic species; aquatic and riparian vegetation.

Three main initiatives should be taken:

1. River Flow Requirements
   - Develop and apply a methodology for determining river environmental flow requirements and include these requirements under the water allocations system.
2. River health assessment and river improvement program
   - Develop and implement a river health index system to monitor the condition of rivers and use this as a tool to inform River Basin Management Plans.
3. Capacity building and training
   - Training and capacity building for WRD, PID, FWFD and EPD staff on river health.

Flood Management

Floods usually occur in the summer season from July through October, as a result of torrential rains during the monsoon season, sometimes exacerbated by snowmelt runoff. The frequency of floods has considerably increased in recent years with five consecutive extreme flood events occurring in 2010, 2011, 2012, 2013 and 2014. This is consistent with the expected impacts of climate change. Severe flooding in the Indus Basin results in loss of life and high flood damages, for example damages exceeded $10 billion in the 2010 event.

The current approach to flood management involves flood forecasting and warning; flood gauging (although there is a limited network of such gauges); source control of run off, especially by dams; flood protection by levee construction; emergency management (including evacuations); post flood recovery; and flood reporting. However, the current reports are limited in the information they contain which limits their value for future flood planning. There appears to be no asset inventory with information on the various flood control structures and their condition, and there is no asset management plan for their maintenance, rehabilitation or replacement.

There is a large library of flood related legislation in Pakistan and a large number of agencies involved in flood management. For Punjab this includes the PID and its Flood Risk Assessment Unit (FRAU), WAPDA, PMD and the Federal Flood Commission (FFC). The capacity and effectiveness of these organisations was not assessed during this assignment.

The Flood Risk Management (FRM) approach in Punjab should be strengthened by taking a more comprehensive approach. This would involve: strengthening institutions; strengthening data and information management and capacity

to model floods for planning and forecasting purposes; flood planning including a whole of landscape approach and spatial planning/zoning; flood preparedness and asset management; flood forecasting and warning; flood protection; flood disaster management; flood recovery, and flood communication and reporting.

Internationally an integrated approach to flood risk management is taken where risk is calculated as:

risk = frequency x cost of damage.

This is used to determine the priority actions. Hydraulic modelling is a critical tool to assess flood risk, impacts and to assess mitigation options. Models are also used to forecast flood events and inform flood warnings.

The proposed roadmap for improved flood risk management recommends:

a) Strengthening of FRAU (staff, resources) and updating its mandate to take a more comprehensive approach.

b) Review and adapt international best practice for Punjab.

c) Build a strong data and information management system including monitoring networks, undertake flood mapping informed by modelling, apply flood planning, preparation of a 5-year rolling risk based provincial flood management plan, spatial zoning, drainage plans, including climate change in planning.

d) Update and implement improved flood preparedness, flood warning and recovery programs.

Watershed and Hill Torrent Conditions

The barani (rainfed) areas of Punjab cover about 40% (7 Mha) of Punjab and are home to over 19 million people. The Barani areas have been neglected by government, as much of the focus is on irrigation. Dry lands sustain about 80 percent of livestock and contribute to provincial production of wheat 12%, rapeseed & mustard 73%, barley 53%, gram 65%, sorghum 65%, and ground nuts 89%. The focus of this chapter is the Pothohar Plateau, Hill torrent areas and the Cholistan desert.

The Pothohar Plateau

The Pothohar Plateau is 22,275 km^2 with a population of 17.6 million. It is drained by the Haro and Soan rivers and rainfall is 380-510 mm annually. Its soils are very fertile.

The productivity of Pothohar has decreased by 2.5 to 7 times due to over grazing and removal of vegetation for fuel wood. Issues in the area include: unreliable rainfall; subsistence- farming system; old cultural practices; small size and fragmented farms; low soil fertility; unsuitable cropping pattern; soil erosion; limited farm inputs.

Only 3% of the 4.3 BCM annual runoff is regulated through small and mini dams. The remaining 3.4 MAF goes to the Indus and Jhelum rivers. There is considerable scope to construct more dams, reduce large-scale soil erosion, mitigate floods, and conserve soil. Past projects have demonstrated the feasibility of rainwater harvesting and raising livelihoods.

The area is managed by the Barani Area Development Authority which works under the Planning and Development Department (PDD) and is also responsible for soil conservation works. Once a WRD is formed, this Soil Conservation Department could be transferred to PID to work under Chief Engineer, Pothohar.

Participative integrated watershed plans should be developed for the Soan and Haro river watersheds and comprise measures such as:

- Identification of interventions for reducing rainwater runoff
- Prioritization of watersheds and sub watersheds
- Identification of rainwater storage sites

- Assessment of site specific conservation approaches
- Suitability assessment of perennial crops/trees
- Interventions in agriculture practices
- Public awareness and community mobilization.

The Cholistan Desert

The Cholistan Desert covers an area of 25,800 km^2 and it joins Thar Desert in Sindh and India. The mean temperature is 28.3^o C and the hottest month is July with a mean temperature of 38.5^o C. Average annual rainfall is 180 mm, falling mostly in July and August. Droughts are common with an annual rainfall in drought years of less than 10 mm. Groundwater is found at a depth of 30-40 m, but is mostly brackish and unsuitable for plant growth. The people follow a nomadic life and the backbone of the economy of area is animal rearing with Tobas (ponds).

The area is under the management of the Cholistan Development Authority, which together with the Pakistan Council of Research in Water Resources, constructs and maintains the watering ponds.

The water resources of the region can be developed by construction of additional ponds; plantation strips along canals; development of aquifer recharge areas; and transfer of flood waters to the dried out water course of the Hakra river. Transfer of the Cholistan Development Authority to PID to strengthen water management should be considered.

Hill Torrent Areas

This area includes two Districts (Rajanpur and DG Khan) between the right bank of Indus River and the Suleman range. It has a population of 4.2 million and total area of 21,575 km^2. It can be divided into two parts: (i) The CRBC, DG Khan canal commands located on the plains with canal offtakes from river barrages and, (ii) Hill Torrents area which include spate irrigation. Of the total area of 2.39 Mha, 17% is canal commanded, 35% spate irrigation, and 48% mountainous and sub-mountainous.

Annual rainfall is about 350 mm and mostly falls during the June to September monsoon. The mean annual summer daytime temperature is 34 C and June is the hottest month with a mean maximum temperature of 41.5 C. The minimum temperature is 4.2 C in January.

Land use is less than 3% in the upper catchment. Approximately 12% of cultivable land is irrigated in the Pachad area, where the torrents flow through the piedmont (fan) area. Various crops are grown under irrigation and for the non-irrigated areas livestock are the main source of income. Natural shrub vegetation is used for livestock grazing and firewood.

In the hill torrent areas, the land has high runoff potential due to the soil type and slope. Flooding and resulting damages are significant in the Pachad area, which is the most underdeveloped area in Punjab.

Problems faced by the farmers of these areas include low crop yields in spate irrigated areas; high maintenance requirements for bunds; high cost of diversion structures; poor financial resources; damage from floods; heavy sediment load; low priority by researchers and the government.

Hill torrents are managed by Project Circle D.G. Khan under the administrative control of the Chief Engineer of the Zone of PID. There have been quite few projects investigating management of hill torrent areas and possible interventions. The main objective of recent hill torrent management projects has been to reduce the flood damages and improve water availability for irrigation.

Increasing the capacity and support for local staff is important and requires: more staff with a clear mandate and authority; improved knowledge of decision and policy makers; innovative technologies.

Roadmap

The proposed roadmap includes:

a) Development of participative, integrated 'watershed/area' management plans in each area, which are accepted by communities and government. The plans should cater for climate change, raise local livelihoods, protect local land and water resources, and also protect downstream water resource conditions.

b) Participation, awareness raising and capacity building for farmers and government staff in each area.

c) Implementation of agreed integrated 'watershed' management plans. Depending on local conditions works could include- revegetation, erosion control, sustainable grazing; rehabilitation of existing and construction of new infrastructure; flood forecasting and warning; groundwater recharge and rainwater harvesting; improved irrigation efficiency, conjunctive use, management of salinity and reduction of drainage outflows.

Irrigated Agriculture

Large scale irrigation development started in the British Raj era. Soon after annexation of the territories of Punjab in 1849, the British rulers started an integrated gravity-run canal construction program. This system became the world's largest contiguous canal command irrigation network supplying irrigated agriculture for 33 million acres of land in the Indus Basin.

On independence, the international border between Pakistan and India divided the Irrigation System. The irrigated agriculture on the Ravi and Sutlej rivers in Punjab was truncated, without consideration to any geographical or environmental issues and the Lower Riparian areas of command in Pakistan Punjab were deprived of irrigation supplies.

The dispute with India on water rights was eventually resolved under the auspices of the World Bank by the signing of the Indus Water Treaty in 1960 between the two countries. Under the Treaty India was entitled to the exclusive use of the three eastern rivers (Ravi, Beas and Sutlej), while the western rivers (Chenab, Jhelum and Indus) were allocated to Pakistan.

Indus Basin Project was launched with financial aid from the World Bank and International consortium to undertake works for restoring the supplies of the western river irrigation system by transferring water from eastern rivers. Two large storage dams, 8 inter-river link canals, one sub link, one syphon, one canal crossing complex and 5 barrages were constructed under the Indus Basin replacement works.

The construction of storage and link canals allowed the operation of the Indus irrigation system in an integrated manner, with greater control and improved river water utilization. As a result, the average annual withdrawals increased from 67 MAF in 1949-52 to 85 MAF by 1959-60, and 95 MAF just after the construction of the Mangla Dam in 1967-68. The withdrawals further increased to 101 MAF just after the Tarbela Dam was completed and reached a peak of 108 MAF in 1979. The canal withdrawals remained at this level up to 1989-90 but have now declining to around 105 MAF due to a reduction in reservoir capacities caused by progressive sedimentation. This withdrawal is likely to be restored and further enhanced on completion of Mohmand Dam on river Swat and Basha-Diamer dam on river Indus.

The irrigation infrastructure comprises 13 barrages / headworks, 25 main canals (3,993 miles long with total off-take capacity of 120,000 cusec), 528 miles of inter river link canals (with total off-take capacity of 110,000 cusec), 2,794 number of distributaries and minors of 19,387 miles length. In addition, 57 small dams and an extensive network of surface drains (6,122 miles long), 2,100 miles' flood embankments are operated and maintained by PID. The system serves 8.5 ha (20.78 million acres) of culturable command area through 58,000 outlets and has an average cropping intensity of 125%–150%.

The current Punjab irrigation system supplies on average 69 BCM (55.94 MAF) of water annually to 21.71 million acres (8.79 million hectare) of Culturable Command area. There are 15 Diversion structures with 45 main canals which have a discharge range from 15 to 42.5 m^3/s.

Surface Drainage is supplementary and complementary to any irrigation system. The irrigation canals cut across drainage lines which impeded natural drainage and therefore man-made drains are required to capture drainage from trapped areas. Drains are also required to take seepage flow and irrigation excess from the agriculture fields prevent waterlogging and to attain acceptable yields. Drains also play an important role in managing salinity. The irrigation system was initially constructed without drainage which was added in an ad-hoc fashion to address flooding and water logging issues. The current drainage system is therefore suboptimal.

Major challenges include:

- Growing demand
- Available water already committed
- Aging infrastructure
- Poor water use efficiency
- Low productivity
- Low value crops
- Inadequate water information management system
- Inequalities in water distribution
- Unsatisfactory operation and maintenance
- Over exploitation of groundwater
- Deteriorating water quality in drains, canals and rivers
- Financial constraints
- Institutional constraints

Improvement opportunities include:

- Upgrade, reconfigure and modernise irrigation supply system
- Selectively line canals
- Construct large dams on the main rivers and small dams on tributaries to increase storage and capture of flood flows.
- Improve the monitoring and decision support system including use of real time data
- Land levelling and use of more efficient irrigation methods
- Change cropping patterns
- More efficient operation of irrigation delivery system
- Improved maintenance of canals, gates/barrages, and drains
- Revise water allocation system
- Revise pricing/tariff structure

Urban Water Supply, Sanitation and Urban Integrated Water Management

Punjab has the largest provincial population in Pakistan with of 110 million people, with 37% living in urban areas and 63% in rural areas. Drinking water and sanitation services are lacking (eg. less than 1% of Lahore has a functioning water supply scheme). Provision of drinking water supply and sanitation facilities for the increasing population is a serious challenge.

Challenges to providing clean drinking water supplies in urban areas are:

- surface and groundwater is contaminated by untreated industrial, commercial, and domestic effluent.
- Inadequate operation and maintenance of infrastructure.
- Significantly increased arsenic levels and other heavy metals in the groundwater.
- Leakages from old water and sewerage pipelines contaminating urban drinking water.
- Uncontrolled land conversion from irrigation to urban uses reducing groundwater recharge.
- In rural areas 88% of water is unfit for drinking, due to brackish groundwater.

- Lack of water storage or artificial recharge to augment the deleting groundwater resource.

A high proportion (75%) of households in Punjab have access to improved sanitation. However this varies widely across the province and between urban and rural areas. Disposal of raw sewerage however is poor and used for irrigation or disposed directly into drains and rivers. This is a serious health risk as evidenced by widespread infection by water borne diseases in the province.

Both the ADB and the World Bank work with the government to improve infrastructure and management aspects of water supply and sanitation.

From a water resource perspective urban water is an important sector, with important consequences for the Basin's water resources and how they are managed:

- Groundwater resources and their quality are diminishing, and alternative good quality water supply is needed.
- Water availability in the Ravi and Sutlej rivers is insecure and therefore other mechanisms to supply water are required.
- Raw sewerage is disposed into drains and rivers, degrading water quality.
- Stormwater causes local flooding and downstream pollution. It is a potential source of water for agriculture and recreation, following rudimentary treatment by wetlands.

Proposed actions relevant to the river basin plan include:

a) Prioritising settlements with critical water supply issues so that the RB Plan and Doan plans can consider options for providing/arranging surface and groundwater.

b) Prioritising sections of rivers and aquifers with poor water quality so that wastewater pollution control policies and investments can be targeted.

c) Prioritising urban areas with drainage and flooding issues to target investments and manage local river flooding.

d) Prioritizing sections of rivers which have high community value such as for recreation, so they can be addressed by river management plans.

e) Adapt the international IWM approach for urban water management to better manage and utilize stormwater and wastewater.

f) Capacity building for adoption of IWRM to lessen non-point source pollution loads and to use stormwater beneficially.

1 INTRODUCTION

Growing competition for scarce water resources has driven major changes in the way river basin planning is undertaken. This has resulted in a shift away from 'technical' and Master planning approaches designed to maximize water availability and led to more strategic Integrated Water Resources Management (IWRM) approaches to basin planning **Figure 1-1**. These approaches aim move beyond the additional large infrastructure approach to taking a more balanced approach involving policy management measures in order to optimize outcomes by balancing the competing demands of different sectors of the economy, the natural environment, and society as a whole. The adoption of IWRM overall and for river basin management presents many challenges, mainly because, while it results in better outcomes, it adds complexity and requires many fundamental changes to the overall water management approach.

TRADITIONAL VS IWRM APPROACH TO RB PLANNING		
Traditional Approach		**IWRM Approach**
Surface water balance of the basin- now and future	FOCUS	Society's priority issues and needs- water quantity, quality, aquatic ecosystem, surface and groundwater Water accounting that traces real water savings
Surface water runoff, river flow	NATURAL FEATURES	River basin conditions, surface water runoff, river flow, groundwater yield, ecological processes, river basin conditions
Environmental Allocation (quantity)	ENVIRONMENTAL FEATURES	River operational rules which mimic natural ecological processes and water for environmental assets
Water demands per sector- now and future	SOCIO ECONOMIC FEATURES	All societal, economic, cultural and spiritual values which are supported by water
Water Balance Infrastructure Planning Inter basin transfers	DECISION MAKING PROCESS	Define issues and threats Define societal objectives Assess options to meet objectives Trade-off analysis for objectives Stakeholder participation including the community
Internal conflicts of interest Sector based Top-down, command and control Supply fix Technical, expert driven management organisation	MANAGEMENT APPROACH	Separation of WR governance responsibilities Integration and cooperation across sectors Stakeholder participation Supply and demand management Open, transparent, communication processes

Figure 1-1: Traditional vs IWRM approach to Water Resources Management

Basin planning has been undertaken over many years, for different purposes, and in different types of river basins in many countries. In some countries this is well organised, on-going and is an integral part of overall water resources management while in other countries it is more sporadic, less organized, or develops organically over time. While our understanding of

the process, nature, methodologies and techniques for basin planning has developed, the one true lesson is that river basin planning is successful where it has adapted to the local needs and is considered to be an integral part of water resources management.

This report, assisted by others in the TA, responds to the issues identified in the project terms of reference and namely to: (i) improve capacity of PID in water resources planning and management, (ii) develop basin-based water resources management approaches and specifically river basin plans for rivers and related link canals, and, (iii) identify technical, institutional, and policy interventions for IWRM of river basins.

Discussions with Punjab Irrigation Department (PID) indicated that it is at an early stage in understanding, developing, and implementing an IWRM and river basin management approach. Further, there are a range of policy decisions that are needed to decide the most appropriate way forward for river basin management in Punjab and PID wished to consider these and international experiences, particularly from the Murray Darling Basin in Australia.

A range of locations for developing river basin plans was considered during the TA and finally it was decided that a ‘river basin’ plan would be prepared for the Punjab part of the Indus River Basin and this would assist with how it could be “mainstreamed” into the Punjab IWRM approach. Since most of Punjab Province is within the Indus Basin, this approach is similar to a Provincial water resources plan/strategy. Such an approach is common as a first step in water resources management internationally as it sets the jurisdiction wide approach and priorities including for river basin planning and management.

1.1 WHY DO RIVER BASIN PLANNING?

Water resources planning and management is about providing for the social, economic and environmental well-being of the community whatever the scale of the planning. At its core,

The primary purpose of a River Basin Management and Plan is:

- Equitable sharing of the river basin’s connected water resources (quantity and quality) between the different and competing water using sectors including the environment.
- Water resource protection (quantity and quality) to ensure access to acceptable water resources for present and future generations
- Bulk water supply to all water users in a fair and equitable manner.

The water resources within a river basin are “connected”, and as a result so too are the water resource demands, uses, the management issues, and the activities that affect water sources and their dependent systems. Following this, once the water resources of a river basin become well developed (e.g. 40-50% of river discharge is diverted for other uses) water availability and water quality become compromised and conflict arises between upstream and downstream users, between water using sectors and between the economy and environment.

Resolution of competing interests or conflicts over access to water, particularly in dry times, can only be properly addressed at a river basin scale where all water is considered. Here, the competing interests, demands and trade-offs for water for the environment and native fisheries; living; habitations, towns and cities; irrigation; industry; aquaculture; power generation; etc. needs to be assessed and dialogue held. Similarly flood management should be based on river basins for flood planning and warning and as decisions taken for flood protection, modification of the floodplain or to divert flood waters in one location might be felt a considerable distance away.

It is also at the river basin scale that the different responsible management authorities and water users for surface water, groundwater and land use in the same ecological, hydrological and hydrogeological system can be coordinated and regulated through the river basin plan. This usually requires adjustments and possibly new institutional arrangements, planning and management approaches.

Once achieved, and subject to river basin conditions, an effective river basin plan should result in improved economic, environmental, and social conditions and specifically:

- Improved and sustainable living conditions from the reliable supply of good quality water,
- Increased irrigated agriculture productivity and farmer incomes from the timely supply of reliable and good quality water,
- Increased industrial production from access to reliable water supplies,
- Improved water quality in rivers and surface water bodies,
- Improved ecological condition of river ecosystems and increased community values such as for recreation, fishing, tourism etc,
- Reduced economic, and social losses from flooding and improved environmental outcomes from improved flood management.

While river basin plans respond to higher level government policies and plans (e.g. national/provincial policies), once developed, the actions identified will be incorporated into the plans of other sectors and lower levels of government (e.g. Districts) as relevant. One good intermediate indicator of the success of a RB Plan is the extent that its recommendations and actions are captured in the work plans of other agencies and sectors.

1.2 THE STRUCTURE OF A RIVER BASIN PLAN

River basin planning is the process by which decisions are made over the competing uses and different sectoral demands for water resources and associated systems consistent with water availability within a basin. The plans will also include objectives and the measures for developing, protecting and harnessing the resources of the basin for the health and safety of the river itself. In its most developed form basin planning brings together a range of different disciplines and themes, from hydrology and engineering to ecology, economics and sociology.

Depending on the size and complexity of issues in the river basin/sub-basin the RB Plan will be at a more strategic level and determine the priority needs and regulatory arrangements in the basin with implementation orchestrated by the responsible departments and levels of government (Figure 1-2):

- The RB Plan will include thematic plans that follow hydrological boundaries and rivers for the sharing of the basin's water resources and for the regulation of the separate water using sectors often via water use and pollution control licencing.
- The plan also identifies the priority water resource themes in the basin (e.g. to address issues of scarcity, quality, development opportunities) and 'hotspot' locations where more localised and detailed plans can be developed.
- The different water using sectors such as urban water authorities, irrigation, and drainage authorities, prepare their own IWRM and business plans consistent with any rules and any 'hotspot locations' identified in the RB Plan. The authorities plan, budget, and manage these according to their management responsibilities and boundaries such as a command area or zone.

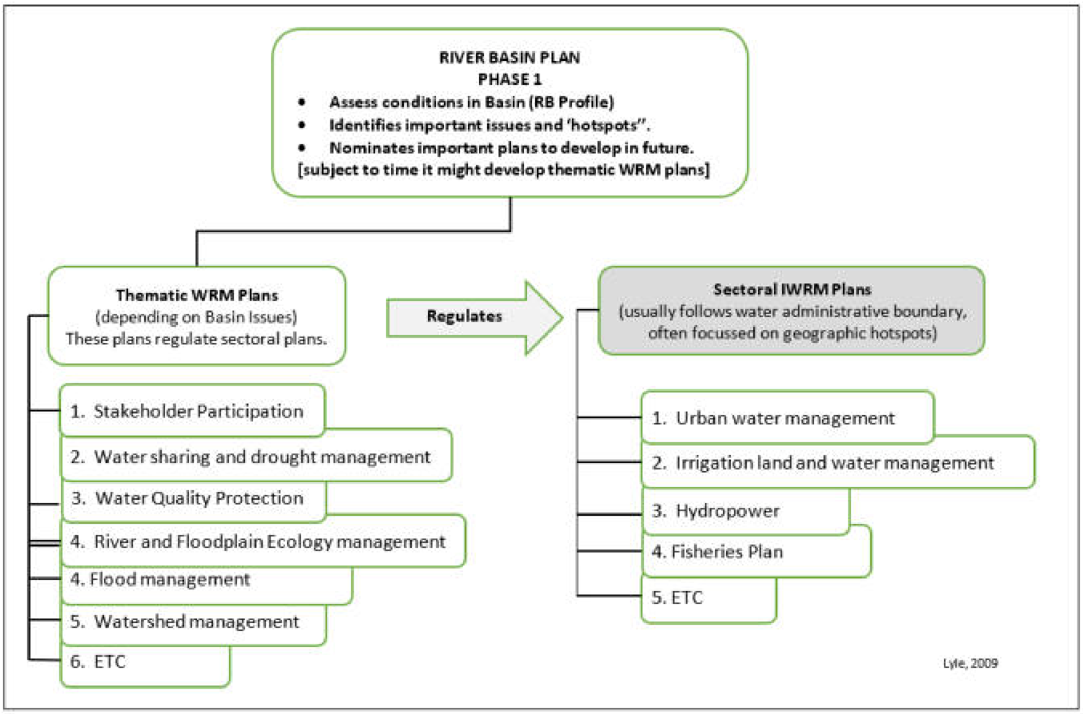


Figure 1-2: Relationship between RB Plans and Sectoral Plans

1.3 THE RIVER BASIN PLANNING PROCESS

Preparing river basin plans can be difficult and complex, especially at first as it involves a new water governance and management paradigm and approach involving:

- Establishing River Basins as the fundamental unit for applying and coordinating water resources management,
- Identifying and agreeing key water management issues,
- Developing RB plans that include programmes of measures to deal with the issues, and plans for their implementation, and,
- Establishing and maintaining appropriate monitoring networks.

There is also a tendency to try and implement the planning process in full from the start, which can lead to a result that is disappointing to decision makers who find it too academic, technical to the exclusion of water user experience, and taking an excessive amount of time. For these reasons, taking a more measured and fit for purpose approach involving initial detailed planning on only 1-3 key issues of importance in the basin and then to build on this success with later revisions and plans is advisable. The often referred to Murray Darling Basin Plan was initially 4-5 detailed thematic plans developed and refined over many years and then brought together into the current integrated river basin plan.

An established, stepwise approach to developing a River Basin Plan is shown in Figure 1-3. Important aspects include:

(i) A cyclical and adaptive approach: The planning process is sequential and on-going. The initial plan will typically be based on limited information and with only partial reference to community preferences. The plan is monitored regularly (annually), and minor adjustments made. It is reviewed in a more significant way every 10 years or so although this cycle length will be determined by the maturity of the planning process and plan. The first plan might be limited in its scope and a significant revision made after a shorter period. A mature plan that is effective in its execution might be formally reviewed and revised at a longer timeframe.

(ii) Links to the formal economic development planning cycle: In some countries, there is a formal 5-year economic development planning process in which case the RB plan would be linked into this planning cycle.

(iii) RB Plan initiation: Once RB planning is to be implemented either on a pilot basis or formally into the water resource management approach, it is important that the government understands and is committed to developing the RB Plan and implementing its findings. Guidelines for preparation of the plan are often prepared at this stage and a project plan is needed with interdepartmental management and technical planning teams established and reporting to government decided. Consultants might also be used for specific tasks. A stakeholder assessment and plan for their participation prepared. The planning process will also benefit from having a ‘champion’ of the project who has senior recognition and can easily meet with leaders.

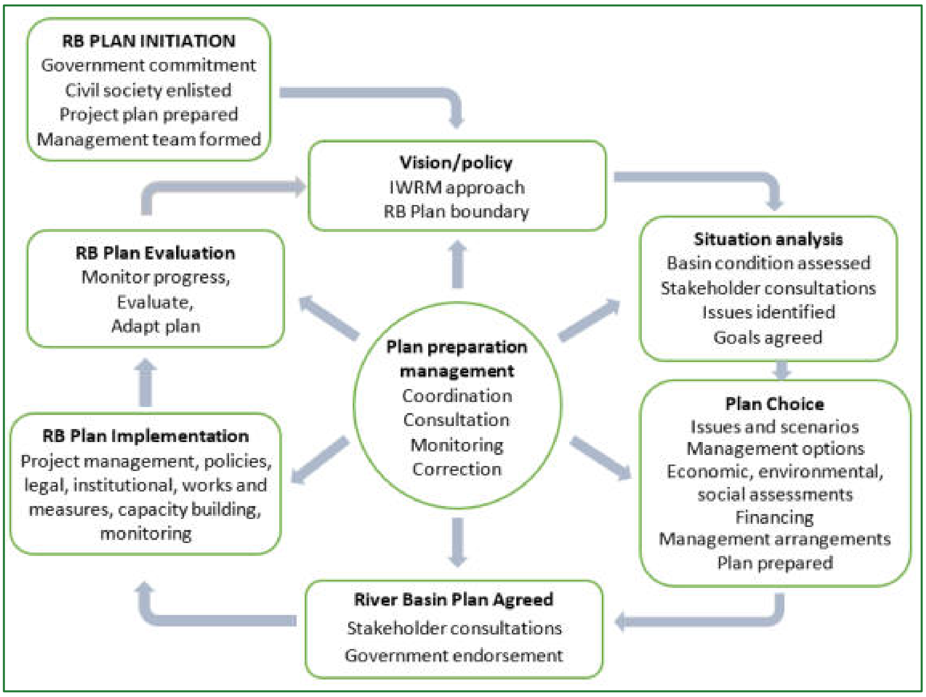


Figure 1-3: Cyclical approach to preparing a River Basin Plan

(iv) Plan preparation and management: Management arrangements for plan development will be decided at Plan initiation. The peak committee could be the apex water management body (e.g. Provincial Water Resources Commission) which comprises leaders from each of the involved government departments. Alternatively, it could be a River Basin Organisation formed specially for the task or more permanently although this needs to be approached with care (refer to the Basin Governance chapter). There will also be a Plan working group (PWG) who lead and arrange for the various tasks to be undertaken and for the drafting of the plan. Best practice involves a link to the Basin community for direct involvement and feedback from civil society to the apex committee.

(v) Vision/Policy: Involves an aspirational goal for the plan and what it will achieve in the longer term. An IWRM approach will be taken. Often the limits of the river basin boundary is not exactly clear. For example, where there is no clear hydrological boundary, where there are inter-basin transfers or drainage systems, jurisdictional boundaries that cut across the hydrological boundary; river basins are very small, and the planning capacity could easily manage a larger area, or the river basin is very large necessitating a more strategic or sub-basin approach depending upon the critical issues.

(vi) Situation analysis: This is often referred to as a river basin profile or status report. It involves stakeholder consultation and collecting all information on the river basin including of the natural resources; institutional

arrangements; economic, environmental, and social conditions. Information management systems (GIS, remote sensing, mapping) are established and used here. Issues and their location in the basin are identified and the specific goals of the plan agreed.

(vii) Plan Choice: This phase involves analysis of the basin conditions and assessment of the surface and groundwater resources, water quality, ecological and river channel conditions, current water usage by the different water using sectors, and future sectoral water demands in the Basin. Matters such as Climate Change, environmental conditions and water requirements, flood and drought management, and opportunities for real water savings and transfer to other uses and particularly uses of higher value such as urban and industrial water supply are commonly considered. Decision support tools are used here (refer below). Initial assessment (e.g. to pre-feasibility stage) will be made of economic, environmental and social aspects of management options. Importantly financing needs and sources will be assessed and management arrangements for plan implementation proposed. The results of these assessments is then compiled into a draft RB Plan which will comprise programs, or Key Result Areas, of works and measures.

(viii) Agreement of RB plan: The draft plan is presented to stakeholders (see below) for comment and revisions as required. The final phase involves government endorsement of the Plan with a commitment to implement in future government budget cycles.

(ix) Plan Implementation: The responsible authorities implement the plan under the guidance and monitoring of the management committee and PWG. Financing could be via a budget agreed by government specifically for the plan or, more usually, via departments' annual budget allocations.

(x) Plan evaluation: The Plan's PWG monitors, evaluates and adapts as implementation progresses. Progress is reported to the management committee.

(xi) River basin modelling and decision support tools: Decision support tools such as GIS, remote sensing, river basin models are used to assess future scenarios such as climate change and changing water demands. While there are fully integrated river basin planning and management models, at an early stage it is also possible to use relatively simple spreadsheet models before moving to a more sophisticated level. Where river and water distribution networks, operational rules, land uses, and climate conditions are to be used, the more sophisticated river basin model that integrates these is best used. Tools to prioritise management options should be used and these range from multi-criteria analysis which is relatively straight forward and can be increasingly complex including by weighting options against specific criteria and include a risk assessment approach. There are more sophisticated approaches using tools such as Analytical Hierarchy Process and Bayesian Networks. These require specialists and can take some time to apply. While they ultimately give more rigorous results, the MCA approach is faster and more transparent.

(xii) Stakeholder participation: Stakeholder participation is essential to plan development and implementation. Stakeholders include relevant government departs and agencies, especially in the river basin and at the operational level as well as from civil society including the basin community. Planning is both a top-down and bottom-up process. A top-down approach is necessary to provide direction and integration for planning and to ensure that it is information and evidence based. The bottom-up involvement informs the plan of local conditions and needs. Stakeholders are important for a number of reasons including:

- They have in depth and local understanding real water related issues and problems and can make a valuable contribution in identifying these.
- Their understanding and involvement is important for gaining support at the political level.
- Plan implementation will inevitably require the involvement and assistance of the community and private sector, and this will be more improved if there is understanding and support for the plan from early on.

- A thorough stakeholder analysis should be undertaken at project initiation to inform plan management of stakeholders and their interests and authorities. A stakeholder participation plan, especially for key stakeholders should be prepared at this time.

2 OVERVIEW OF PUNJAB INDUS RIVER BASIN

2.1. INTRODUCTION

Pakistan has the fourth largest irrigation network serving 20.0 million hectares of land for cultivation. Punjab is the biggest province with respect to population with 110 million people (census 2017). As of 2019, Punjab had a gross domestic product (GDP) of $163 billion, which accounts for 57% of the country's GDP of $284.2 billion. It is short of freshwater resources facing severe food scarcity challenges due high rate of population growth and unabated increase in water demand. The province touches the foothills of Himalayan Mountain ranges in the north and extends to very flat desert areas in the south. Five major rivers flow through it including the mighty Indus. These rivers flow from north to south draining the Himalayan range.

2.2. PUNJAB SUB-BASINS AND DOABS

The Punjab sub basins have been identified on the basis of hydrological boundaries, irrigation and drainage facilities and management arrangements. The province is underlain by a different type of geologic formation consisting of intermountain valley system in Pothohar Plateau, to an alluvial plain in the northern part of Punjab and more or less desert conditions to Bahawalpur areas. Indus River and its eastern tributaries drain the central part. The province can be divided into four hydrogeological zones. These Zones (See **Figure 2-1**) depict different types of climatic and geologic conditions that ultimately control the occurrence and movement of surface and groundwater. These are

- Alluvial plains of Central Punjab (Doab areas)
- Pothohar Plateau and Salt Range,
- Piedmont deposits of Suleiman Range (DG Khan area), and
- Cholistan Desert.

In the Alluvial Plain of Central Punjab (Doab areas), the alluvial deposits, which often are more than 500 m (1500 ft) thick consist of sands of various grades with minor amounts of silt, clay and gravels. With a very flat terrain. the sediments constitute a large and contiguous unconfined aquifer and are highly transmissive. With an extensive canal system for irrigation, cultivation is the main activity contributing to the national economy.

The Pothohar Plateau and Salt Range are the rainfed areas, average annual rainfall is about 750 mm (30 inches). Unconsolidated sand and gravel and semi-consolidated conglomerates and sandstone constitute the aquifer material. Yields of wells vary greatly in accordance with local geological conditions. Well water is in general suitable for drinking and agricultural purposes.

In the Piedmont deposits of Suleiman Range (right side of Indus River), the sediments comprise intercalation of sand and clay and are fairly transmissive. The GW quality in this area is often too salty for either drinking or irrigation. The conditions in Cholistan desert are arid, where the average rainfall is 125- 130 mm; there is little GW and most of it is saline.

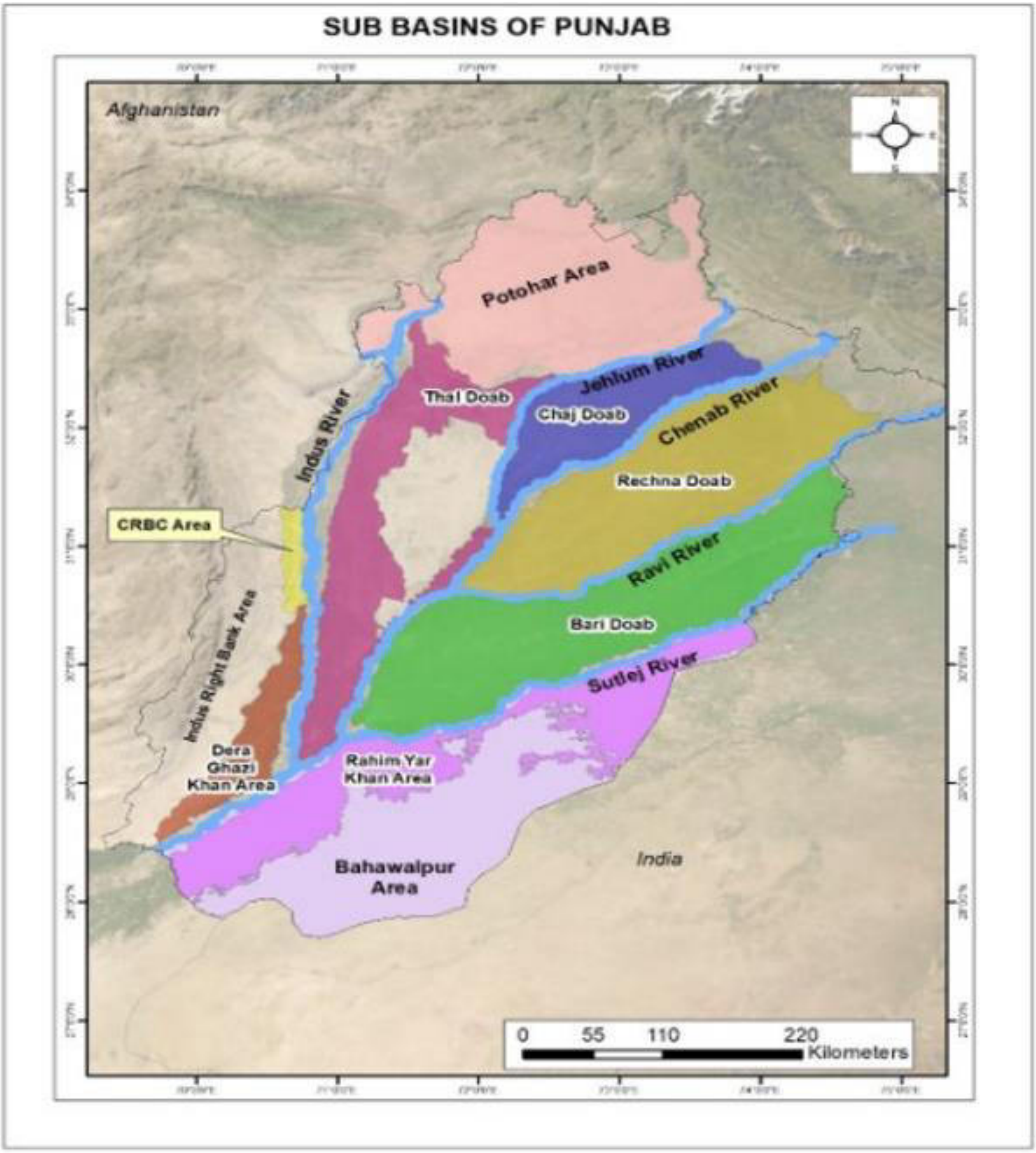


Figure 2-1: Punjab Irrigation Sub-basins and Doabs

2.3. ADMINISTRATIVE AREAS AND POPULATION

Punjab has 112 million people, which is over 50% of the country's population. Administrative and sub-basin wise, population is given in Table 2-1. Districts, divisions, total area, population density and population growth rate for all 7 sub-basins are summarized as follows.

2.4. LITERACY AND EDUCATION

The Economic Survey of **Pakistan** 2019 report says that **literacy** rate has increased in **Punjab** from 46.56% in 1998 to 64.7% in 2018.

Table 2-1: Area and Population of Punjab Irrigation Sub-basins

IRRIGATION SUB BASINS	POPULATION	AREA (KM²)
1. THAL IRRIGATION SUB-BASIN	11,353,468	23,116
2. CHAJ IRRIGATION SUB-BASIN	9,016,508	13,521
3. RECHNA IRRIGATION SUB-BASIN	29,066,627	25,315
4. BARI IRRIGATION SUB-BASIN	34,226,828	17,070
5. BAHAWALPUR IRRIGATION SUB-BASIN	11,464,031	45,588
6. DG KHAN IRRIGATION SUB-BASIN	4,192,403	19,257
7. CRBC IRRIGATION SUB-BASIN	675,756	2,665
8. POTHOHAR RIVER SUB-BASIN	17,600,000	22,275

2.5. CLIMATE

Most of the province lies in the lowland zone (semi-arid to arid) and some parts, north of Salt Ranges are included in the highland zone (cool and humid). It has extreme climate with hot summers and cool to cold winters. It is positioned at the western tail end of the tropical monsoon (summer rain bearing winds coming from Bay of Bengal) and at the eastern tail end of western depressions (winter cyclone system originating from the Mediterranean Sea).

Temperature ranges from -2°C to 45°C, but at times can reach 50°C (122°F) in summer and can descend to -10°C in winter. Punjab has four major seasons: First is hot-dry, pre-monsoon (April to June) when temperature rises as high as 43.3°C and there very limited rainfall. Second is slightly less hot but humid monsoon season (July to September). Third is cooler / mild and mostly dry weather (October to November). Fourth is cold weather with light showers of rain from western disturbances (December to March) when temperature drops as low as 4°C.

Average annual rainfall ranges between 960mm in the sub-mountain region to 460mm in the plains. Most rain falls from the summer monsoon, which enters Punjab from the north-east. These areas also receive rainfall from western depressions and convectional currents. Thunderstorms are common in the north and north-west. The amount of precipitation keeps decreasing southwards. The southern area receives much less rain and spells of high temperature. Extreme heat, dryness, dust storms with hot and dry wind are the main features of the southern arid parts of the province. **Table 2-2** summarizes the mean monthly rainfall in major cities of Punjab.

Table 2-2: Mean Monthly Rainfall Data for Punjab Stations (mm)

MONTH	BAHAWALNAG AR	BAHAW-ALPUR	FAISAL-ABAD	ISLAM-ABAD AP	JHELUM	KHANPUR	LAHORE AP	MULTAN	MURREE	SIALKOT
JAN	11.4	7.4	11.1	56.2	40.4	5	22.7	7.6	111.9	41.4
FEB	17.3	10	19.1	84.1	56.7	7.9	39.3	15.5	166.5	49.6
MAR	15.7	10	23.8	92.4	65.9	5.4	36	18.4	181.2	52.8
APR	10.8	10.5	23.7	63.2	40.2	4.3	21.1	14.2	131.8	33.5
MAY	13.2	7.1	14.9	35.8	29.6	4.5	23.4	11.9	83.4	26.8
JUN	39.2	16.2	43.8	75.3	57	6.5	54.5	13.1	142	64.1

MONTH	BAHAWALNAGAR	BAHAW-ALPUR	FAISAL-ABAD	ISLAM-ABAD AP	JHELUM	KHANPUR	LAHORE AP	MULTAN	MURREE	SIALKOT
JUL	70.8	40.4	101	307.8	243.1	33.3	196.8	49.6	339.5	312.6
AUG	34.2	39.1	87	340.3	231.6	33.2	182.9	41.8	302.4	277.3
SEP	14.9	16.5	42.5	110.7	65.4	12	74.6	24.6	130.9	89
OCT	7.9	4.7	4.7	31.7	22	2.7	18.5	5.6	63.1	23.3
NOV	2.5	1.4	2	14.4	10.1	0.4	5.2	1.2	33.3	9.1
DEC	3.6	4.7	7.1	36.3	27.1	4.8	10.8	5.7	72.2	24.2
ANNUAL	**241**	**168**	**380.5**	**1,248**	**889**	**120**	**686**	**209**	**1,758**	**1,004**

2.6. LAND USE

Punjab has a total geographical area of 20.63 Mha representing 25.9% of the country's total area, making Punjab the second largest province. Land utilization status is available for 86% of the total area; whereas 14% area remains unreported. Another 14% of the total area is not available for cultivation due to either being completely barren or due to the presence of roads, villages, houses, canals, etc. That leaves 72% of the land area available for cultivation.

Punjab land utilization 2017-18 is given in Table 2-4. The province has 8.5 Mha of irrigated land and intensive cropping has increased its cropped area to around 16.93 Mha and so far, has managed to produce adequate food for its population.

Table 2-3: Punjab Land Utilization 2017-18 (Mha)

GEOGRAPHICAL AREA	TOTAL AREA REPORTED (COL 3 TO 6)	FOREST AREA	NOT AVAIL. FOR CULTIVATION	CULTURABLE WASTE	CULTIVATED (7+8)	CURRENT FALLOW	NET AREA SOWN	AREA SOWN MORE THAN ONCE	TOTAL CROPPED AREA (8+9)
1	2	3	4	5	6	7	8	9	10
20.63	17.53	0.48	2.95	1.47	12.64	1.87	10.77	6.16	16.93

2.7. WATER RELATED ADMINISTRATION IN PUNJAB

Six government departments and agencies are involved in the administration of water and water related resources:

(vi) Indus River System Authority (IRSA) is the main institution which regulates the inter provincial share of water and overseas that regulations are followed in letter and spirit.

(vii) Water and Power Development Authority (WAPDA) is the authority under central government to develop and operate large water storages and their power generation units. It releases stored water in the rivers as per IRSA instructions according to provincial shares.

(viii) Punjab Irrigation Department (PID) is the main water related department and is responsible for planning, design and management of large water infrastructure including river works, canals (link and other), drains and flood protection embankments and monitoring of groundwater and its use. PID manages transfer of the bulk water

supply for irrigation (around 90% of the available water) from rivers to distributary canals. PID conducts the policy, planning, and design centrally whilst field services are provided through its zonal offices and commands.

(ix) Punjab Agriculture Department (PAD) is responsible for agricultural and on-farm water management (from irrigation outlet to farmland). Field services and agricultural extension are provided through its field offices located in Faisalabad, Lahore, Kalashah Kaku, Chakwal, Bhakkar, Bahawalpur, Sahiwal, Sargodha, and Multan.

(x) Punjab Public Health Engineering Department through Water and Sanitation Agencies (WASAs) in major cities manage domestic and municipal water supplies.

(xi) Environment Protection Department (EPD) is responsible for monitoring the water quality of industrial effluents and managing water-related ecosystems. EPD has field offices in every district of the province.

(xii) Department of Local Government develops rural water supply and sanitation.

(xiii) Industrial water use is managed either privately or by the Department of Industry.

Planning and Flood Commissions are other national level agencies concerned with water related issues and implementation of new projects. The National Disaster Management Authority (NDMA) also provides support to the local administration in managing major floods.

2.8. IRRIGATION, URBAN WATER SUPPLY AND DRAINAGE

The canal system in Punjab transfers around 98 billion cubic meters (BCM) of irrigation water annually, at a rate of about 3,398 m^3/s. The irrigation water supply infrastructure involves 13 barrages, 25 main canals with a combined length of 6,390 km, 13 inter-rivers Link canals with a length of 845 km, 2,794 distributary canals with a length of 31,000km and 58,000 canal outlets within the five rivers basin (Indus, Jhelum, Chenab, Ravi and Sutlej rivers).

This infrastructure also supplies water to urban centers, towns, villages and habitations. In addition, there are 57 small to medium sized dams, 9,795 km of surface drains and 3,360 km of flood protection embankments. This infrastructure is the backbone of irrigated agriculture in the Punjab. It has significantly contributed to water and food security and generated a wealth of knowledge and experience in the management practices of canals-based irrigation water delivery systems.

2.9. INDUSTRIES AND DEVELOPMENT

A large number of industrial units are operating in the Punjab at cottage level, small to medium & large-scale units. Some of these are listed below:

- Cement
- Car assembly units
- Chemical
- Flour Mills -
- Glass
- Soda Ash
- Textile Composite
- Sports
- Leather
- Garments
- Tobacco
- Sugar
- Livestock
- Cooking Oil

These industries are spread all over Punjab, some are located in dedicated industrial zones and most of them along main roads or near quarry areas close to available raw materials. Major industrial zones are located in Lahore, Faisalabad, Sialkot, Gujranwala and Gujrat.

2.10. AGRICULTURE AND AGRICULTURE INDUSTRY

Agriculture holds a key position ¡n the economy of Punjab. It has a 21% share in GDP and provides employment to 47% of the workforce. The sector acts as source of raw materials for the country's major industries: textile, leather, rice processing, edible oil, sugar and various food processing industries. Agriculture-based products account for around three quarters of the total National exports, of which about 60% is contributed by Punjab. Over the years, the agriculture sector has maintained a satisfactory growth, to effectively cope with the challenge of ensuring food security for the country's growing population.

Punjab has 10.81 million hectares (53%) as the net sown area; the area that is cultivated at least once in a year. The total cropped area is more than the net sown area, since land is used during two seasons: Rabi (October to March) and Kharif (April to September). As per the Census of Agriculture 2010, there were 5,249,800 agriculture farms in Punjab. The majority of these farms were very small. Approximately 42% of the farms have an area of less than one hectare and these farms made up only 8.9% of the total farm area. Farms of 1-10 ha represent 55.6% of the total number of farms and 68.9% of the total area. Farms of 10 ha and above represent only 2.4% of the total farms, but contain 22.2% of the total farm area, as shown in **Figure 2-2**.

The agriculture sector of Punjab ¡s diversified, producing all types of agricultural crops. The province contributes more than half of the total national production in most of the agriculture commodity groups. Punjab's total agricultural production in 2015 was 130 million tons, which accounted for 74% of the total national agricultural production of 176 million tons. Overall, two thirds of the total cropped area of Punjab was used for the three largest crops; wheat, cotton and rice. Fodder is another large and important crop which derives its importance by feeding the large livestock population of the province. Fodder crops accounted for 10.6% the cropped area, whilst maize and sugarcane accounted for 4.1% and 4.3% of the total cropped area. Higher value crops like oilseeds, pulses and vegetables are cropped on smaller areas. In 2014, the share of these crops in the total cropped area of the province was around 10%.

Cash crops constituted the largest share of total provincial agricultural production at 41%, with fodder crops for livestock accounting 29%; cereal crops accounting for 21%; and higher value-added crops including fruits, vegetables, condiments, pulses and oilseeds, jointly accounting for around 9%.

The agriculture sector is facing many other challenges stemming from lack of resources and ineffective crop management practices. Provision of irrigation water remains one of the biggest challenges. Water availability is insufficient, and the situation is exacerbated by its inefficient use. Flood irrigation is the most commonly used method and is not efficient. Use of high efficiency irrigation systems (HIES) is not common, due to lack of awareness and high initial costs; especially for smaller farmers. The degree of mechanization is low and farmers have to rely on old farming techniques leading to lower crop productivity.

An integrated strategy, aimed at ensuring provision of adequate resources and removing critical growth barriers, can transform the sector from its current, suboptimal to optimal level of performance. The Government of Punjab is undertaking efforts to reposition agriculture as the engine of economic growth in the province by focusing on higher value-added crops and implementing initiatives to improve productivity by promoting modern agricultural practices.

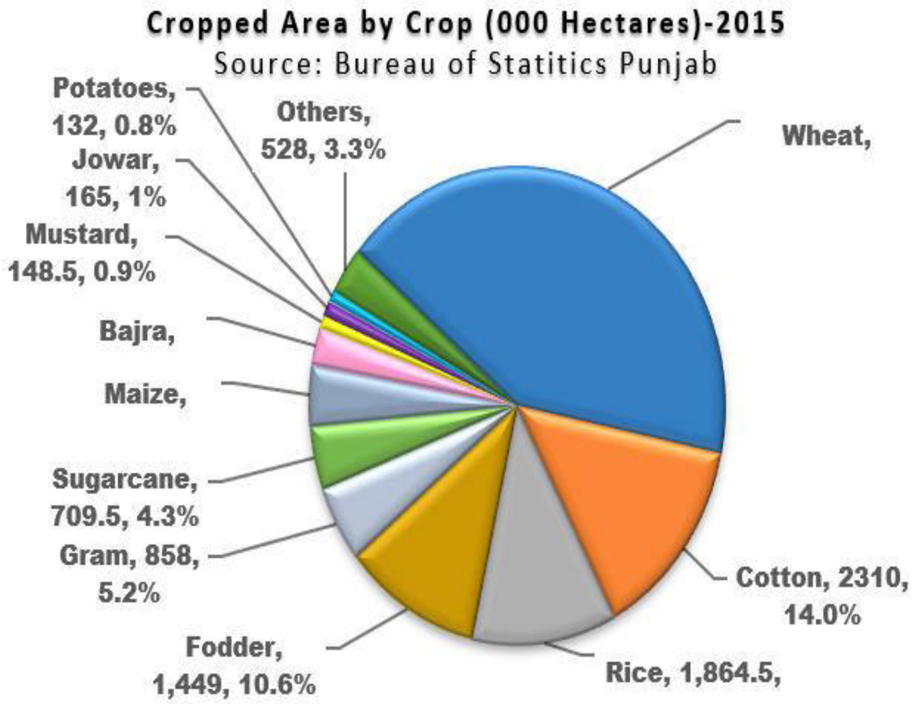


Figure 2-2: Cropped Area by Crops

2.11. SOCIO-ECONOMIC ISSUES RELATED TO PUNJAB RIVER BASIN

From the previous discussion, it is apparent that due to social conditions (small land holdings and low incomes), government policy is pushing for a restructured agriculture with higher productivity and higher value crops. For this to happen, the infrastructure and its O&M need to be upgraded to improve the levels of water supply service and more efficient irrigation systems/technologies should be introduced. The O&M of such a range of infrastructure has been challenging due to changing agro-climatic and socio-economic environments, political economy, governance related issues, and dwindling institutional capacity vis-à-vis financial constraints.

2.12. POVERTY

Half of the population of Punjab lives in a rural environment. Poverty is pervasive in rural areas and in the slums of the urban areas. About 31% of the Punjab population live below the poverty line, compared to 40% in Pakistan on an overall basis. The government of Pakistan recently estimated that only 12.4% population live under absolute poverty with income less than USD 2 per day. However, independent sources do not agree with this estimate and government has constituted a group to evaluate the figures. Over 45% of the rural population is landless. Rural households, including the landless, derive 44% of their income from agriculture, directly or indirectly. The rural poor tend to be employed mostly as agriculture wage workers. Rural Punjab is highly dependent on services from the public and private sector. Thus, reforms to improve public service delivery and stimulate rural growth that raise agricultural and non-agricultural wages are fundamental for reducing poverty.

2.13. CHALLENGES IN CHANGE MANAGEMENT

In Punjab, the fresh groundwater reservoir was developed as an unintended by-product of leakage and seepage losses from the canal irrigation system and from irrigation return flows. As a result, the groundwater contribution to the crop irrigation has increased from about 10% in the 1960’s to more than 50% in 2018. Groundwater also contributes over 70%

of domestic water supply. Groundwater pumping by about one million wells (tube wells) in Punjab has greatly contributed to an increase in cropping intensity from 67% originally to around 131%. However, large-scale unregulated pumping seriously undermines the groundwater resource by creating water table drawdowns and mobilizing salts from the underlying brackish water aquifer, which impacts the land surface and causes land degradation.

Socio-economic development, expanding urban centers, industrial growth and development of infrastructure of high social and economic value in the floodplains is also causing problems of increased greywater, water quality degradation, damages to water and land-based critical ecosystems, frequent flood damage, water related health hazards, poor drainage, water logging and salinity and declining water productivity.

2.14. CLIMATE CHANGE

A significant warming trend of about 0.54°C in the annual mean temperature has been observed from 1961 to 2007 in Punjab. The warmest year recorded until 2007 was 2004, and the highest increase is observed during winter when the temperature rise was 0.97°C. The summer mean temperature increase was 0.22 ^{0}C during this period [1]. Central and southern Punjab annual precipitation increased by 0.63% from 1901 to 2007. Monsoon rains increased by 0.57%, and winter precipitation increased by 0.99% [Ali, M., et al 2004].

The climate change impacts, urbanization and industrialization may further worsen the situation leading to significant flood damages, droughts, water quality and land degradation, agricultural productivity loss due to increased temperatures and water demands, damage to the ecosystem, etc.

A comprehensive management of water resources and water related disasters requires developing and operationalizing integrated water resources management (IWRM) and water-related disaster risk management (DRM) approaches. As most of the water resource is allocated, cross-sector water competition (irrigation, domestic and municipal, industry, environment and social) might cause conflicts among the water users.

2.15. SOURCES OF WATER

2.15.1. AREAL RAINFALL

One of the major sources of water is rainfall, which contributes to groundwater recharge, meets evapotranspiration requirements of vegetation and contributes to stream flows. The annual areal rainfall for Punjab province has been estimated for the period of 50 years (1961 to 2010) using the standard techniques and data from Pakistan Meteorological Department by *Faisal and Gaffar 2012*[3]. The annual areal rainfall varies from 128 to 571 mm indicating a wide variability.

Trend analysis indicates that there is a slightly increasing trend in areal average rainfall in the last 60 years. If the increasing trend continues, the province might face more frequent and intense floods in the future? The mean annual areal rainfall is 384 mm with a standard deviation of 97 and a coefficient of variation of 25%.

3 *Faisal, N. and A. Gaffar. 2012. Development of Pakistan's new area weighted rainfall using Thiessen Polygon Method. Technical Note. Pakistan Journal of Meteorology, Pakistan Meteorological Department, Vol. 9, Issue 17: July 2012*

The median annual rainfall value of 441 mm is close to the mean value. There are distinct wet and dry years and the highest annual rainfall is 4 times higher than the lowest annual rainfall. The wide variability in mean annual rainfall indicates that the phenomena of drought and floods in the last 60 years continued and there are chances that it will not only be continued but the droughts and floods will be more frequent and intense – most of the climate change experts predicted this change in arid areas including Pakistan. For more details one can see the IPCC4 Fifth Assessment of 2014.

Annual Rainfall in Irrigation sub-basins/Doabs for the period 2009 to 2020 is given in **Table 2-4**. Mean, maximum and minimum values of each Doab are also given. Rechna and Chaj Doabs have higher rainfall than other Doabs. Bahawalpur Doab has the lowest rainfall.

Table 2-4: Annual Rainfall in Doab Areas (mm) (Data Source: PMD)

YEAR	THAL	CHAJ	RECHNA	BARI	BAHAWALPUR	DG KHAN	CRBC
2015	289	514	645	457	233	203	100
2016	294	554	307	503	66	144	66
2017	176	454	236	237	61	137	56
2018	110	166	159	107	82	94	87
2019	425	551	663	404	258	486	425
2020	446	716	559	453	303	462	384
MEAN	336	467	485	344	141	238	192
MAX	569	716	689	503	303	486	425
MIN	110	166	159	107	61	34	26

2.15.2. SURFACE WATER

Surface water is the largest resource of water available to the province from the contiguous part of the upper Indus basin. The primary agreement that allocates water among the provinces of Pakistan is the Indus Water Apportionment Accord of 1991. Water entitlements of Punjab from the Indus River System as per the Accord are 55.94 (MAF) per annum. Pakistan has experienced severe shortages after the signing of the accord, which has created serious differences between Punjab and Sindh. Disputes over sharing of shortages still ensue between provinces and may further worsen due to the impact of climate change, leading to extreme floods and droughts.

The data of canal water diversions indicate that these were quite variable, depending upon seasonal conditions, ranging from 43.5 to 51.25 MAF. Shortages in river flows are shared among the provinces as per apportioned allocations. Conflict

4 Inter-governmental Panel on Climate Change Fifth Assessment Reports 2014 – a) Working Group I Report on ‘Climate Change – The Physical Science Basis; b) Working Group II Report on Climate Change – Impacts, Adaptation and Vulnerability; c) Working group III on Mitigation of Climate Change; and d) Climate Change 2014 Synthesis Report.

over water leads to lack of trust between the provinces, especially between Punjab and Sindh, and also between Sindh and Baluchistan.

2.15.3. SURFACE WATER QUALITY

The quality of surface water is deteriorating due to the disposal of untreated municipal and industrial wastewaters and saline drainage effluent from agricultural areas [Imran S., et al, 2018)]. River waters have very high suspended solids, particularly during high flow conditions and many rivers have stretches which do not support aquatic life. The range of water quality characteristics in some of the major rivers in Pakistan as reported by Aziz is presented in **Table 2-5**. Only a few major urban cities in Punjab use surface water sources for domestic water supply; these include Islamabad, Rawalpindi, Murree and Chakwal.

Table 2-5: Water Quality of Rivers in Pakistan

PARAMETERS	INDUS AT KOTRI	CHENAB AT RAKH BRANCH CANAL	RIVER RAVI AT BALLOKI	HARO AT KHANPUR	SOAN AT CHIRA
PH	7.1 - 7.5	7.0 - 8.0	7.4 – 8.35	7.7 – 8.2	7.5 – 8.0
ELECTRICAL CONDUCTIVITY (µµMHOS/CM)	257- 487	125-286	280-430	-	-
TOTAL DISSOLVED SOLIDS (MG/L)	154- 315	149-213	98 - 250	156 - 204	116 - 256
SUSPENDED SOLIDS	10 - 2000	137 - 340	156 - 605	16 - 4320	11 - 6130
DISSOLVED OXYGEN (MG/L)	1.5 – 6.9	6.8 – 7.9	6.3 – 8.2	-	-
BIOCHEMICAL OXYGEN DEMAND (MG/L)	1.5 – 5.0	1.4 – 2.5	2.3 – 3.9	-	-
CHEMICAL OXYGEN DEMAND (MG/L)	7.0 – 19.0	11.0- 30.0	16 - 80	-	-
FAECAL COLIFORM (/100 ML)	150 - 400	1050 - 5000	1200 - 15000	-	-
CALCIUM (MG/L)	12 - 46	35 - 53	29 - 59	28 – 44	24 - 36
MAGNESIUM (MG/L)	3.0 - 29	13.5 - 40	8.0 - 22	12 - 23	7.0 - 28
CHLORIDES (MG/L)	6.0 - 100	30 - 50	20 -30	7.0 - 13	7.0 - 25
SULPHATES (MG/L)	6.0 - 140	28.6 - 46	27.6 – 39.3	16 - 77	5.0 - 34
NITRATES (MG/L)	4.2 – 10.5	2.0 – 3.6	0.53 – 6.0	-	-

In rural areas, where the groundwater is saline, irrigation canal water after treatment is supplied for domestic use. Unfortunately, the surface water quality has not been monitored on a routine basis as a raw water source for domestic supplies and no reliable data are available in this respect.

The Indus River provides 65% of total river flows, while the share of Jhelum and Chenab is 17% and 19%, respectively. The months of peak-flow are June to August, which is the monsoons period. Flows for Kharif and Rabi crop seasons are 84% and 16%, respectively. Thus, it becomes all the more important to store as much water as possible during the high-flow period for use during low-flow period. Under such circumstances, the availability and integrated management of storage-reservoirs in the country becomes critical.

2.16. GROUNDWATER

Since the 1980's, the use of groundwater for irrigation in Punjab Basin has increased substantially. It now supplies almost 50% of irrigation water for agriculture, and also supplies domestic water for many cities and towns, as well as industrial demand.

The only possibility to reduce the higher growth rate of tube well development in the province is to introduce efficient practices of water use in all sectors – domestic, industrial, commercial and agriculture and the impact of this on the water balance and groundwater availability should be monitored.

Present groundwater pumpage for agriculture in Punjab Basin is about 55 MAF as given in **Table 2-6.** Doab groundwater use during the Kharif season, Rabi season and full year are given in **Table 2-7**.

Table 2-6: Punjab Basin Groundwater Pumpage for Agriculture (Agriculture Statistics of Pakistan 2017-18)

DESCRIPTION	ELECTRIC	DIESEL
TUBEWELLS/LIFT PUMPS	155,951	944,890
DAYS PER YEAR	183	124
HOURS PER DAY	6	5
DISCHARGE (CFS)	1.5	0.7
PUMPAGE (AF)	21,227,379	33,891,095
TOTAL PUMPAGE (AF)	**55,118,474**	

Table 2-7: Irrigation Sub-basin Groundwater Use

IRRIGATION SUB-BASIN	KHARIF	RABI	ANNUAL
THAL	7,140,003	1,004,106	8,144,109
CHAJ	4,638,226	1,864,999	6,503,225
RECHNA	10,432,226	7,196,301	17,628,528
BARI	4,200,406	7,082,731	11,283,138
BAHAWALPUR	3,462,338	1,392,677	4,855,015
DG KHAN	1,876,155	196,723	2,072,877
CRBC	165,541	21,963	187,504
TOTAL	**31,914,895**	**18,759,500**	**50,674,397**

The management of groundwater has long been neglected, and with increasing demand for water, PID require capacity and institutional support to manage its vast fresh groundwater resources for a sustainable future. Water quality in the vicinity of canals and water courses is of good quality due to natural filtration of soil strata, which provides a good source of drinking water in rural areas.

2.16.1. GROUNDWATER QUALITY

The major sources of groundwater pollution in Punjab are from industrial and municipal effluents, resulting in accumulation of heavy metals and trace elements in groundwater aquifers and surface water bodies. Over-abstraction of groundwater also leads to progressive deterioration of fresh groundwater sources from lateral and vertical movement of deeper saline groundwater. Other sources include drainage effluents and disposal of saline water into canals, which disproportionately affects downstream users.

About 5.6 million tons of fertilizer and 70 tons of pesticides are being consumed in the country annually. A major portion of it is consumed in Punjab. The use of pesticides is increasing 6% annually. A study by EPA Punjab [2005] found that 25% of samples had concentrations of heavy metals beyond WHO limits. Groundwater includes water from shallow dug wells, shallow tubewells and deep tubewells. The quality of shallow wells and tubewells around cities and in peri-urban areas is affected by domestic and industrial effluents, because these effluents are disposed into ponds and waterways. Seepage of these effluents affects the quality of shallow groundwater. The majority of samples analysed for large cities and peri-urban areas are polluted with bacteria, heavy metals, and chemicals.

2.17. WASTEWATER

Around 4.9 MAF water is currently being used in the province for domestic, industrial and commercial purposes. Approximately 3.3 MAF are used for domestic and 1.62 MAF are used for industrial/commercial uses. Around 80% of water can be recovered from effluents from domestic and industrial use (PWP and GWP 2000[5]). Thus, 3.61 MAF is available as effluent from domestic, industrial and commercial uses. In addition to this, 0.16 MAF of agricultural drainage effluents are estimated using design drainage capacity in Punjab (WAPDA 2005[6]). Thus, the total wastewater available in Punjab is around 3.77 MAF, which can be taken as a resource. This is a sizable amount of water which should be kept separate from storm water, so that these can be managed through cost-effective treatment refer to **Figure 2-3**.

5 PWP and GWP. 2000. Framework for Action. Pakistan Water Partnership, Global Water Partnership

6 WAPDA. 2005. Drainage Master Plan of Pakistan. Water and Power Development Authority, Lahore, Pakistan

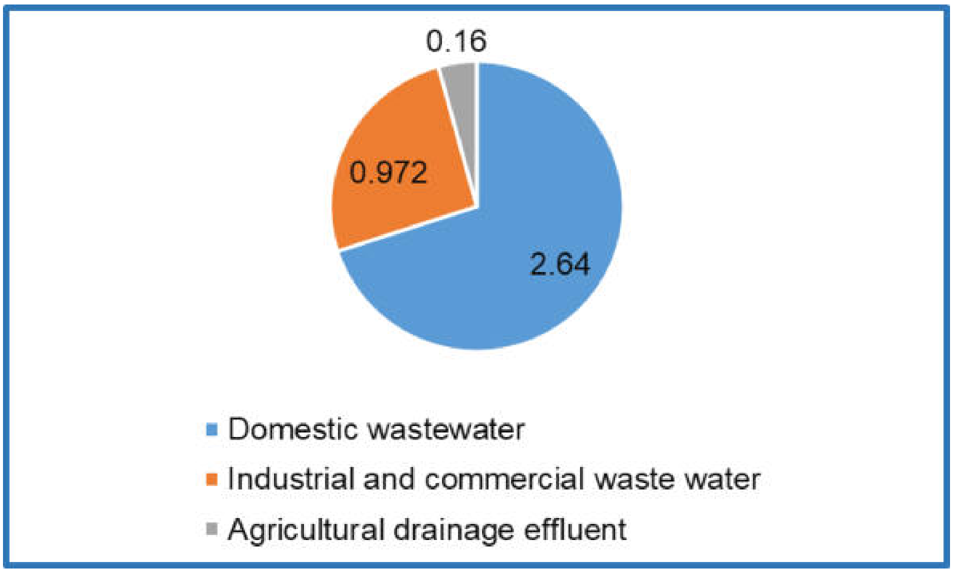


Figure 2-3: Punjab's availability of wastewater in MAF

In urban areas, the stormwater, sewage and industrial effluents are dumped into the same drainage system and thus treatment is difficult. Therefore, a plan of action is needed for future management of stormwater (urban and rural), sewage and industrial effluents. There is a need to enforce a policy to handle and manage wastewater resources separately, so that treatment is easy and cost-effective.

In the rural areas, there is also a need to handle domestic, commercial, industrial and stormwater, separately. Currently, in rural areas sewage and commercial effluents are disposed into the village ponds which were developed for stock water purposes and having allocation from canal supplies under the warabandi system. Stock water important and there is a need to rehabilitate the stock water ponds by separating the sewage and commercial effluents. These stock water ponds can also be used in future for recharging groundwater.

Approximately 66% of total livestock diseases are water borne, which is higher than human (60%) levels. The PID/WRD could enforce a reform that in village ponds, where sewage is disposed, the water allocation from canal water will be terminated. This simple tool would help to manage the quality of stock water ponds; and these ponds can also serve as recharge ponds. Landscaping around the stock water ponds would help to reduce the sediment load of inflows during the rainy season.

2.18. CONTRIBUTION OF SURFACE AND GROUNDWATER IN IRRIGATED AGRICULTURE

The total irrigated area in the Punjab province during 2013 was around 14.89 million ha. Of this, the largest area falls under the canal commands dependent on groundwater, representing 8.15 million ha or 55% of total irrigated area, followed by canal commanded (sufficient surface water so that groundwater is not required or groundwater brackish, 3.41 million ha), tubewell commanded (2.67 million ha), wells (0.33 million ha) and others (0.07 million ha) **Figure 2-4**. In summary around 77% of the irrigated area is dependent on groundwater to some degree**.**

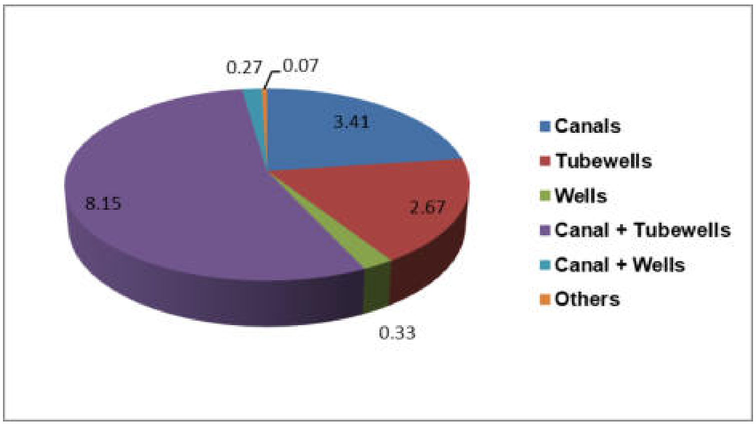


Figure 2-4: Area under different sources of irrigation (Agriculture Statistics of Pakistan 2017-18)

2.19. CURRENT POPULATION AND PROJECTIONS FOR 2050

The population of the province was around 73.6 million in 1998, which has increased to 110.8 million in 2020. Punjab is the most urbanized and industrialized province of Pakistan, after Sindh. The population density is 495 persons per km^2. The urban and rural populations are approximately equal. The forecast population growth rate is 1.66% up to 2020, 1.65% up to 2025 and 1.63% up to 2050, as suggested by Punjab Population Welfare Department under a study “Population Situation in Punjab”. The increase in population is estimated to be 23.6% in the next three decades 2020-2050.

2.20. CURRENT WATER USE BY SECTORS AND PROJECTIONS

Total water uses by the major sectors of water use (domestic, industry and commercial, and agriculture) is around 103 MAF. Agriculture is the largest user of water, consuming 98 MAF or 95% of total water use in the province. Thus, only 5 MAF or 5% of water is used by the domestic, industrial and commercial sectors. Due to constrained water availability, any further increase in the use of domestic, industrial and commercial sectors would come largely from agriculture, which would need to become more water efficient. Canal supplies can be provided to those urban areas having access to the irrigation system network or by its extension.

2.1.1 DOMESTIC WATER USE AND PROJECTIONS

Currently around 3.3 MAF (4 billion m^3) water is used for domestic purposes. The projections made for 2025 indicates that an increase of 0.3 MAF (0.4 billion m^3) would be required to meet the demand in 2025. The projections made for 2050 indicate that an increase of 2.1 MAF (2.6 billion m^3) would be required to meet the demand in 2050. A water allowance of 100 litres per capita per day (148 litres/capita/day for tap water and 74 litres/capita/day for other sources) is assumed, while estimating the current use and projections based on the current average water allowances fixed by WASA and PHED (GOPu and World Bank 2006). This is the water allowance also recommended by WHO and World Bank considering the health hazards of very low level and adequate to meet the requirement of population in the province.

The additional amount of water needed in 2025 seems a small amount of water (i.e. 9%, 0.3 MAF) to meet the demand of the domestic sector. However, by 2050 domestic use will increase by 64% (2.1 MAF). The estimated volume of water for domestic use by 2050 is 2.2% of the current water used for irrigation as shown in **Figure 2-5**.

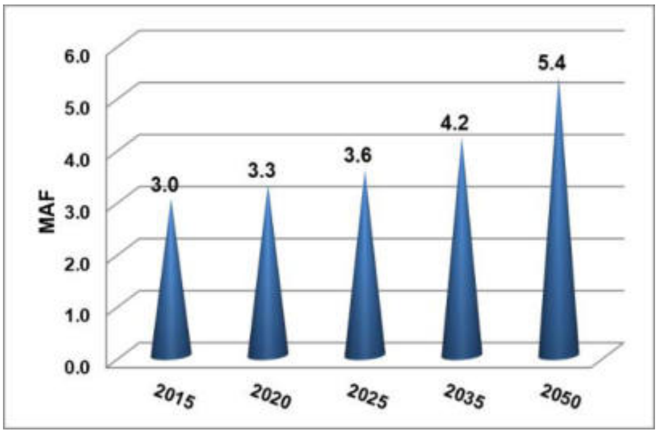


Figure 2-5: Punjab's domestic water use and projects in MAF (Data Source: Population Census Reports, WASA, PHED, GOPu and World Bank 2006, GOPu and IUCN 2010)

2.20.1. AGRICULTURE WATER USE AND PROJECTIONS

Currently, the agriculture sector consumes 95 MAF. This would increase to 106 MAF in 2025, 115 MAF in 2035 and 124 MAF in 2050. The increase in the next decade would be around 18% than the current use basing the increase on a population growth rate of 1.66% and 1.65% for the periods of 2020 and 2035 and 2035 to 2050, respectively. It is not possible to provide additional amount of water because new resources of water are harder to find. The expansion in irrigated area will not be a feasible strategy. The sustainable and low-cost option is to enhance water productivity at a growth rate of 1.66% per annum against the annual growth rate of agriculture sector which ranges between 2 to 3% per annum in the last decade, which requires enhancement of crop productivity and reduced water use to mature a crop.

This would be achieved by adoption of water efficient technologies, improved production practices, more productive and higher value crops and varieties, improved operation and maintenance of irrigation systems, and reduced non beneficial losses of water.

2.20.2. INDUSTRIAL WATER USE AND PROJECTIONS

The current water use in industrial and commercial sector is 1.91 MAF (2.36 BCM), which is a sizable amount of water. The projections for 2050 indicated that the industrial water use will be 3.98 MAF (4.91 BCM) having an increase of 2.07 MAF (2.55 BCM) or 849 million m^3 per annum (0.22% of current irrigation water use). The growth rate of the industrial sector in Punjab was 5% during 2001-2011 and the Punjab growth strategy suggested a growth rate of 8% in the next decade. However, water projections for 2025 and 2050 are based on growth rate of 5% per annum, as these industries have to be water efficient in the next decade. The additional water required for the industrial sector of water use will be met out of the savings made in water use in the agriculture sector. The strategy for making savings in water use shall be prepared.

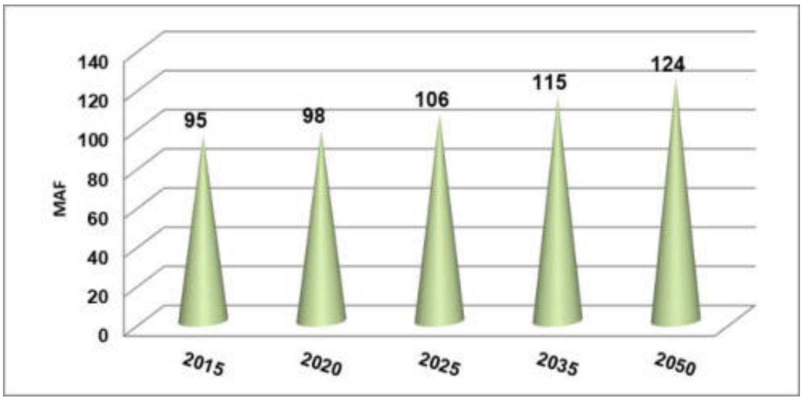


Figure 2-6: Punjab's current agricultural water use and projections in MAF (Source: IRSA, GOPu & PWDD 2012)

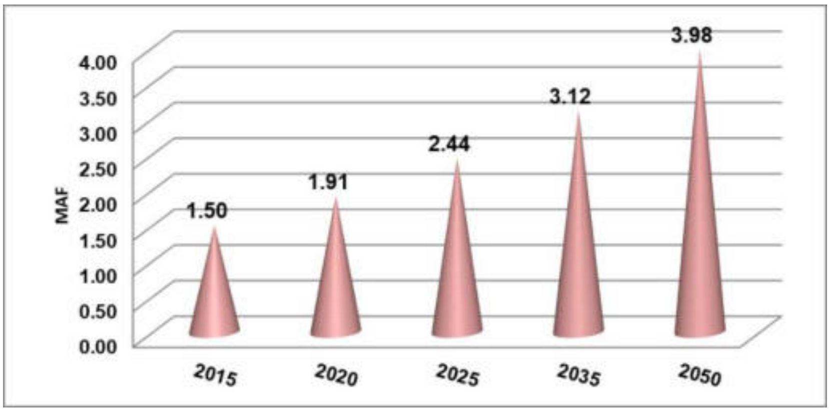


Figure 2-7: Punjab's current industrial water use and projections (Data Source: IRSA, PID, GOPu and PWD 2012[7])

2.21. ENVIRONMENTAL CONDITIONS

According to recent estimates of the Punjab Irrigation Department (PID), around 40% of the area in the province is underlain by groundwater of marginal to brackish in quality, which is unsuitable for irrigation without conjunctive use of surface and groundwater along with amendments to manage sodic water.

There are 135 surface drainage systems including over 670 drains, with an aggregate length of about 6,600 km, which drain an area of about 5.79 million ha. Surface and sub-surface drainage systems are ineffective, resulting in much of the

7 PWD. 2012. Situation of population in Punjab. Population Welfare Department, Government of Punjab

drainage effluent being either retained in the basin or disposed into rivers and canals causing degradation of water quality and often impacts on downstream water users.

Due to an ineffective drainage system, 25,769 ha of canal command area has been affected by waterlogging and shallow watertables representing 0.2% of the total canal command area (June 2020 Watertable monitoring data). Around 32% of the canal command area is affected by salinity and sodicity, representing 2.7 million ha. In general, the head reaches of some canal commands are facing waterlogging and tail reaches are facing soil salinity/sodicity – a clear indication of the poor performance and lower delivery performance ratio of the canal irrigation system.

The likely shortage of canal water every one-in-two-years puts a heavy load on the groundwater as the abstractions are increased in the dry years, and the net recharge to groundwater is decreased considerably. The recharge is increased every one-in-two year when the rivers are in high flows and canal diversions are also increased.

The absence and non-implementation of legislative measures and standards has been the root cause of the deterioration in observed water-quality. The issue is becoming very serious, as many aquifers and open waterbodies, like lakes, rivers and streams are being increasingly contaminated by pollution from industrial, agricultural and municipal wastes. According to estimates, pollution in River Ravi, due to sewage disposal from the city of Lahore, kills over 5,000 tons of fish every year.

On the spatial basis, the overall water quality of rivers was found to be good. The contamination sources for the upstream of the Chenab River includes wastewater from Sialkot city, which comprises tanneries, surgical, textile, metallurgical and pharmaceutical industries (Ullah et al. 2009). Approximately 52 ML of wastewater is generated from Sialkot city each day, with ultimate disposal in Chenab River through various drains and streams (Qadir et al.).

In the midstream region, the Gujranwala city has textile, dying, ceramic, electronics, metal utensils, kitchenware, and steel industry and Faisalabad city has substantial textile, fertilizer, sugar, and paper. Textile wastewater is usually alkaline and contains a substantial concentration of pollutants, including organic and inorganic matter, solids, oil, and grease content, while the paper industry contributes to organic matter and suspended solids. The bleaching of paper is a very environmentally degrading process as it produces complex chlorinated compounds UNIDO (2006). Whereas, in the downstream area, the Multan region contains a number of ghee, fertilizer and textile industries disposing untreated wastewater to the river's mainstream channel.

The major source of heavy metals is the weathering of rock minerals, pesticides, industrial activities, and air pollution. Lead and iron are also contributed from upstream in India. Whereas water was fit for irrigation with a few exceptions, there was a minor salinity hazard to the crops.

Water quality typically deteriorates as the river flows downstream and also from the high-flow (July-September) to the low-flow (October-June) season. In October, the COD and BOD increases even above the water quality standards for effluents and DO level dropped down to zero. At this level of DO, no aquatic life can exist. Persistent Organic Pollutants (POPs) were found to be highest near the Indian border during high-flow conditions. The concentration of most of the organic pollutants decreased as the river flows downstream. Not a single drain complied with the permissible NEQS limits. Most of the shallow groundwater sources near the drains were found to be contaminated with physio-chemical, microbiological pollutants, heavy metals and even POPs. The main reason for contamination was the recharge from contaminated water from the rivers and drains.

The environmental, recreational and fishery etc values of rivers are dependent significantly on river flow as well as water quality and some other factors such as channel form. River flow is substantially reduced in the two eastern rivers (Ravi and Sutlej) as the upstream waters are assigned to India and this has seriously affected the condition and values of these rivers which has been exacerbated by pollution. The condition of rivers in Punjab has received little study.

3 PLAN GOALS

An overall vision is proposed for the River Basin Plan which aims to achieve a number of goals. In practice the vision is connected to a series of Key Result Areas (KRAs) that address the urgent needs identified from the reviews of thematic areas, which are presented in more detail in each of the plan chapters. The hierarchical relationship between the vision, goals, KRAs, strategies and actions is shown in **Figure 3-1**, which will be reflected in the higher level Provincial Plans and budgets and in the business plans of the different departments.

The work plan is organised into strategically related KRA's, where specific actions for implementation are identified. The KRAs are the important issues which need to be addressed urgently in order to achieve the Plan's vision and goals. They are largely self-contained areas of work focussed on the responsible agencies and which aim to minimise duplication between sectors and prospective Development Partners.

Each KRA identifies important strategies and activities for the next 5-10 years and identifies the agency responsible for each strategy and action. The Actions identified in the Plan are included in the 5 yearly and annual work plans of the relevant government agencies. The Provincial Water Resources Department would be the lead agency for coordination and implementation of the Plan, under the auspices of the Provincial Water Resources Council in cooperation with various line agencies.

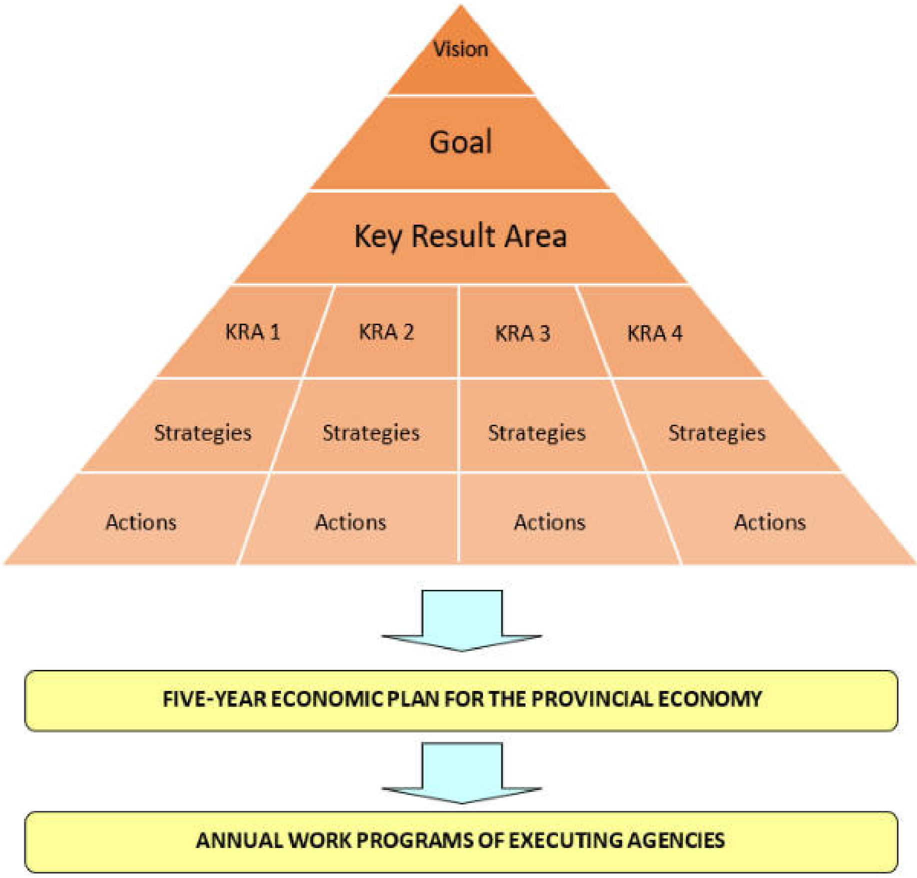


Figure 3-1: Relationship from Plan Vision to Key Result Areas

3.1 VISION FOR THE PUNJAB INDUS BASIN RIVER BASIN PLAN

The vision is for an economically prosperous, socially developed, and environmentally sustainable Punjab Indus River Basin.

3.2 GOAL FOR THE PUNJAB INDUS BASIN RIVER BASIN PLAN

The Punjab Indus River Basin Plan is to result in the sustainable use of the water and related resources for the welfare and economic benefit of the basin's people while protecting, and where possible, improving the environmental conditions of the basin and downstream communities.

3.3 PLAN IMPACT

The impact from a successfully implemented plan will include:

- Equitable access and enhanced security of water resources in Punjab for all current and future users;
- Safe drinking water and sanitation services for all residents;
- Improved water quality for surface waters and ground water;
- Improved aquatic ecosystem health including rivers, lakes, wetlands and floodplains;
- Reduced risk of flooding, drought and disease;
- Improved water use efficiency;
- Improved agricultural productivity;
- Sustainable use of water resources including balancing abstractions of groundwater to recharge;
- Improved drainage to reduce water logging.

3.4 KEY RESULT AREAS OF THE PLAN

The proposed Key Result Areas for the Plan are as follows:

KRA 1: Equitable Water Sharing and Climate Change

KRA 2: Sustainable management of Doab irrigation land and water systems

KRA 3: River Health and Uses

KRA 4: Reducing Risks and Impacts from Floods, droughts and disease

KRA 5: Sustainable management of watershed, hill torrent and desert areas.

Chapter 13, The Way Forward, briefly describes these KRA and the likely actions involved. In developing these into detailed Key Result Areas, further consultation is required with PID and other involved agencies to estimate the costs and benefits, analyse and prioritise the actions.

3.5 TYPICAL PROGRAMS OR ACTIONS REQUIRED

The following list provides an example of the projects, actions and tools required to achieve the objectives of Vision 2050:

- Monitoring and Data management: Implementation of improved flow and water quality monitoring and data management systems to provide the information needed to inform improved assessment of the existing situation, to inform improved planning and to inform improved system operation.

- Management of Ground Water Extraction: Policies need to be developed and implemented to manage groundwater extraction to ensure it does not exceed recharge.
- Drinking Water and Effluent Discharge Standards and Regulations: Standards and regulations need to be developed/refined for drinking water and effluent discharge to ensure safe drinking water and to reduce the impact of effluent discharge.
- Wastewater Treatment: Improved wastewater treatment facilities will be required for sewerage and industrial effluent.
- Solid Waste Management: Improved solid waste collection services are required which need to be supplemented by public education programs to reduce littering.
- Flood Mapping: Improved flood hazard mapping is required to assist with improved flood management.
- Flood Warning and Response: Improved flood warning and response systems are required with response system including evacuation, road closures, flood clean-up, provision of temporary housing, food and health services.
- Development Control: Policies and regulations will need to be developed to control development on floodplain to ensure that unsuitable development does not occur in flood risk areas.
- Infrastructure Upgrades: The canals and control systems will need to be upgrades to improve the efficiency of operations. This may include lining of canals to reduce losses or desilting to improve hydraulic efficiency.
- Dams to Manage Hill Torrents: Dams will be constructed in selected areas to manage Hill Torrent flows reducing flood damages and increasing water supply during non-flood periods.

4 BASIN GOVERNANCE

4.1 INTRODUCTION

The Punjab Indus River Basin has complex management arrangements that result from the usual sectoral approach to water resources management, shared responsibilities between federal and provincial agencies, the focus on irrigated agriculture rather than IWRM, and, shared responsibilities for the MOM of infrastructure.

This chapter documents and comments on governance arrangements in Punjab from the perspective of river basin planning and management. This is relevant to the River Basin Plan in order to be clear about:

- Government agencies with responsibilities relevant to the RB Plan and its implementation
- River basin and sub-basin boundaries and considerations in their definition in Punjab Indus Basin
- Water resource planning and management units and their connection to a river basin plan
- Arrangements for river basin management organisations for integration and coordination of agencies
- Water allocation and sharing (quantity and quality) in the river basin since this is the primary purpose of RB planning

The chapter refers to planning and management. Planning is a part of the conventional management cycle of Objective-Plan-Implement-Monitor-Review. The type of planning and management also differs from the national and river basin level which are focussed on strategic planning, policy and programs to the local level where there is greater emphasis on operational management activities with planning as a part of the work process.

4.2 CURRENT DEPARTMENTAL ROLES FOR WATER RELATED MANAGEMENT

Water reform is taking place in Punjab resulting from the new Water Act and the creation of the Punjab Water Resources Commission (WRC) and Water Services Regulatory Authority (WSRA). The Water Act is a narrow instrument when compared to Water Laws elsewhere and does not cover the full gamut or water resource management functions. As a result, the precise distribution of responsibilities of the PID including with, or as a transformed Water Resources Department, as well as the relationships with other Departments is evolving.

Currently and as in most countries, water related responsibilities are spread across levels of government and different Ministries and Departments particularly for water resources, agriculture, rural and urban water supply, and the environment. In common with other countries, more operational activities take place at Provincial and lower levels of government. Other CDTA reports provide more detailed description of agency responsibilities and of the options for elevating IWRM into the provincial departmental arrangement.

An overview of the agencies at the national and provincial levels with direct water resource management functions relevant to river basin management within Punjab Province are:

4.2.1 INDUS RIVER SYSTEM AUTHORITY (IRSA)

IRSA is responsible for implementing Pakistan's Water Apportionment Accord for sharing water between the provinces following the transboundary water sharing arrangements of the Indus Water Treaty. IRSA specifies and reviews river and reservoir operations and communicates these to WAPDA and provincial irrigation departments. IRSA's development of operational plans is based on rolling 10-day irrigation demand estimates provided by the provinces to determine required reservoir releases. It is also involved in monitoring reservoir operations under normal and flood conditions to be implemented by WAPDA and PID. In determining the reservoir operating plans for flood mitigation, IRSA is guided by flood forecasting by PMD, as well as their own modelling and analysis.

4.2.2 WATER AND POWER DEVELOPMENT AUTHORITY (WAPDA)

WAPDA is the main Authority to plan and implement new water and power projects. It operates some of the major headwater reservoirs and hydropower facilities for water supply, flood mitigation, and power generation as well as some barrages and canals (refer to section on management units).

4.2.3 PLANNING AND FLOOD COMMISSIONS AND NATIONAL DISASTER MANAGEMENT AUTHORITY

The Planning and Flood Commissions (PFC) and National Disaster Management Authority (NDMA) provide support to local administrations in managing major floods.

4.2.4 PUNJAB WATER RESOURCES COMMISSION AND THE WATER SERVICES REGULATORY AUTHORITY

The new, 2019, Water Act provides for the establishment of the Punjab Water Resources Commission (WRC) and the Water Services Regulatory Authority (WSRA) and the Act is to provide for the comprehensive management of all water resources and to regulate their use for conservation and sustainability purposes. The Act is focussed on and provides for water abstraction and disposal licensing of water and sewerage undertakers. It also enables the WRC to direct on the management of controlled waters (all water in Punjab)'; the issuance of drought orders; management of pollution in water protection zones; retention of vegetation in and near water bodies; and, to benefit environmental and recreational values.

values.

4.2.5 PUNJAB IRRIGATION DEPARTMENT

The PID is the main water related department although its focus is irrigation. It is responsible for planning, design and management of large water infrastructure including river works, canals (link and other), drains and flood protection embankments. PID manages transfer of the bulk water supply for irrigation (around 90% of the available water) from rivers to distributary canals. PID conducts the policy, planning, and design centrally and the field services are provided through its zonal offices and commands.

From the perspective of river basin management and planning a distinction is made between:

(i) PID Head Office Lahore: PID Head office Lahore (PID HO) which is the province wide policy, planning and monitoring function and described in detail in the ITPID institutional reports.

(ii) PID Irrigation Zones: Irrigation Zones are an administrative device for water, irrigation and drainage management. Zones are the field operational arm of the PID, responsible for managing headworks, irrigation command areas, rivers and flooding, and surface drainage.

It is of significance that for (i) one river falls under several PID zones from top to bottom and between left and right banks and (ii) one Doab is under the management of several Zones and command areas. These arrangements complicate integrated management of resources.

Other river basin management related work units in PID are:

(i) Strategic Planning and Reform Unit (SPRU) which has the objective of strategic planning, monitoring and evaluation, and facilitation in implementation of the various reform activities,

(ii) Directorate of Land Reclamation (DLR) which has objectives relating to irrigation and farm water management including soil, water and plant conditions, management of saline, sodic and waterlogged soils, groundwater use for irrigation and the monitoring of groundwater.

(iii) Flood Risk Assessment Unit (FRAU) was established for storm monitoring, flood forecasting and warning, monitoring, and to support flood planning and management

(iv) Management of Hill Torrents is under the Project Circle D.G. Khan and the administrative control of Chief Engineer D.G.Khan, Irrigation Zone of PID.

4.2.6 PUNJAB AGRICULTURE DEPARTMENT

The Punjab Agriculture Department (PAD) is responsible for agricultural and on-farm water management (from irrigation outlet to farmland). Field services and agricultural extension are provided through its field offices located in Faisalabad, Lahore, Kalashah Kaku, Chakwal, Bhakkar, Bahawalpur, Sahiwal, Sargodha, and Multan. PAD is important for river basin management as its activities will contribute to: (i) structural adjustment measures as water becomes more scarce, (ii) support adjustment of cropping patterns, (iii) promote water use efficiency and water productivity on farms, (iv) conduct programs for farm water savings and for salinity and watertable mitigation at the farm level.

4.2.7 PUNJAB ENVIRONMENT PROTECTION DEPARTMENT

The 18th constitutional amendment made provinces responsible for ecological matters (Young 2019). The Punjab Environment Protection Department (PEPD) is mainly responsible for water pollution control, water quality, and leads the Province's Climate Change initiatives. EPD has field offices in every district of the province. Its activities are primarily focussed on pollution control and waste management with little activity regarding river water quality monitoring, aquatic ecosystems, and river health. Its reports[8] refer to strengthening environmental and water quality monitoring systems and revitalizing the ecosystem system of Ravi river basin.

4.2.8 PUNJAB ENVIRONMENTAL PROTECTION AGENCY

The Punjab Environmental Protection Agency (PEPA) is under administrative control of Environment Protection Department and with respect to water it implements the provisions of Environment Protection Act (2017), prepares, and establishes the Punjab Environmental Quality Standards with the approval of the Punjab Environmental Protection Council and attends to their enforcement. Its efforts are direct towards pollution control from industry and urban areas.

4.2.9 PUNJAB DEPARTMENT OF FORESTRY, WILDLIFE AND FISHERIES

Of most relevance is the representation of the sector to ensure adequate water supply for extensive fisheries in rivers, canals, reservoirs, lakes, waterlogged areas and possibly of the conservation of wildlife and ecological condition associated with such areas. However, PDFWF activities do not seem to involve the systematic conservation of river health and river ecosystems[9]. Reference is made to civil works for the protection, conservation and sustainable development of the wetland at Taunsa barrage district Muzaffargarh.

4.2.10 PUNJAB PUBLIC HEALTH ENGINEERING DEPARTMENT AND DEPARTMENT OF LOCAL GOVERNMENT

Punjab Public Health Engineering Department (PPHED) manages the domestic and municipal water supplies and sanitation for major cities through Water and Sanitation Agencies (WASAs) and Development Authorities for large cities. For smaller, habitations not covered by these arrangements, the Department of Local Government (PDLG) develops rural

[8] https://epd.punjab.gov.pk/system/files/On%20Going%20and%20New%20Scheme%20.pdf

[9] https://fwf.punjab.gov.pk/wildlife

water supply and sanitation arrangements. PPHED efforts are important to determining and managing urban water demands, efforts to reduce water losses from pipe networks and to ensure drinking water quality in supply pipes and managing supply during drought periods.

4.2.11 PUNJAB DEPARTMENT OF INDUSTRY

Industrial water use is managed either privately or by the Punjab Department of Industry.

4.2.12 KHAL PANCHAYATS

Khal Panchayats (KP) are farmer-based, tertiary canal level, water user associations established by a new Act in 2019. Responsibilities include development and implementation of the warabandi plan, compliance with the plan, dispute mediation, and assistance with water fee collections. The KP is to work closely with the local PID Sub Divisional Canal Officer. Under the Act, every farmer entitled to receive water for irrigation is a member of the KP. The Act also established a KP Authority that is chaired by the Minister for Irrigation and includes farmer representatives and Irrigation, Agriculture and Finance Department Secretaries.

The initiative was established to ensure implementation of warabandi system, thereby minimizing water disputes and distribution of irrigation water supplies to all water users. The KP also provide an avenue for consultation with farmer water users in relation to river basin management.

4.3 INSTITUTIONAL ASSESSMENT FRAMEWORK

Water resources management activities are commonly assigned between responsibilities for:

(i) regulator/standard setter

(ii) resource management

(iii) service provision.

The merit and need for separate roles are widely accepted, however there are different views as to which functions belong to the regulator and the resource manager. For example, the issuing of water abstraction licenses and pollution permits is seen by some as a function of the regulator, others, however, see all aspects of water quantity and quality management as an integrated function and prefer the water resource manager to be responsible for quantity and quality measuring and monitoring, allocation of water shares, managing a water licensing and pollution permitting system and generally managing to the standards set by the regulator. Some have the resource manager developing and proposing the arrangements to the regulator who reviews and in due course approves the rules and then audits their implementation following implementation arranged via the resource manager.

4.3.1 THE REGULATOR/STANDARD SETTER

- develops/approves water quantity, quality and other natural resource objectives, standards, guidelines, and rules including bulk and retail water entitlements;
- develops and implements a financial/economic or pricing regulatory regime;
- establishes contracts with agencies (e.g. the resource management or operator/service providers) for implementation of the above requirements;
- audits the performance of the water sector as to compliance with standards.

4.3.2 THE RESOURCE MANAGER

- develops policies, strategies and organisational arrangements to comply with objectives and standards set by the government and regulator;

- undertakes strategic water (surface and groundwater) assessments;
- develops legislation to support regulatory standards and policies;
- plans and allocates water through water sharing plans including for the environment, and develops and maintains provincial level water accounts;
- plans, supervises and monitors implementation of strategies to protect:
  - water quantity and quality for surface water and groundwater,
  - flood management and dam safety,
  - water source areas,
  - river health and aquatic ecosystems.
- establishes contracts/operating agreements with operators/service providers specifying the services to be provided, financing, performance indicators, and then monitors compliance;
- builds technical capacity, information and knowledge, and a strategic water research program for strong policy, planning and management;
- supports interagency coordination and participation;
- promotes public participation and water awareness.

4.3.3 THE OPERATOR/SERVICE PROVIDER

Provides services according to the operating agreements established with the resource manager and regulator:

- implements agreed water allocation and other plans and strategies, and ensures compliance, monitoring and water accounts as specified in operating agreements;
- builds, manages and operates river headworks and water supply, sewerage, drainage, irrigation, hydropower systems according to operating agreements;
- maintains infrastructure of above;
- plans and undertakes measures to protect the water source;
- undertakes measures to protect rivers, water dependant ecosystems and for related needs such as fisheries, recreation, cultural and heritage requirements;
- provides technical advice and assistance to others;
- charges others for services provided.

Often the operator/service provider is further subdivided into:

(i) a *river or headworks (bulk water) operator* which is responsible for water supply to the individual 'retail water' operators. This includes the above functions for headworks such as reservoir and barrage operation, flood management, river management, water source protection, etc.

(ii) a *water supply* (*retail water) operator* which supplies water and drainage services to the end users such as in urban areas, habitations, and irrigation command areas.

(iii) The arrangements for some functions will vary according to local arrangements and preferences and some service provision might be implemented by other departmental agencies, for example:

a. river water quality, ecosystems, river health, and environmental flows might be managed by the environmental department. However, it is common for these to be managed through the water resource manager as their management is considered best integrated with related functions such as water allocation, flow regulation, river flow monitoring, flood and floodplain planning.

b. water source protection is often land management related and could be managed by the land protection or agriculture department. However, as it is a critical issue for maintaining the current and future water resource, often it will be managed through the water resources manager for regulated water protection areas.

4.3.4 OVERVIEW OF AGENCY RESPONSIBILITIES

A preliminary summary of the current Departmental water resource management responsibilities is shown in **Table 4-1**[10]. Closer investigation indicates that the responsibilities of the Regulator and Resource manager for most water themes are only partly addressed, whilst in some cases there are overlapping responsibilities. The WRC and WSRA are not included here as the arrangement is yet to be implemented, the extent of the regulatory function and the exact sharing of responsibilities with other departments is unclear.

Table 4-1: Matrix of Current Institutional Responsibilities

WATER THEME	IRSA	WAPDA	PID	PFC	PDLG	PEPD/EPA	PAD	PPHED/PDLG	PFWF	PDI	KHAL PANCHAYAT	SIGNIFICANT WEAKNESS
SURFACE WATER												
QUANTITY	R	O	M, O								O	R
QUALITY			O			M, O						R, M
GROUNDWATER (2)												
QUANTITY			O									R, M (2)
QUALITY												R, M (2)

[10] This is an initial assessment only. A more detailed analysis requires interviews, survey, and review of reports for a detailed and more accurate assessment.

WATER THEME	IRSA	WAPDA	PID	PFC	PDLG	PEPD/EPA	PAD	PPHED/PDLG	PFWF	PDI	KHAL PANCHAYAT	SIGNIFICANT WEAKNESS
RIVER												
FLOOD CONTROL			M, O	M	O							R
CONDITION (RIVER HEALTH)			R, M, O			R			R			R, M, O
USE (RECREATION, HERITAGE, CULTURAL)		O	O									R, M
WATER SOURCE PROTECTION			O			O						R, M, O
SECTORAL												
IRRIGATION AND DRAINAGE			R, M, O								O	
FARM WATER PRODUCTIVITY							M					
URBAN WSS (4)					O			M, O				
INDUSTRY WATER USE										M		
FISHERIES									M			

IRSA= Indus River System Authority; WAPDA= Water and Power Development Authority; PID= Punjab Irrigation Department; PEPD/EPA= Punjab Environment Protection Department / Environmental Protection Agency; PAD= Punjab Agriculture Department;

PPHED = Punjab Public Health Engineering Department; PDLG = Department of Local Government; PDI = Punjab Department of Industry; PDFWF= Punjab Department of Forestry, Wildlife and Fisheries; PFC= Planning and Flood Commissions.

(1) R= regulator; M = resource manager; O= operator/service provider

(2) The roles of R, M, and O are significantly diminished under the current legislative arrangement where groundwater is under the ownership of the holder

(3) River use caters for recreational, heritage, and cultural uses of rivers

(4) Urban WSS has more levels of government involved. However, this not included here as the report focus is IWRM rather than sectoral management

4.4 THE PUNJAB INDUS RIVER BASIN PLANNING UNITS

4.4.1 CONSIDERATIONS IN DECIDING PLANNING UNITS

As described in the introduction, the primary purpose of a River Basin Management and Plan is to enable society's social, economic, and environmental goals through:

- equitable sharing of the river basin's connected water resources (quantity and quality) between the different and competing water using sectors including the environment.
- water resource protection (quantity and quality) to ensure access to sustainable and acceptable water resources for present and future generations
- bulk water supply to all water users in a fair and equitable manner.

In its purest form, a river basin is defined by its hydrological boundaries, namely, *"a river basin is a portion of the surface of the earth where all water falling on and running off its surface collects in a network of channels and exits the watershed at a single point"*[11]. Ideally this is the determinant of the planning and management boundary, very often however this is not possible. There are no complete river basins of significance in Punjab and a range of factors are relevant to deciding the boundaries of the river basin and the approach to planning and including:

Goal and purpose: The purpose of the RB plan is mostly related to equitable water sharing with the priority issue related to sharing of quantity, flow, flooding, water quality or a combination of those. In some countries, the RB plan will try and address all issues when the plan is developed- an integrated plan. In other countries, the RB Plan will address the critical issue such as water scarcity, river water quality, ecological condition, or flooding etc. In due course, as more issues are addressed, an integrated plan will eventuate. While the first is comprehensive, it is much more difficult and expensive to develop and implement and will take longer and may not adequately address the critical problem fully.

Scale: Scale is an important consideration in deciding the form of planning as IWRM is applied at different administrative and basin scales: national, river basin/sub-basin, and local, preferably in a hierarchical order. A national and provincial IWRM plan determines the overall objectives and the main strategic directions for the development and management of water resources in the country/province. A national/provincial plan addresses the boundary conditions for the development of IWRM plans at a basin level, which, in turn, determines the boundary conditions for local IWRM plans (e.g. irrigation commands, cities, etc)

River basins-sub-basins- catchments- watersheds can be considered as nested basins with increasingly more detailed planning and management possible. The larger the river basin, the more difficult it becomes to collect all information and for analysis. Usually for a large river basin (e.g. 500,000+ km^2) such as the Indus, the plan would be strategic and focused on large infrastructure and natural resource assets, with lower levels being more operational. At the lowest level (e.g.

[11] 2 Spatial and Temporal Scales for Watersheds." National Research Council. 1999. *New Strategies for America's Watersheds*. Washington, DC: The National Academies Press. doi: 10.17226/6020

catchment/watershed (500 km^2), plans will be much more detailed and operational, focussing on hotspot issues. This scale connects with local government and other local area plans.

Jurisdictional boundaries and responsibilities: River basin boundaries seldom coincide with sovereign and administrative boundaries. In such cases, the boundaries might need to be modified from the hydrological boundary and where the basin involves different countries this can be especially challenging. These issues are easier to manager when the basin is located in separate provinces or states within a federation, as the nation state is able to guide the province using a range of mechanisms. In such cases, river basin planning at the different levels (transboundary, national, provincial) is connected via a system of nested basins where flows between levels are treated as boundary conditions (e.g. the required or historic flow and/or water quality condition).

Surface water and Groundwater Basins: Often boundaries of groundwater and (surface) river basins do not coincide. Mostly the two resources can be planned and managed separately as at a river basin scale, as the main interaction and exchange between surface and groundwater is through river losses and gains. At the local scale (catchment/watershed, command area, local area plans) there is a more extensive interaction between surface and groundwater and land and vegetation condition and planning should take an integrative approach.

River basin or natural resources management planning: River basin or hydrological boundaries are not the most relevant for all types of natural resources planning. For example, terrestrial ecosystem and vegetation management will follow ecological zones. In some instances there is a need to include or integrate other natural resource planning with RB Plans e.g. for water source protection, land use overlays are used. River basin and watershed plans will also need to be integrated into local government spatial planning, such as for land use planning to protect groundwater resources and to regulate land use in flood prone areas.

4.4.2 PLANNING AND MANAGEMENT UNITS FOR RIVER BASIN PLANNING AND MANAGEMENT

There are a number of water management units within the Punjab Indus Basin that are potential units for ‘river basin’ or more appropriately, water resources planning or are an important geographical unit.

4.4.2.1 The Indus River Within Punjab Province

The Indus River is an international transboundary river with water sourced from upstream countries, whilst other downstream provinces have a share of this water. For Punjab province the boundaries are a mix of hydrological and administrative boundaries. Within Punjab, the Indus River is a complex and interconnected water distribution system with rivers, barrages, and link canals enabling extensive water transfer across the province. (**Figure 4-1**).

The Panjnad river (river reach from junction of the Chenab and Sutlej rivers to the Indus River) is the major tributary of the Indus River in Punjab and is on its left bank. It captures the runoff and flow from the Jhelum, Chenab, Ravi, and Sutlej-Beas rivers and their catchments. Under the Indus Water Treaty in 1961, water in the Eastern Rivers (Ravi, Sutlej) is allocated to India and in the Western Rivers (Indus, Jhelum, and Chenab) to Pakistan. The sub-basin is also referred to as the ‘5 rivers sub-basin’.

The Soan river is another tributary on the left bank of the Indus which discharges runoff from the Pothohar Plateau.

There are a number of tributaries on the right bank, but mostly these are in an upstream country with only a small area in Punjab (e.g. the Kabul river) or are small. The hill torrent areas and DG Khan command area is also within this overall area.

These areas are the initial foundation defining the river basin boundary. They are connected to varying degrees by the Indus River and, for the 5 rivers area by the link canals.

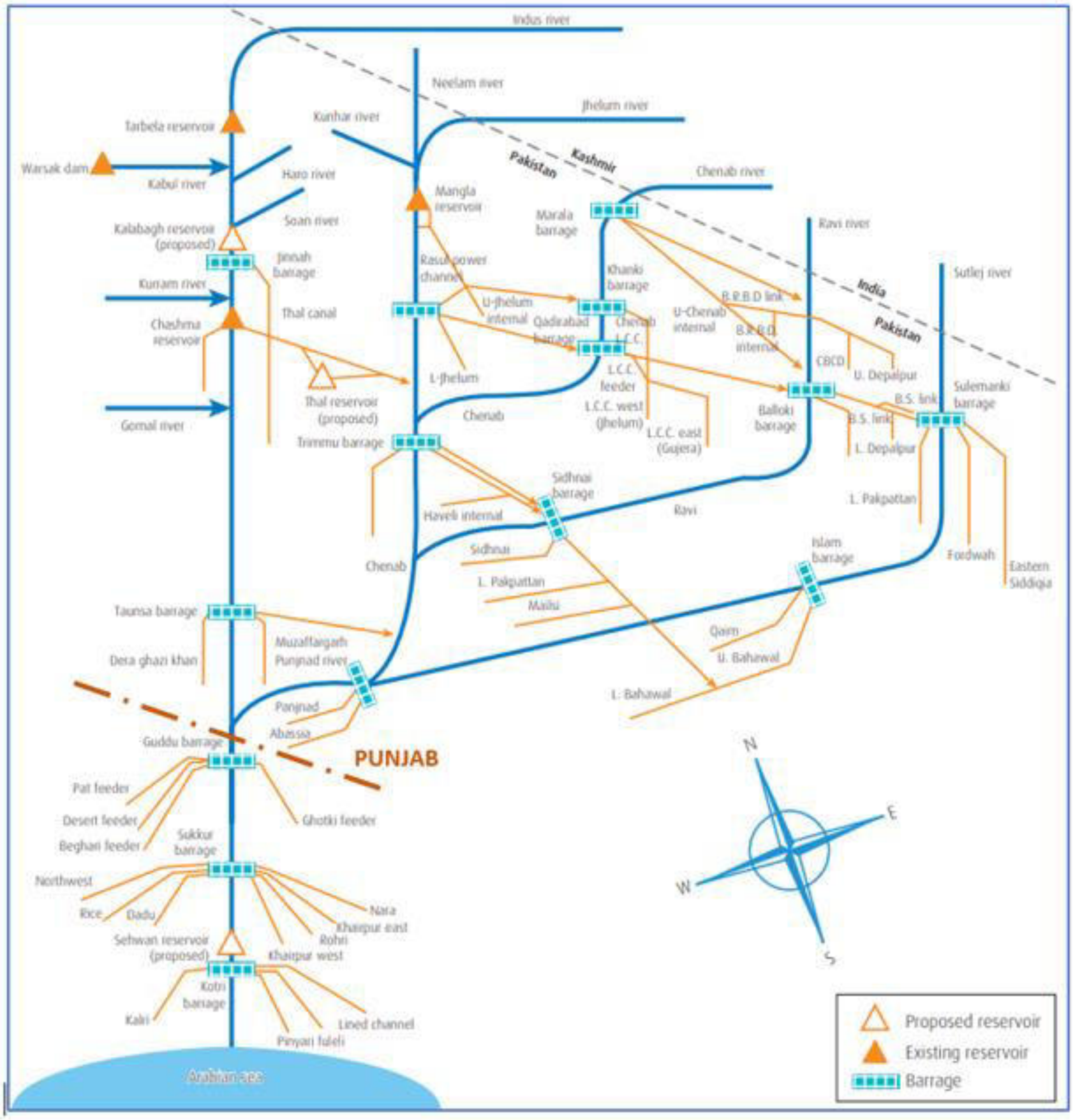


Figure 4-1: Schematic representation of rivers, link and main canals in Indus Basin (Source: Young et al, 2019)

4.4.2.2 Link Canals and main canals of the 5 Rivers sub-basin

There is a high degree of interconnection between the Indus River and the Panjnad (5 rivers) sub-basin with link canals connecting rivers, command areas, and cities (**Figure 4-1**). This connection enables considerable scope for water transfer between rivers and scope to better manage water sharing between cities and irrigation systems in times of excess and shortage.

4.4.2.3 Doab Floodplains

The flat floodplains between the rivers in the 5 rivers Sub-Basin are referred to as 'Doabs' (**Figure 4-2**). Because of the flat landscape, hydrological boundaries between rivers are mostly indiscernible with little effect on surface water hydrology. These Doabs are predominately irrigated command areas with water supplied by the associated river and link canals. The

Doabs are used as groundwater sub-basins for groundwater planning as, although the whole Indus plain is an unconsolidated sedimentary basin, the rivers provide static boundary conditions.

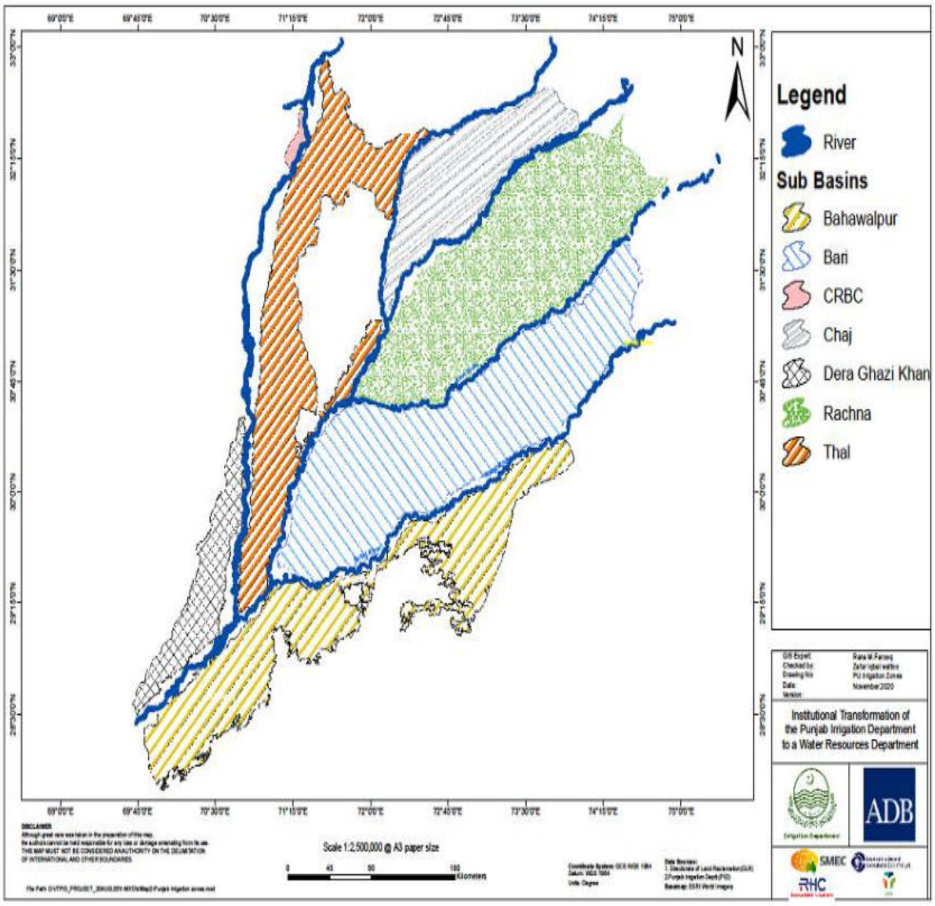


Figure 4-2: Doabs in 5 Rivers sub-basin

There is no hydrological runoff feature that separates one Doab or river from another, and it is of significance that:

i. Each Doab is associated with two rivers (flooding, water supply and drainage), and each river is connected to two Doabs.

ii. Doabs and rivers are highly interconnected by link and main canals. This provides an opportunity for water sharing and water quality management across the 5 rivers area. A river basin plan should include this critical attribute.

iii. The Doab planning approach does not include all essential management units for river basin management and integration of land, water and environmental attributes. Specifically, rivers are not included and so issues such as river, wetland and floodplain ecology; recreation and cultural needs; river fisheries; river water quality (and the role of dilution flows); flooding; riverbank and bed protection; are not included. As a result:

   a. Current Doab water balances are deficient as they do not include river inflows and outflows but only canal inflows (river offtakes) and hence there is a missing water balance element. River groundwater losses and gains, and drainage returns, are not specifically considered.

   b. The Doab approach is unlikely to identify important river focussed management needs such as the national priority Ravi River ecological preservation project. Important considerations for this project include supplying surface water from wider sources (e.g. through link canals, new infrastructure as well as groundwater).

iv. Doabs are in essence a land management unit where the current planning is for sectoral command area and urban water management (irrigation, urban, GW, salinity and water table).

4.4.2.4 Punjab Irrigation Zones

Irrigation zones (Figure 4-3) are administrative arrangements for link canal, irrigation, flood, drainage and some river (e.g. barrage operation, riverbank protection) management.

Irrigation zones appear to have been established according to command areas (Figure 4-4) and as a result one Doab, river, or link canals is managed by several zones. From a planning, administration and management perspective there are likely to be advantages if zones aligned with river basin features such as rivers and link canals so that each could be managed holistically.

Usually, having water management functions on one supply feature (e.g. river barrages, link canals, flood control structures) managed by several separate organizations requires greater coordination and communication which can result in delays and reduced performance.

Figure 4-3: Punjab Irrigation Zones

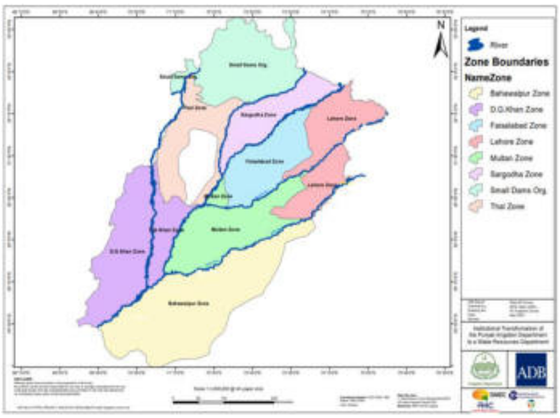
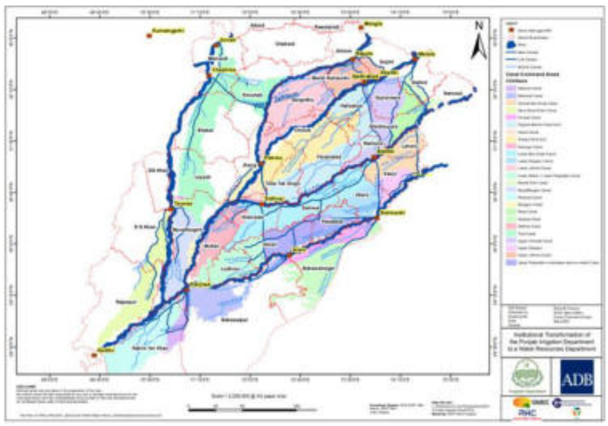


Figure 4-4: Command Areas in Punjab Province



4.4.2.5 Irrigation Command Areas

Irrigation command areas (**Figure 4-4**) are an irrigation sector management matter. A provincial level water management plan, or river basin plan, would deal with bulk water entitlements and allocations to a command area and urban water user level; or it could deal with water sharing to a lower level, especially where there are significant groundwater resources that could affect the water sharing plan. Decisions such as this should made on a case to case basis as water sharing models are being set up.

4.4.2.6 Drainage Networks

There are extensive surface drainage networks in the command areas with the main drains shown in **Figure 4-5**.

While water is mostly supplied from the north side river, the drain network usually (though not always) discharges to the south side river.

Again, the planning and management of the drain system is a sectoral matter, whether to deal with drainage from irrigation land, river flooding, or to take outfalls and over topping from canals.

Drainage discharge to rivers is an important element of the water balance and it is important from a water quality perspective. Currently information on these is lacking.

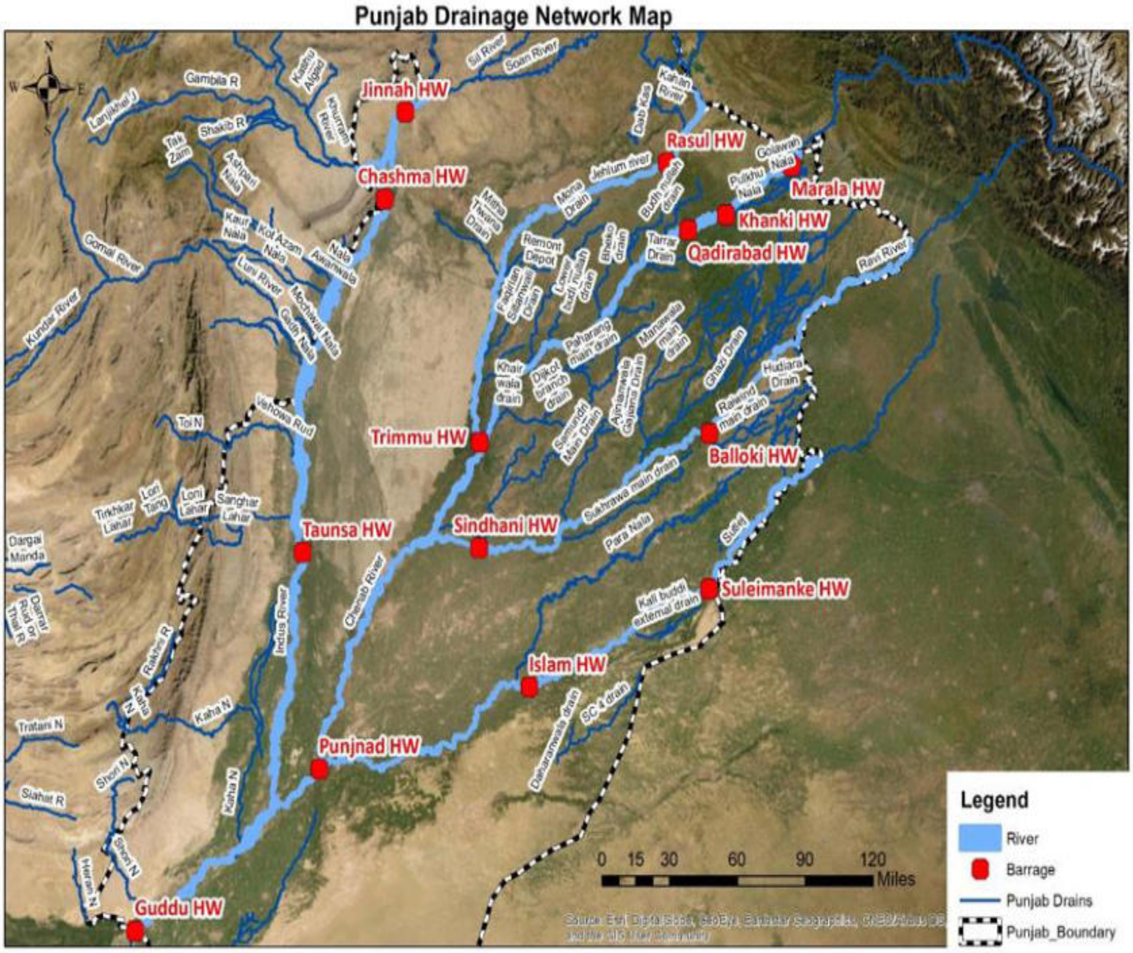


Figure 4-5: Main Irrigation Drainage

4.4.3 RECOMMENDATION

4.4.3.1 A Hierarchical System of Planning and Planning Units

A hierarchical system of plans will be required for strong water resources management, and these should comprise:

i. **Provincial Policies and Strategic Plans** that provide the overarching umbrella, guidance, and priorities under which river basin plans are developed.

ii. **River basin plans**, principally for sharing and managing the surface water resource but they will also identify other priority localised needs within the river basin. It will have details of actions and broad budgets, as well as strategic elements. When well developed, the plans will have more specific actions and targets, such as bulk water entitlements for the major water users in the basin and for water quality.

iii. **Localized planning and management** should be undertaken consistent with the rules and policies established by the river basin plan and interactively for the following planning and management units.

a. Land management units: Doabs (sometimes referred to as irrigation sub-basins), watersheds, hill torrent areas, Cholistan Desert. Integrated Land and Water Management Plans would be developed for these areas on a priority basis. The plans would address interconnected issues such as surface and groundwater management, land use and revegetation, refining water allocations, drainage, water quality, scope and impacts of improving water use efficiency and productivity, etc.

b. River management units: Individual rivers are managed for river health, environmental and water dependant purposes such as recreation, fisheries, etc. The Ravi Ecosystem Plan is a good example.

c. Sectoral infrastructure management units: Provision of water services for irrigation systems, urban WSS, hydropower, flood control.

d. Hotspot 'units': Management is directed to priority 'hotspot' areas of the above suffering significant resource degradation or in need of urgent conservation or modernisation.

4.4.3.2 The Appropriate River Basin Management Unit

Remembering that the primary purpose of river basin management is the equitable sharing of the basin's water resources, the two main options for river basin planning units are discussed below.

Option 1: One river basin (preferred): The Punjab Indus River Basin which includes the right and left (5 rivers area) banks of the Indus River in Punjab. The main output of the plan would be optimised water sharing to meet the governments goals and water demands in Punjab.

Advantages

(i) The Indus water distribution system is highly interconnected by the Indus River as well as the link canal system. Planning at this scale would explicitly consider moving water throughout the network from water surplus areas (e.g. KG Khan) to water deficient areas (parts of the 5 rivers area) and from irrigation to urban areas for example.

(ii) The scale would result in a Province wide strategic plan, rather than being caught up in a lot of detail and missing the big picture and opportunities for water sharing and resource augmentation. It would identify hotspot locations (e.g. rivers, Doabs, new or in need of rehabilitation infrastructure) for critical attention

(iii) This basin corresponds to the whole Punjab water system, so that the planning would support development of a Punjab Water Plan and related policies in due course.

(iv) There is an existing river basin model (Indus River system Model)[12] developed for the area that could be used immediately. It includes the rivers, link and main canals in Punjab and could be easily extended to lower-level canals and have a link to groundwater conditions.

Disadvantages

(i) The large scale of the plan might result in general recommendations only

(ii) The large size increases the number of stakeholders that should be involved

(iii) Developing the plan would probably take longer than one plan (e.g. for the 5 rivers area)

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[12] https://publications.csiro.au/rpr/download?pid=csiro:EP186945&dsid=DS7

Option 2: Two river Sub-Basin distribution areas: 5-Rivers Area; and the Indus Right Bank (KG Khan and CRBC).

This option could be for all areas or just the area(s) requiring better management.

The Pothohar sub-basin is considered a local watershed for local management with limited impact on overall water availability in the Indus system.

The Cholistan Desert is not considered as an important area here due to the low rainfall, saline groundwater, low potential and few downstream impacts.

Advantages

(i) The scale could result in focussed action-based plans.

(ii) Developing one plan (e.g. the 5 rivers area or left bank areas) could provide a faster result

(iii) Stakeholder participation would be easier to manage

Disadvantages

(i) Proper optimisation of the province's water use needs to involve both left and right banks due to the opportunities for re-allocating and augmenting overall water supplies.

(ii) Planning in this way would miss the interconnections between sub-basins and the opportunity to prioritise projects across the province.

(iii) The planning would not directly support development of a Punjab Water Plan.

(iv) The existing river basin model would need to be operated as separate models, although this is not a significant issue.

Option 1 is the preferred approach as it would prepare a water sharing and sustainability plan for the whole Punjab system and it captures all available water resources and interconnections between water use areas in Punjab. It reduces the number of levels of planning and connects to and enables strengthening of the important Punjab Water Policy leading to provincial strategies and plans.

4.4.4 RIVER BASIN ORGANISATIONS IN PUNJAB?

River Basin Organisations (RBO) are sometimes established to plan and manage the water resources of a particular river basin or sub-basin, and catchment/watershed.

There are many different models of River Basin Organisations (RBO) ranging from very formal and powerful River Basin Authorities through to River Basin Commissions and to River Basin Coordinating Committee/Council. The RBO typically include government agencies with management responsibilities in the Basin, independent technical experts and representatives of civil society. The RBO has an executive office for coordination, technical and administrative support. The purpose, functions and performance of RBO vary considerably, reflecting national governance and cultural paradigms, existing organisations and institutional arrangements, and the RBO's legal mandate and level of resourcing. The usefulness of RBOs is also highly variable. A guiding principle should be that, like any organisation, an RBO should serve an important, agreed, and unique purpose; usually it is conflict management, sharing of the water resource, and integrated and sustainable water resources management.

The functions of an RBO include:

- coordination and conflict resolution especially between sovereign governments;
- establishing a dialogue and means for integrated planning and management between members;
- integrated water and natural resource sharing policies, plans and rules for management of shares (this includes pollution sharing);
- ensuring the ecological sustainability of water dependant ecosystems;

- coordinated planning, development and operation of major projects to ensure better outcomes;
- improving data, information and models to build the trust, confidence and policies of participants;
- raising the level of awareness and participation of the basin community in water planning and management decisions.

Whether it is appropriate to establish a RBO should be considered carefully, based on the need and cost (**Table 4-2)**.

(i) A strong and well-resourced RBO especially for international, transboundary river basins such as the Indus Basin is important. The RBO would report to a Council of Ministers from member countries (e.g. the Mekong River Commission);

(ii) There is also likely to be a strong need for an RBO in a national river basin where states/provinces have sovereign responsibility for managing the water resources and water dependant systems of the basin, such as for the Indus Basin in Pakistan. The RBO would report to a Council of Ministers from national and provincial governments.

(iii) For a Basin that is within the border of one sovereign government, the need for an independent RBO is less clear, as existing agencies already have responsibility for managing the basin's resources and the government cabinet is an established mechanism for resolving any conflict. If there is such an RBO it could report to the Minister of Water Resources or Chief Minister. This arrangement causes conflict and complicates the mandate of the Department of Water Resources which resists the intrusion of the RBO into its management sphere.

It is important to recognise that there are significant costs in undertaking coordination and in establishing an RBO and therefore it is important that there is justification for its establishment.

Important questions that should be asked in deciding whether an RBO is needed and an interpretation of the situation in Punjab as shown in Table **4-2**.

Table 4-2: Questions to consider in deciding whether to proceed with a RBO in Punjab

KEY QUESTION	SITUATION IN PUNJAB
IS THERE A SPECIAL NEED THAT CANNOT BE ADDRESSED BY EXISTING INSTITUTIONS?	No. Important issues can be addressed by government, WRC, and existing agencies adopting improved policies and approaches.
IS THERE IS CONFLICT BETWEEN DEPARTMENTS AND WATER USERS IN THE BASIN?	There is little conflict between Departments
	There are conflicting demands for water between water sectors and within command areas. The WRC mandate addresses conflict for water sharing between sectors. PID has a mandate to address conflict in command areas Communications with non-government stakeholders could reduce conflict
WOULD JOINT PLANNING, DATA SHARING, AND PARTICIPATION OF STAKEHOLDERS GIVE BETTER MANAGEMENT?	Yes. This could be achieved through the WRC/WSRA supported by WRD with a stakeholder participation mechanism
THERE IS NO OTHER EXISTING ARRANGEMENT THAT COULD	WRC supported by WRD could address and serve the purpose at least initially

KEY QUESTION	SITUATION IN PUNJAB
RESOLVE AND SERVE THE PURPOSE OF A RIVER BASIN ORGANISATION?	
IF THERE IS A NEED, WHAT IS THE SIMPLEST APPROACH TO ADDRESSING THE PROBLEM?	Establishing the WRC/WSRA supported by the WRD is the most immediate and appropriate solution

In conclusion, at this stage of evolution of water resources management in Punjab, *the WRC/WSRA supported by the WRD is sufficient to provide for provincial water resources management including at a river basin level*. However, there appears to be *a need for a stakeholder participation and communication* approach.

4.5 WATER ENTITLEMENTS, ALLOCATION AND SHARING[13]

4.5.1 WATER APPORTIONMENT ACCORD (WAA)

Water in the Indus Basin is allocated according to Pakistan's Water Apportionment Accord (WAA) with provincial shares (entitlements) of the baseline volume of 144.749 BCM/y allocated to Punjab (48%), Sindh (42%), Khyber Pakhtunkhwa (7%), and Baluchistan (3%) and which is further indicated on a seasonal basis. The baseline volume has been available in 90% of years (Anwar and Bhatti, 2018). The WAA includes guidance for the sharing of water in dry years, although provinces have different interpretations of this and it remains contentious. In the 10% of wet years Punjab and Sindh each receive 37%, KP 14%; and Baluchistan 12%. This is far less contentious as in excess years, KP and Punjab in particular, usually receive higher than average rainfall, and thus demand for additional irrigation supply in these provinces can be low and 34.5-37 BCM of unused water flows unused beyond Kotri barrage.

The Indus River System Authority (IRSA) which is under Pakistan's Ministry of Water Resources, is responsible for making rabi and kharif seasonal water allocations to the provinces from the Indus and Jhelum – Chenab rivers based on data from the rim hydrological gauging stations. There is no allocation made from the Ravi and Sutlej rivers as India has the full entitlement of the runoff from these rivers. The WAA also assigns shares and accounts for water inflows during the flood season. This water is utilized for irrigation, partially in Punjab, but most discharges through the Indus River. The IRSA has an established process for estimating flows and availability; however, the process and estimates are not publicly available.

The WAA makes no reference to water quality. While it recognises environmental flows downstream of Kotri barrage environmental flows are not provided elsewhere in the Basin's rivers. There has been no agreement of the required environmental flow below Kotri barrage however, historical flows below the barrage from 1976-77 to 2014-15 have been consistently above a figure identified by an international panel of experts. The adequacy of this figure is contentious however and it has been disputed in subsequent reviews.

[13] This section is substantially based on Anwar and Bhatti (2018), Hashmi and Prathapar (2021), Young et all (2019); Punjab Water Policy (2018)

Anwar and Bhatti (2018) compared allocated and actual water supply data to Punjab according to the WAA and IRSA based operating rules and found that the allocated amount in both instances was substantially greater than the actual annual supply for the period of 1993-2015. They speculated that this could be a result of canal capacity constraints, which they concluded that this was unlikely as a similar supply deficit occurred in years of water shortage. They indicate that for up to tier 1 and 2 flows (up to 145,000 Gm^3/y) the water accounting and monitoring approach is the most likely significant cause of the mismatch. Young at al (2019) indicated that, water orders (indents) far exceed the available water and the capacity of the irrigation system, and Prathapar (pers comm), indicated that restricted canal capacity is the most likely cause. It is unclear whether the methodology for calculating the provincial shares from the rim station data is itself a factor.

Once water shares are determined IRSA informs the provinces of the 10-daily water availability with maximum, minimum and most likely flow scenarios. The WAA states that the basis for sharing shortages and surpluses would be by a pro-rata adjustment of the ten-daily seasonal allocations of the different canal systems.

An important future issue will be the water allocation for South Punjab Province and the traditional allocation of water in PID Punjab in Indus Zone Canals and JC Zone canals.

4.5.2 WATER ALLOCATION AND SHARING IN PUNJAB

Under the Irrigation and Drainage Act 1860, all river waters are allocated to agriculture so that other sectors mostly use groundwater. Each canal in Punjab has a given water allowance and a sanctioned command area. According to the Act, a farmer's share of this is his water right (entitlement) and this is based on his land holding.

Water orders (or indents) for command areas are communicated by PID to IRSA every 10 days, and this informs the release of water from headwater reservoirs and then releases from barrages into link, main, secondary and tertiary canals. PID determines these indents by compiling water requirements from the tertiary level up to the command area, based on the cropping pattern and rainfall. These are then adjusted based on water held in the reservoirs, river losses and gains, along with lag time and demand at the main canal head. Any shortage is distributed proportionately at the tertiary level.

The Water Policy notes that the warabandi formula is based on an erroneous assumption that there are no water conveyance losses in earthen channels and canals.

In practice, it is understood from discussions that there is little regulation of water diversions at barrages and through the link, main and secondary canals by adjusting outflow gates or cross regulator settings in canals. There are few cross regulators along link and main canals to stop discharge and flooding when there is a canal bank failure. The system works automatically based on water levels maintained in the khal (water course). Each outlet draws its share based on the water level and time allocated (7 to 10.5 days) which is based on discharge and land area. The Khal Panchayat has no role in water distribution and regulation and only plays its role on legal matters such as disputes among farmers.

The (actual) current steps in the water allocation process are:

1. IRSA makes the seasonal allocation to the Provincial level following the rules of the WAA. This allocation is specified as the maximum, minimum, and most likely inflow scenarios in increments of 10-day supply volumes.
2. PID allocates this water between command areas according to the established water allocation shares. Allocations to command areas are increased or decreased pro-rata with the actual supply compared to the historic and established water entitlement. For example, in a drought situation all command areas would have an equal pro rata reduction in supply.
3. Command areas assign their water allocation to tertiary (Khal Panchayat) level according to established water entitlement shares.
4. Water allocation to farmers is controlled by warabandi of an outlet, each farmer knows his time allocation, it does not change.
5. Farmers decide their cropping pattern.

6. Water supply infrastructure is operated accordingly on a weekly (7-10.5 days) rotation warabandi schedule
    a. Deliveries are measured at offtake gates/structures from link and main canals to command areas, and at offtake gates/structures within command areas to the tertiary level canals (Khal Panchayat). Measurements are not made within Khal Panchayat. Records are kept in the responsible office.
    b. Abiana (fixed water charges) are to be set by the Khal Panchayat supported by the canal officer and are based on the command area of an outlet. The KP Act is new and so the actual role of the KP in water distribution downstream of the outlet is still evolving.

4.5.3 FUTURE ROLE OF THE WATER RESOURCES COMMISSION AND WSRA IN WATER ALLOCATION

Section 4 of the Water Act states that the duty of the Punjab Water Resources Commission is to allocate water resources for domestic, agricultural, ecological, industrial or other purposes in different areas of the Punjab as needed. Although the actual approach for implementing this has not yet been decided, it is assumed that its role will be at a more strategic level of approval of the allocation between sectors and of the long-term entitlements and perhaps of the annual water allocation plans. The PID is expected to continue its operational role of preparing, recommending the plans to the WRC, and then implementing the plan.

Under the Water Act, the WSRA (Section 8) is *to "ensure that the undertakers discharge their duties and perform their functions"* and *"ensure that the activities authorized under the license of water abstraction or license of water disposal are properly carried out"*. This implies that the WSRA will monitor the performance of the PID zones and command areas in their operation of canal systems and services so delivered. At the local level, undertakers could include the Khal Panchayat and the WSRA could monitor their performance in implementing the seasonal water allocation and setting of water tariffs. However, the actual arrangements, following from the new Act are yet to be finalised.

4.5.4 THE WARABANDI SYSTEM

The warabandi system is a straightforward management approach as it does not require regular adjustment of canal flows and discharges and hence is relatively labour efficient. However, it is not efficient from the perspectives of economic or water efficiency and productivity perspectives. Higher value crops (e.g. horticulture, vegetables) usually require more regular supply according to crop demand and are less tolerant of waterlogging or salinity. Technologies such as drip irrigation which can provide a yield and water productivity benefit, require water on demand which is not possible from a warabandi system unless there is off-canal storage.

Moving to a crop demand/ irrigation ordering system would require a change in infrastructure, management skill and technology. Current technologies such as buried pipe systems automated or not, or manual or fully automated canal control are common internationally and are being increasingly adopted in developing countries. However, they incur relatively high costs and need to be planned carefully.

4.5.5 INFRASTRUCTURE OPERATION RESPONSIBILITIES

Arrangements for operating water regulation infrastructure and measurement and recording discharges in the Punjab Indus Basin are as in **Table 4-3**.

Table 4-3: Infrastructure operation responsibility in Indus Basin within Punjab Province

STRUCTURE	NATIONAL	PUNJAB
RESERVOIRS:	WAPDA Tarbela Dam	PID Mangla Dam, Khanpur, More than 50 small dams in Pothohar region

STRUCTURE	NATIONAL	PUNJAB
BARRAGE	WAPDA Chasma barrage	Director Regulation PID: Jinnah Barrage on River Indus Taunsa Barrage on River Indus Rasul Barrage on River Jhelum Marala Headworks on River Chenab Qadirabad Barrage on River Chenab New Khanki Barrage River Chenabhttps://en.wikipedia.org/wiki/Punjab_Irrigation_Department - cite_note-17 Balloki Barrage on River Ravi Barrage on River Chenab Sidhnai Barrage on River Ravi Islam Barrage on River Sutlejhttps://en.wikipedia.org/wiki/Sulemanki_Headworks Panjnad Barrage on River Indus
LINK CANALS	WAPDA: Chasma-Jhelum Link –Indus-Jhelum	Director Regulation PID: Taunsa-Punjnad Link –Indus-Chenab Rasul-Qadirabad Link –Jhelum-Chenab Marala-Ravi Link –Chenab-Ravi Bambanwala-Ravi-Bedian Link –Chenab-Ravi-Sutlej Upper Chenab-Balloki Link –Chenab-Ravi Qadirabad-Balloki Link –Chenab-Ravi Trimmu-Sidhnai Link –Chenab-Ravi Balloki-Sulaimanke Link –Ravi-Sutlej Sidhnai-Mailsi Link –Ravi-Sutlej
MAIN AND SECONDARY CANALS	WAPDA: Chasma right bank canals. Greater Thal canal offtakes from CJ link at AdhiKot	PID command areas UCC, CBDC, MR Link, Dipalpur Upper, Dipalpur Lower, LCC East, LCC West, UJC, LJC, Thal C, LBDC, Haveli C, Mailsi C, Pakpattan Upper and Lower, Fordwah, Eastern Saddiqia, Bahawal ,Abbasia, Panjnad, Muzzaffargarh, D.G Khan,Rangpur CRBC and Greater Thal Canals.
TERTIARY CANALS		Khal Panchayat in consultation with PID command area's Sub Divisional canal officer.

4.5.6 COMPLIANCE WITH THE SEASONAL ALLOCATION

The water allocation process is but one part in achieving the objective of reliable and suitable level of service for the water supply to end users. Regardless of the sophistication of the water allocation process, most irrigation systems are not able to meet this objective due to deficiencies in infrastructure; infrastructure operation; flow measurement; water accounting; and enforcement of water offtake rules.

Indicators of the effectiveness of the water allocation and sharing mechanism can be directly gauged by comparing the allocation with the water supplied to different supply levels and particularly to individual farms, however this requires reliable and accurate measurement. The most direct and immediate measure the effectiveness is whether the allocation reaches the tail end. Remote sensing is another tool for monitoring, where it is not possible to measure deliveries.

The Punjab Water Policy indicates that farmers at tail-end receive 30- 40% less water than their allocation.

4.5.7 ALTERING WATER ALLOCATION PLANS

There are usually two levels of water allocation plan. The first of these is a long-term water allocation or '<u>water entitlement</u>' such as the supply of a defined volume of water in 90% of seasons around which a water licence is defined. The second level is the seasonal '<u>water allocation</u>' which is actual allocation made according to seasonal water availability. Both of these can be specified at the bulk water supply levels (e.g. for irrigation system authorities, urban water authorities) and for individual farmers.

Currently the seasonal water allocation is adjusted depending upon seasonal water availability and might be more or less than the 90% condition. In times of more significant water shortage, supply to urban areas will be prioritised with a reduction in supply to irrigation.

Longer term more permanent changes to water rights by transferring water entitlement and allocation from irrigation to other important sectors especially urban, domestic and industrial uses for urban and industrial growth will be required. In addition, changes are needed as land ceases to be irrigated due to urbanisation or lost from productive agriculture due to land degradation etc. Several large cities have applications for surface water for drinking purposes and there are at least two large thermal power plants seeking water for cooling purposes.

The Punjab Water Policy has set priorities for future consumptive and non-consumptive uses of water as:

1 Drinking and Sanitation
2 Irrigation
3 Livestock, fisheries and wildlife
4 Hydropower
5 Industry and mining
6 Environment, river system, wetland, aquatic life
7. Forestry including social forestry
8 Recreation and sports
9 Navigation

The policy however does not describe how changes would be implemented and such a guideline should be developed. In practice, while higher priority users will have a higher order of security of supply, and, usually all sectors will suffer reduced supply at times of shortage with none of the sectors suffering a full loss of allocation. This can be a highly political issue and needs to be supported by a strong evidence and policy base, prepared well before the event.

Hashmi and Prathapar (2019) refer to a 'Command Area Modification Policy' that is awaiting final approval by the government. The Policy outlines the reallocation procedure when there is a change in canal command areas (both addition and exclusion). Key aspects of the policy include redetermination of a command area's water allowance; a readjustment of the allocation; and, adjustment when additional irrigation supplies become available. It also refers to the modification of

the physical limits of a command area under certain circumstances. This reallocation approach is also likely to be politically difficult. Some countries allow adjustments to be made via market mechanisms which are be between willing individuals however this requires accurate measurement and records of water entitlements and deliveries. Payment by government or local governments or industry to targeted command areas (e.g. to upgrade the irrigation system or to buy out willing farmers) is another mechanism for encouraging voluntary adjustment of allocations.

The most important issue will be the water allocation for South Punjab and the traditional allocation of water in PID Punjab in Indus Zone Canals and JC Zone canals. The main constraint is depleting water storage of Terbela and Chashma Reservoirs. Construction and operation of a large new reservoir would require at least 8 to 10 years and climate change could affect water availability and demand in this timeframe.

4.5.8 SOME FUTURE DIRECTIONS

(a) Punjab Water Policy

The Punjab Water Policy recommends the adoption of the following policies for water use and allocation:

- Assess the water requirements for different sectors and assign priority for allocation of water for various sub-sectors of water use in the order of domestic water, livestock, water for agriculture, water for industry and commercial uses, water for environment, forestry and recreational uses
- Gradually shift to volumetric supply of warabandi instead of fixed time warabandi system
- Reassess water allocation of different canal systems and reallocate water among different canal command areas accordingly
- Enforce measures to reduce, reuse and recycle water in domestic, commercial and industrial sub-sectors
- Harness information technology to improve monitoring and operations

(b) Key issues

This limited assessment finds significant issues relevant to the water allocation approach:

<u>Water Apportionment Accord:</u> There are clearly issues with the WAA which are well described by Anwar and Bhatti, however this is beyond the terms of reference and resources of this CDTA. The cause of the significant difference between Punjab's WAA allocation and the abstraction should be studied in depth to find ways to reduce the discrepancies.

<u>Goals to be achieved by Water Allocation:</u> The Water Policy indicates the goals of: (i) balancing productivity and conservation, and, (ii) balancing supply and demand. This needs an in-depth exploration of what these goals mean in practice.

<u>Does the current water allocation system achieve its goals?</u> The Water Policy notes low water productivity, low value crops, and tail end effects. While many factors such as farmer capacity, access to capital, land holding size affects farm productivity, the water allocation and its compliance system and level of water supply service is critical for higher productivity, higher value crops, elimination of the tail end effect, and the capacity to cope with water shortage. Efficient and productive use of water is not normally associated with the warabandi approach.

<u>Modernising the water balance approach:</u> Currently water balance assessments are rudimentary and give a wide range in estimates of water availability, use empirical estimates for some of the water balance components, and have limited scope for calibration and verification. River basin modelling of the river and canal water supply network incorporating current and future water availability; water demands including of the environment, climatic conditions and change, river and canal conditions (e.g. discharge capacities, groundwater loss/gain), and groundwater conditions, is needed to look at the future possibilities for sharing water under different conditions. Once calibrated, the models can be used to develop water entitlements, seasonal allocations, and operating rules.

River flow requirements (e.g. ecology and river health, recreation, cultural and heritage) are an outstanding issue and can be linked to environmental flow needs. These can be considered partly as a non-consumptive use as they travel through the river system, however in some cases the water might become available for abstraction downstream of the specific river flow needs. The above models will evaluate this.

4.6 OBSERVATIONS AND BEACONS FOR CHANGE

Observations on the current water resources governance arrangements in Punjab and their implications for river basin management are as follow:

Extent of IWRM and River Basin Management: The emphasis for water resource management and river basin management in Punjab stems from the WAA and the allocation and supply of water for irrigation to the tertiary level. Integrated management of groundwater, river condition and uses, and water quality is very limited, with little integration across themes and limited integration with surface water. River basin management and IWRM would look to strengthen this.

Regulators, managers and operators: Water resources management in Punjab is very operationally and irrigation focussed. There are gaps, lack of clarity and some duplication, especially for the functions of the regulator and water resource manager.

A hierarchical system of planning: A nested system of water resources planning from the Provincial level to river (sub-basin) plans for water sharing (quantity and quality), and then more localised focussed plans such as for Land and Water Management Plans for Doabs, and hot spot plans (e.g. River river) is common. It is important that a gradual approach be taken to build experience and usefulness.

River basin planning boundaries: Two options are suggested (i) the Punjab Indus Basin or (ii) the 5-Rivers Area; Indus Right Bank (KG Khan and CRBC). 'River basin' plans for the Punjab Indus River basin is preferred as it would very closely relate to a Provincial Water Resources Management Plan and provide overall Provincial priorities.

Improving the river basin water allocation system: A range of issues have been identified as needing attention including: reviewing the WAA; delivering on the goals identified for water allocation in the Water Policy; modernising water planning using river basin models; considering the water needs of rivers (environment, recreation, cultural heritage); ensuring compliance with the water allocation system.

River Basin Organisation: It is unlikely that an RBO is needed at this stage and that the WRC/ WSRA supported by the WRD is sufficient. Any consideration of an RBO would be to ensure there is a critical need and benefit that justifies the costs and will maintain interest and commitment from government leaders. It is more critical at this stage to settle the WRC/WSRA and its shared responsibilities with government departments.

The PID/WRD Organisation: The organisational arrangements for PID/WRD are the subject of another report. However, for river basin and water resource planning specific units are needed, as described below:

(i) Establishing units and procedures specifically to strengthen river basin/water resource planning and especially the use of specialised modelling tools.

(ii) Not all-important water functions appear to be included in current water resource assessments and the WRD should address these functions including: (i) river management (river health and catering for services provided by rivers), (ii) water quality management (particularly its monitoring), (iii) groundwater, (iv) water source protection, and, (v) climate change.

(iii) In the longer term, consider aligning WRD zones or other units with the bulk water supply system (rivers and link canals). This could be a province wide organisation or as separate units based on the supply/water regulation system.

5 WATER AVAILABILITY USE AND DEMANDS

5.1 WATER RESOURCE MANAGEMENT IN PUNJAB

The Government has assigned the highest priority to water resources development and management for sustainable and equitable socio-economic development.

Water resource management in Punjab to date is focussed substantially on Doab and command areas with little consideration at the overall river basin level which includes, importantly, rivers and other catchment systems. This is likely to be a legacy of:

i. The fragmented nature of water resource management between the national and provincial levels. The national level deals with the overall water resource assessment, and, water allocation at the interprovincial to the command area level as part of the WAA.
ii. The large majority of water is used for irrigation.
iii. The legislative foundation which states that surface water is for irrigation purposes whilst groundwater is the property of the landowner.
iv. PID is historically a surface water irrigation focussed department with an irrigation development culture.

A Water Resources Department will need to widen its focus to include all elements of water resources and to address the needs of all water using sectors. This requires a full assessment of Punjab's water resources, water uses and demands, to inform their integrated management.

This chapter reports on water availability, uses and future demands for surface water in Punjab. It is complemented by the ITPID water balance report.

5.2 THE INDUS BASIN

5.2.1 PHYSIOGRAPHY

The Indus Basin spans Pakistan, North-western India, Eastern Afghanistan and South-western China. The Indus Basin has a total area of 1,125,000 km^2 and the Indus River is 3,180 km long, making it one of the longest rivers in Asia. The physiography of the basin is defined by the Hindu-Kush in the north-west, Karakoram in the far north-east and the Western Himalayan Mountain ranges in the north and northeast. The Indus River feeds the Indus submarine fan, which is the second largest sediment body on the Earth, comprising approximately 5 million cubic kilometres of material eroded from these mountains.

5.2.2 THE INDUS RIVER

The Indus River is a perennial river fed by the snow melt in the Western Himalayan Mountain ranges (**Figure 5-1**). The streamflow varies greatly through the year: the discharge is at a minimum during the winter months (December to February), there is a rise of water in spring and early summer (March to June), whilst floods occur during the monsoon season (July to September). Occasionally, there are devastating flash floods, causing extensive damage to infrastructure along the river.

The Indus and its tributaries receive most of their runoff from the hilly upper catchments and their flow is at a maximum where they emerge from the foothills. Little additional surface flow is added in the plains.

The water level of the Indus River is at its lowest from mid-December to mid-February. After that, the river starts rising, slowly at first and then more rapidly at the end of March. The high-water level usually occurs between mid-July and mid-August. The river then falls rapidly until the beginning of October, when the water level subsides more gradually.

Annually, the upper Indus carries about 110,000 Mm^3, slightly less than half of the total supply of water in the Indus River system. The Jhelum and Chenab combined carry roughly quarter of the total Indus volume, whilst the Ravi, Beas, and Sutlej combined constitute the remainder.

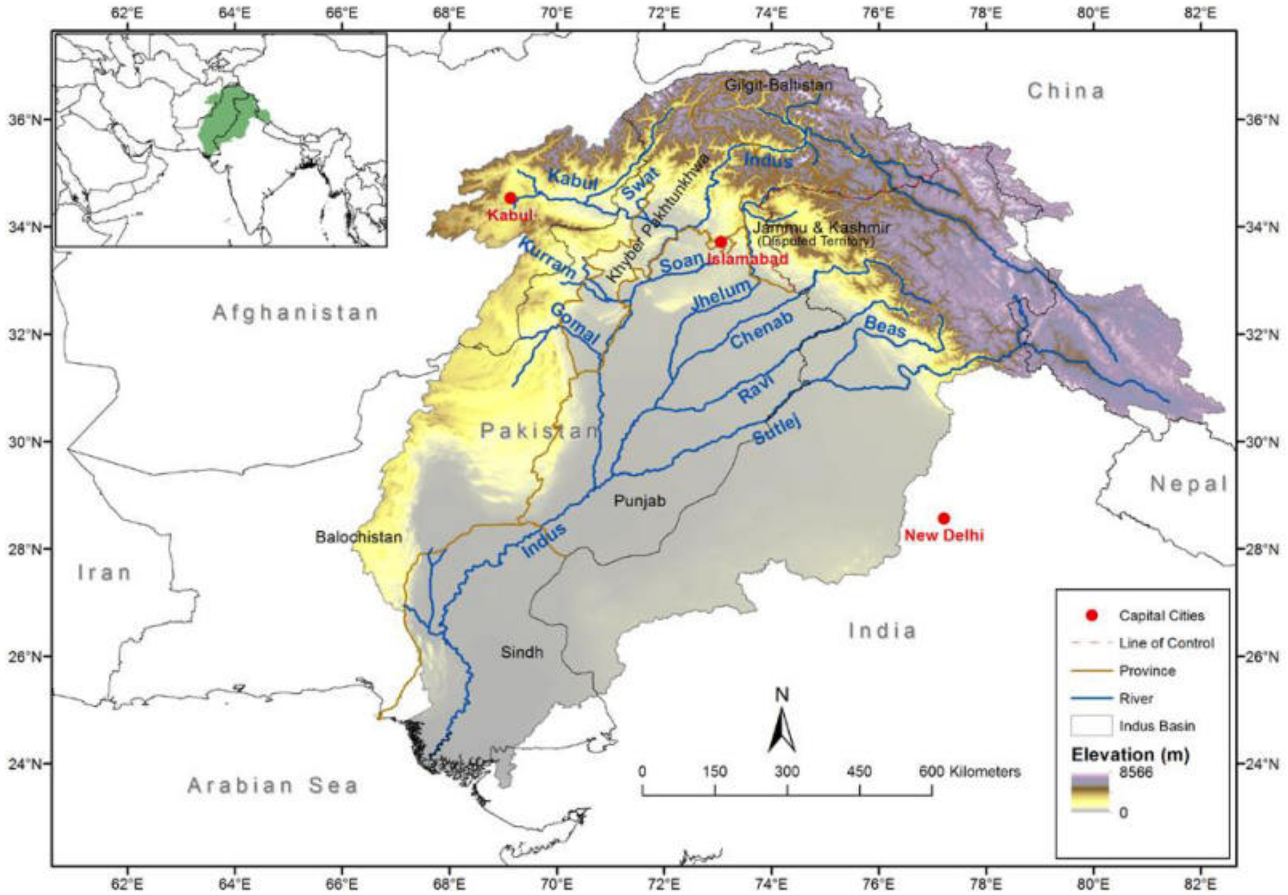


Figure 5-1: Indus Basin showing the major rivers (Source CSIRO, 2019)

5.3 TRIBUTARIES OF THE INDUS RIVER IN ITS PASSAGE THROUGH PUNJAB

5.3.1 THE RIVERS

The Indus River Basin comprises the Indus River and 27 tributaries. It has a total area of about 1,165,000 km^2, of which about 56% (529,134 km^2) lies within Pakistan, whilst the remainder lies in India, China and Afghanistan. The headwaters of the Indus River, and therefore the major source of water, lie outside of the Pakistan.

The Indus River Basin comprises 7 major rivers: Indus, Chenab, Jhelum, Kabul, Ravi and Sutlej-Beas. The origins of the Indus and Sutlej rivers are the Tibetan plateau in China. The headwaters of the Chenab, Jhelum, Ravi and Sutlej-Beas rivers are in the Himalayas in India. The Jhelum and Ravi rivers flow into the Chenab River and the Beas flows into the Sutlej River. The Chenab and Sutlej combine at Panjnad Barrage prior to flowing into the Indus.

The Soan River flows from the Pothohar Plateau and converges with the Indus river in Punjab. The Bunah river, also flows from the Pothohar Plateau and converges with the Jehlum river in Punjab.

The Kabul River originates from the Sanglakh range in the Hindu-Kush Mountains and joins the right bank of the Indus near Attock. The Swat and Panjshir rivers are major tributaries of the Kabul. The Chitral River flows from Pakistan into the Kunar River in Afghanistan which joins the Kabul River near Jalalabad.

The Indus River, its tributaries in Punjab and their catchment details are shown in **Table 5-1**.

Table 5-1: Rivers in Punjab

River	Source	Tributary of	River Length (km)	River Length in Punjab (km)	Catchment Area (km^2)	Catchment Area in Punjab (km^2)	Annual Runoff (BCM)
Indus R.	Tibetan Plateau, China	NA	3,180	808	1,165,000	204966.	243
Kurram R.		Indus R.	320	19	24929	6.83	0.18
Soan R. (Swan R.)	Pothohar Plateau, Punjab	Indus R.	250	240	12810	11923	0.19
Haro R.	KPW	Indus R.	123	70	572	274	0.27
Kabul R.	Hindu-Kush Mountains, Afghanistan; Kunar River, Pakistan; KPK, Pakistan	Indus R., Confluence at Attok, Punjab	700	0% The right bank of the Indus is in Khyber Pakhtunkhwa, Province	87561	0	21.67
Panjnad	Jhelum, Chenab, Ravi, Sutlej at Panjnad	Indus Tributary	2640	2038	327226	169024	15
Tochi R.	KPK	Indus	145	145	5128	0	0.23
Ravi R.	Himalayas, India	Chenab R.	1246	526	16731	539	0.10
Right bank hill torrents	Suleiman Range	Indus	13 hill torrents that are mostly ephemeral rivers and nullahs that rarely reach the Indus		5,000 ha	3.4 (2)	Right bank hill torrents

(1) Panjnab R. is formed about 70 km upstream form the confluence with the Indus River.

(2) Chapter 10 Hill Torrents

5.3.2 WATER SUPPLY UNDER THE PAKISTAN'S WATER APPORTIONMENT ACCORD

Indus Basin water resources are allocated between the provinces according to the Water Apportionment Accord which is described in Section 4.5..

5.3.3 STREAMFLOW

Streamflow has a pronounced seasonal pattern with peak flows in the period from May to September reflecting high (May-July) rainfall and summer temperatures which increase snow and glacial melt. **Figure 5-2** shows Kharif (autumn) inflows

far exceed irrigation demands; however, rabi (spring) inflows are inadequate to meet winter irrigation demand and water storage is required to carry water over to better meet irrigation demands.

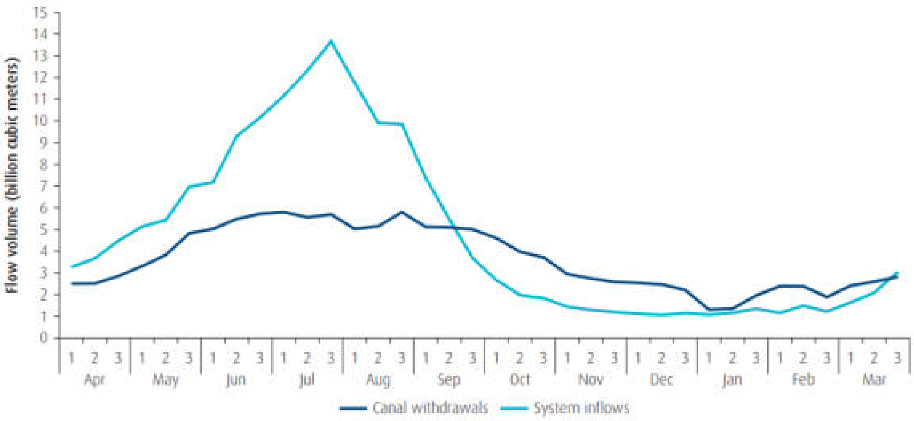


Figure 5-2: Pattern of Pakistan river system inflows and canal withdrawals (Source: Young et al, 2019)

Streamflow hydrographs for the main rivers for the period 2011-2018 (**Figure 5-3** to **Figure 5-6**) show the strong seasonal variability of flows in the Indus River and its major tributaries within the Punjab Province. **Figure 5-3** provides Indus River flows where it enters Punjab whilst **Figure 5-4** provides flows where it leaves Punjab. Notwithstanding the different ordinate axis scale, the difference in flows reflects the large abstractions from the Indus system in Punjab.

Figure 5-3: Indus River hydrograph at Jinnah Barrage

(NB date format is mo/day/yr)

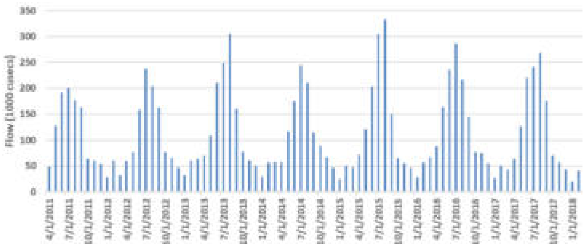


Figure 5-4: Indus River at Guddu Barrage

(NB: Different ordinate axis scales)

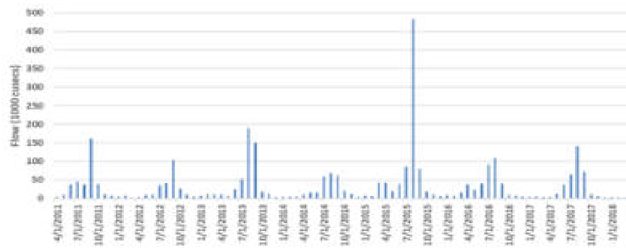


Figure 5-5: Sutlej River above Sulemanki

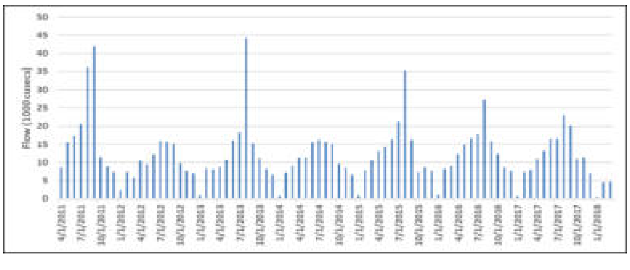
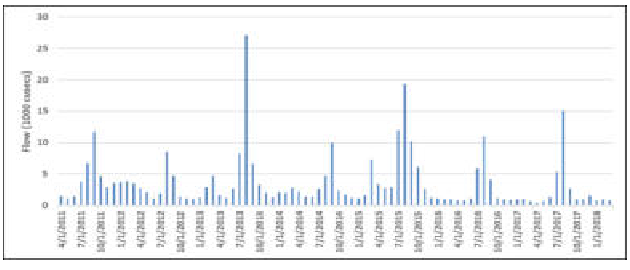


Figure 5-6: Ravi River at Jaser



The eastern rivers; Sutlej river (**Figure 5-5**) and, especially the Ravi river (**Figure 5-6**), have little flow except in flood months due to the upstream development rights and abstractions in India.

5.3.4 RIVER GAINS AND LOSSES

River flow gains (groundwater, rainfall) and losses (groundwater, evaporation) are important factors to consider when managing river water allocations and flows. Between 1940 and 1994, Indus River gains and losses varied significantly (**Figure 5-7**) including along its course in Punjab (Attock-Kalabagh).

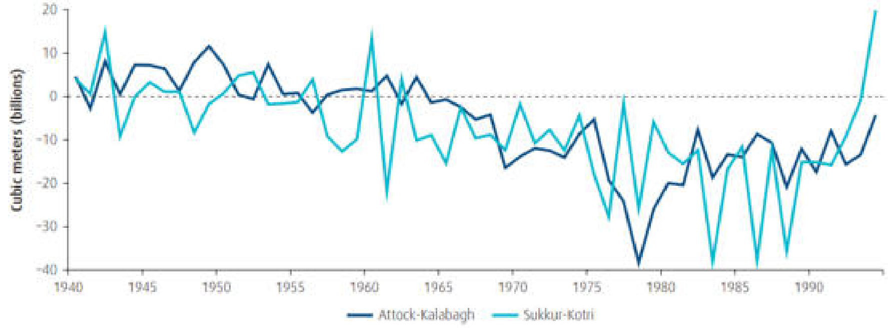


Figure 5-7: River gains and losses (Young et al, 2019)

The change in behaviour from gains in the 1940-65 period to losses in the 1965-1994 period has been largely attributed to construction of Tarbela Dam. However, the increasing losses also coincide with increased groundwater pumping and significant depletion of groundwater levels (Young et al, 2019), which is likely to be a contributing factor, if not the main cause.

The Attock-Kalabagh reach of the Indus River loses 20 BCM/ year at a rate of approximately 0.11 BCM/km. Losses of this order are significant in the overall Doab water balance.

There has been no analysis of the gains and losses for the main rivers of Punjab and this is an important subject for PID/WRD to understand.

5.3.5 IMPACT OF UPSTREAM DEVELOPMENT ON RAVI AND SUTLEJ FLOWS

The inflows from the Ravi and Sutlej Rivers to Punjab have been significantly reduced following the 1960 Indus Water agreement, which allocated the waters of these rivers to India and permitted large scale development and diversion of flows in India, **Figure 5-8**.

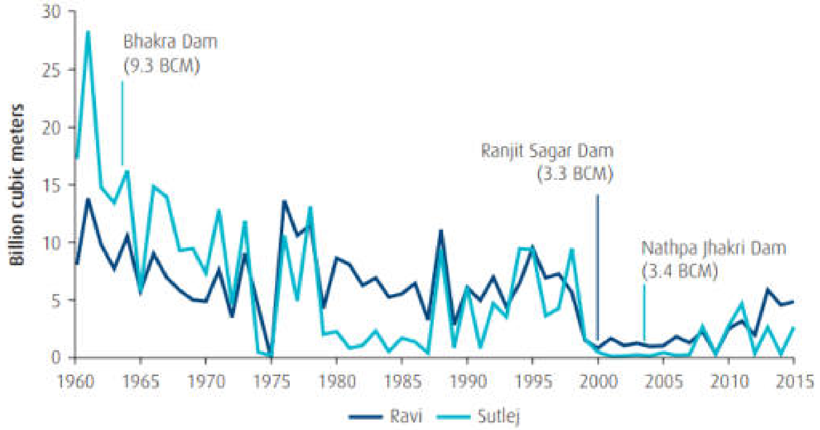


Figure 5-8: Ravi and Sutlej River Inflows to Pakistan 1960-2015 (Young et al 2019)

5.3.6 RIVER BASIN WATER BALANCE

Water balances for the main rivers in Punjab have been prepared to understand river behaviour and water availability.

Punjab river inflows: Includes river inflows from upstream catchments, river gains and losses (rainfall, evaporation and groundwater interactions) within Punjab, return flows from agricultural drains, sewerage and industrial effluent.

Punjab river outflows: Includes abstractions for irrigation, urban and industrial water supply and river outflows from the province. The water balance for major rivers in Punjab is shown in Table 5-2.

Table 5-2: River Water Balances

INDUS RIVER	**Total (BCM/y)**
Inflows to the River in Punjab	
Inflow at Jinnah Barrage	101.67
Tributary Rivers: Kurram, Soan, Haro, Kabul, Tochi, Panjnad rivers.	0
Link and other canals	0
Drains	5.08
Total Inflows	101.67
Outflows from river	
Link canals	9.69
Other canals	4.38
Other abstractions direct diversion by towns, industry, power plants, non-CA irrigation	0
Outflow from Punjab at Guddu Barrage from Punjab	84.54
Total Outflows	98.61
Balance	1.95
JHELUM RIVER	**Total (BCM/y)**
Inflows to the River in Punjab	
Inflow at Mangla	26.90
Tributary Rivers: Bunha river.	0
Link and other canals	3.93
Drains	0
Total Inflows	30.83
Outflows from river	
Link canals	8.87

Other canals	4.80
Other abstractions Towns, industry, direct diversion by small irrigation	0
Outflow from at Chenab river	15.73
Total Outflows	29.41
Balance	**1.42**
CHENAB RIVER	**Total (BCM/y)**
Inflows to the River in Punjab	
Inflow at Marala barrage	29.41
Tributary Rivers: Tawi, Jhelum, Ravi rivers	12.74
Link and other canals	12.34
Drains	0
Total Inflows	54.49
Outflows from river	
Link canals	29.32
Other canals	11.71
Other abstractions Towns, industry, direct diversion by small irrigation	0
Outflow from at Panjnab barrage	11.40
Total Outflows	52.43
Balance	2.05
RAVI RIVER	**Total (BCM/y)**
Inflows to the River in Punjab	
Inflow at Madhopur	0
Tributary Rivers: Baein river	0
Link and other canals	30.31
Drains	0
Total Inflows	30.30704
Outflows from river	
Link canals	18.55

Other canals	7.60
Other abstractions Towns, industry, direct diversion by small irrigation	0
Outflow at Chenab river	2.93
Total Outflows	29.07
Balance	1.23
SUTLEJ RIVER	**Total (BCM/y)**
Inflows to the River in Punjab	
Inflow at Sulemanki Headworks	Nil
Tributary Rivers:	0
Link and other canals	11.04
Drains	0
Total Inflows	11.04
Outflows from river	
Link canals	0
Other canals	8.53
Other abstractions Towns, industry, direct diversion by small irrigation	0
Outflow from at Chenab river	1.93
Total Outflows	10.45
Balance	0.59

5.3.7 SCENARIOS OF FUTURE WATER DEMANDS AND CLIMATE CHANGE

The ITPID water balance study assessed the water balance for the year 2050 by considering population growth and projected water demand for domestic water use; irrigation expansion; and, industrial water use. An estimate was also made of the impact of climate change on crop water demand (**Table 5-3**).

Table 5-3: Summary of increases in future water demands 2050

Sector	Growth 2020-2050 (% of 2020 use)
Domestic water use	64%
Agriculture water use	26%

Sector	Growth 2020-2050 (% of 2020 use)
Industrial water use	11%
Climate change	6% per 1 °C rise in temperature

The following scenarios were evaluated:

- 2050 Base – Domestic and industrial demands increased with no increase in agricultural demand.
- 2050 Scenario 1– All demands increase as per future demand projections. The irrigated area was increased by 26%.
- 2050 Scenario 2– All demands increase as per future demand projections and climate change as a result of temperature increases by 1 degree in 2050 (Amir and Habib 2015[14]). Irrigated areas were increased by 26%. Demands were increased by 6%, 2% and 15% for crop, domestic and industry.
- 2050 Scenario 3– All demands increase as per future demand projections and climate change as a result of temperature increases by 3 degrees in 2050 (Amir and Habib 2015[15]). Irrigated areas were increased by 26%. Demands were increased by 8%, 6% and 29% for crop, domestic and industry.

5.3.8 DISCUSSION OF RIVER SCENARIOS

The water balance scenario assessments, in relation to demands for water from the surface water system assuming the imbalance is met from the water supply system (i.e. groundwater use becomes balanced), is shown in Table 5-4. The imbalance is summarised from the detailed water balance of command areas in Doab and Hill Torrent areas presented later.

Table 5-4: Summary of water balance of water demand scenarios for Doab/Hill torrent command areas

Item	Current Situation	2050 Base	2050 Scenario 1	2050 Scenario 2	2050 Scenario 3
TOTAL IMBALANCE (BCM)	-5.13	-9.85	-26.93	-39.65	-43.95
% of average, canal head inflow	8.4%	16.1%	44.0%	64.8%	71.8%
% of Punjab WAA share	7.4%	14.3%	39.0%	57.5%	63.7%

14 Estimating the impacts of climate change on sectoral water demand in Pakistan, Amir and Habib 2015

15 Estimating the impacts of climate change on sectoral water demand in Pakistan, Amir and Habib 2015

At this stage it is not possible to assign these amounts to individual rivers to consider local impacts and demands because of the complexity of the offtakes and outfalls between rivers and their linkages. To do this adequately and to investigate the various scenarios including others such as new storage facilities or changed operations of existing facilities, seasonal differences, drought and flood impacts and their management, a detailed water routing model is required.

However, the order of magnitude of the impacts of these increased demands can be gauged by comparing them to the current Indus river discharge from Punjab.

Table 5-5: Indus River discharge and supply conditions

Item	Quantity
Indus river discharge from Punjab (BCM/y)	64.47
Gap between WAA allocated and abstracted volumes (BCM/y)	4.39
Total	68.86

The historic withdrawals and adjusted withdrawals of Punjab for data period (1982-83 to 2018-19) are given in **Table 5-5** The actual withdrawals are lesser than historic in 30 years out of 37 years. The reasons of decrease in withdrawals are:

- Pro rata adjustment of canal withdrawals on basin level (Para 14-b).
- Pro rata distribution of Kotri Below constant requirement with canal withdrawals (Para-7).
- Para 4 uses also included in Historic canal withdrawals.
- Impact of Indian and Afghan uses
- Impact of Thien Dam

As per para 14-e, all efforts would be made to avoid wastages. Any surpluses may be used by another province, but this would not establish any rights to such uses. KPK and Balochistan are not getting their share, which is being used by Punjab and Sindh.

5.3.9 RIVER VALUES, USES AND FLOW NEEDS

(a) Values and Uses

Rivers have many important values which include:

Water for urban centres, industry, hydropower and irrigation: Historically, water has been managed to prioritise supply to meet demand for urban drinking water, industrial, hydropower and irrigation.

Recreation: Rivers can provide recreational values, but historically this service has not been valued highly in Punjab. However, as societies become more affluent greater importance is placed on these values as evidenced with the rejuvenation of the Ravi river near Lahore.

River fisheries: Commercial fishing based on natural fisheries and aquaculture in rivers and reservoirs is an important local industry.

Cultural and heritage values: Rivers have cultural significance, especially for indigenous cultures. Heritage values of rivers are often celebrated through literature and song.

Water quality: In some circumstances special releases can be made to manage water quality, such as releases to dilute poor water quality or to disperse algal blooms.

River and floodplain environment: Water is necessary for the environment which includes rivers, wetlands and the river floodplain. How much water should be allocated for the environment is not a simple question as it depends upon environmental, social and economic conditions. The importance attributed to the environment can change over time in response to different socio-economic circumstances. Typically, environmental flows aim to mimic natural flow patterns, protect low flows and maintain or preserve key flow events such as releases to coincide with fish migration events or inundate of floodplains and wetlands.

For Punjab rivers a high percentage of flow has been allocated for consumptive use (irrigation, drinking water and industrial uses) with no consideration for environmental flows. This has resulted in river flow regimes that are highly modified. It may not be feasible to restore the whole system, but instead certain river reaches or wetland sites may be targeted. This would require specialist economic, environmental, and social assessment and involvement of environmental hydrologists. A long record of river flows, including pre-major development (e.g. pre-1950's) flows is required for analysis.

(b) River Flow conditions

The long-term flow characteristics of the Indus River and its tributaries are provided in **Table 5-6**. A longer record with data prior the 1950's (when the most significant development commenced), is not readily available. This data would be invaluable to better understand the natural flow regime and dependant aquatic ecosystem condition.

Table 5-6: River flow conditions

Location	Q_{05}	Q_{95}	Comment on upstream abstractions
Indus River at Jinnah Barrage	5.03	95.54	Little upstream flow regulation or use?
Indus River at Guddu Barrage	4.22	80.30	Significant abstraction and storage (Tarbela reservoir) in Punjab
Jhelum River at Mangla	1.35	25.56	Little upstream abstraction. Significant upstream regulation (Mangla reservoir)
Jhelum River at Chenab river	0.79	14.95	Significant abstraction in Punjab. No major upstream regulation
Chenab river at Marala barrage	1.47	27.94	No significant upstream abstraction or regulation.
Chenab river at Panjnab barrage	0.57	10.83	Significant abstraction in Punjab
Ravi River at Madhopur	0.21	0.08	Extreme regulation and abstraction upstream
Ravi River at Chenab river	0.15	2.78	Abstraction in Punjab. Sizable outfalls into Ravi R from link canals
Sutlej River at Chenab river	0.10	1.83	Abstraction in Punjab. Sizable outfalls into Sutlej R from link canals

Q_{05} : Flows greater than or equal to this occur only 5% of the time
Q_{95}: Flows greater than or equal to this occur 95% of the time

5.4 WATER REGULATING INFRASTRUCTURE

5.4.1 RESERVOIRS

Key data describing water storage infrastructure in the Upper Indus Basin in Punjab is shown in **Table 5-7**.

Table 5-7: Water storage reservoirs in the upper Indus Basin and barrages in Punjab

River	Reservoir	Location	Capacity	Barrage in Punjab
Indus River	Tarbela Dam	KPK, Pakistan	13.69 BCM HP 6,298 MW	Jinnah Barrage Taunsa Barrage
	Kalabagh Dam (proposed)	Punjab	9.7 BCM HP 3,600	
	Bhasha reservoir (under construction)	KPK, Gilgit-Baltistan	10 BCM 4,800 MW	
Soan River	Nil			Nil
Haro River	Nil			Nil
Kabul R.	Naghlu	Afghanistan	0.55 BCM HP 100 MW	
	Warsak Dam	Peshawar, Pakistan	31.2 MCM 243 MW	
Jhelum River	Mangla Dam 3 run of the river HP plants in Jammu Kashmir	AJK, Pakistan	9.12 BCM HP 1,150 MW	Rasul Barrage
Panjnad River	Nil			Panjnad Barrage
Chenab River	6 run of the river HP plants (2 operating, 1 under construction, 3 proposed)	India		Marala Headworks Qadirabad Barrage New Khanki Barrage https://en.wikipedia.org/wiki/Punjab_Irrigation_Department - cite_note-17 Trimmu Barrage
Ravi River	Ranjit Sagar Dam	India	3.28 BCM HP 600 MW	Balloki Barrage Sidhnai Barrage

River	Reservoir	Location	Capacity	Barrage in Punjab
Sutlej River	Nil			Islam Barrage

AJK= Azad Jammu and Kashmir Province; KPK= Khyber Pakhtunkhwa; HP= Hydropower

5.4.2 BARRAGES LOCATED IN PUNJAB

There are a large number of barrages on the rivers in Punjab and their characteristics are provided in **Table 5-8**. Their purpose is diversion of water into irrigation canals.

Barrages provide a barrier to fish migration which leads to fragmented fish populations, the loss of upstream biodiversity and fish population decline. None of the barrages have fish passage structures to facilitate fish migration.

Table 5-8: River Barrage Infrastructure

Barrage	River	Length m	Capacity m3/s	Manager
Chasma barrage	Indus	1,084	870,000	WAPDA
Jinnah Barrage	Indus	1,152	27,000	PID
Taunsa Barrage	Indus	1,325	28,320	PID
Rasul Barrage	Jhelum	975	24,070	PID
Marala Headworks	Chenab	1,364	34003	PID
Qadirabad Barrage	Chenab	1,029	25,496	PID
New Khanki Barrage	Chenab	1,100	31,179	PID
Trimmu Barrage	Chenab	923	18,226	PID
Balloki Barrage	Ravi	-	10,770	PID
Sidhnai Barrage	Ravi	217	4,248	PID
Islam Barrage	Sutlej	503	8,500	PID
Panjnad Barrage	Panjnad	1,036	19,822	PID

5.4.3 RESERVOIR SEDIMENTATION

The operational capacities of Tarbela and Mangla reservoirs are being reduced by sedimentation which affects the water share of the respective provinces under the WAA. Table **5-9** indicates the modelled water shares of Punjab in for the period 1990 and 2020. For this period the share was reduced by -1.3% annually, -0.38% in the late Kharif season and -4.56% in the Rabi season. The early Kharif however, increased by 0.73%.

Table 5-9: Effect of major reservoir sedimentation on Punjab water share (Podger et al, 2021)

Season	Scenario	Punjab (km^3)
Early Kharif	1990 sediment levels	12.33
	2020 sediment levels	12.42
Late Kharif	1990 sediment levels	29.15
	2020 sediment levels	29.04
Rabi	1990 sediment levels	16.00
	2020 sediment levels	15.27
Total	1990 sediment levels	57.48
	2020 sediment levels	56.73

There is a significant and consistent loss of storage. Extrapolation suggests that without additional system storage the Rabi season supplies will reduce by a further 4.6% by the year 2050, giving a total storage loss of 9-10% for the period 1990-2050. Losses for other seasons would be less important.

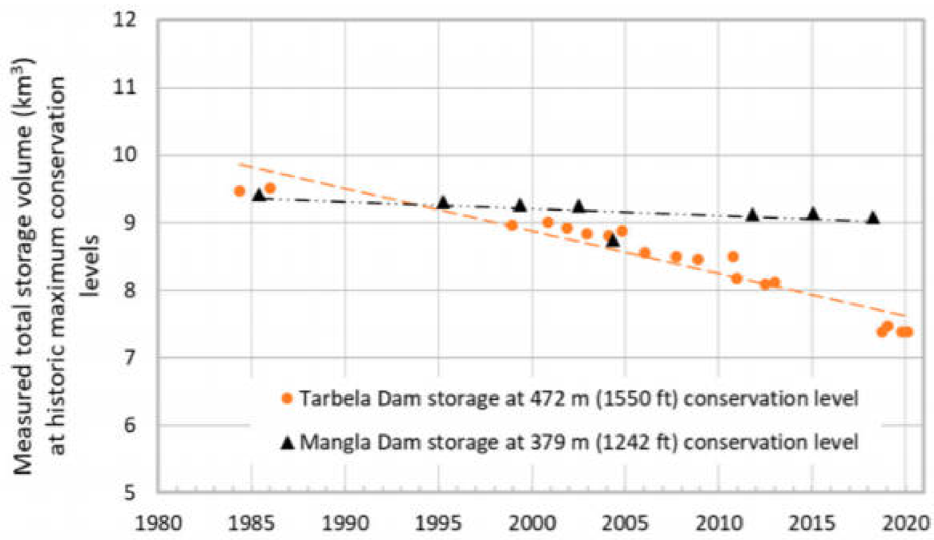


Figure 5-9: Storage volume of reservoirs (Podger et al, 2021)

5.5 THE PUNJAB INDUS BASIN WATER SUPPLY NETWORK

The water system within Punjab consists of a highly connected network of rivers and link canals which enables movement of water from the large water resource of the Indus River, across the smaller rivers and Doabs to the east. This is arrangement was originally conceived to offset the upstream diversion rights for the two most eastern rivers, Ravi and Sutlej, given by the Indus River Agreement to India. However, it also gives scope to Punjab to move water to areas where there is best value and benefit from its use. **Figure 5-10** provides a diagrammatic representation of the Indus River Basin and its irrigation system/water grid. The Indus River and irrigation system within the Punjab ends at the southmost border of Punjab province at Guddu Barrage.

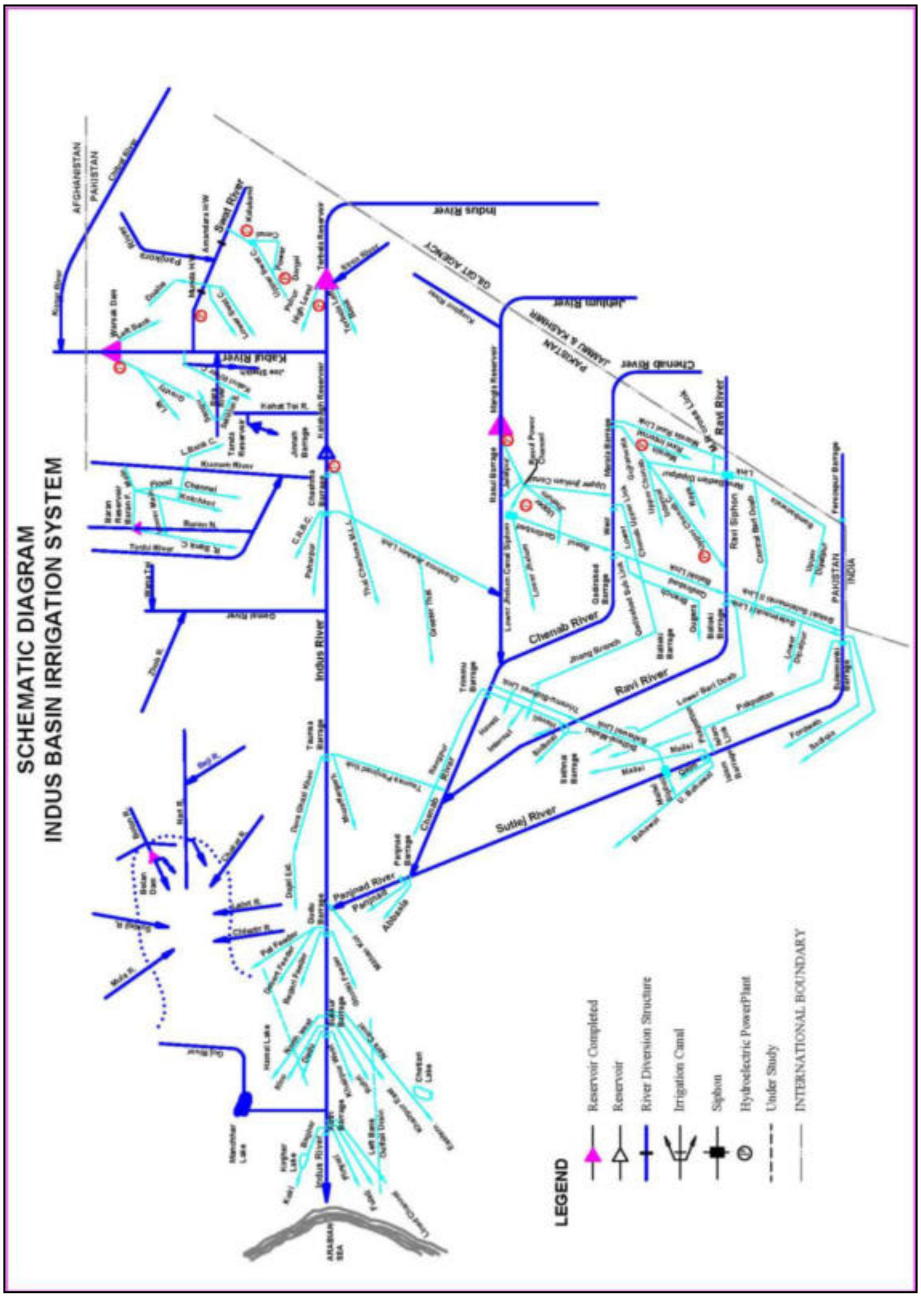


Figure 5-10: Schematic Diagram of Indus Basin Irrigation System

5.5.1 RIVER WATER ALLOCATION AND USE

(a) Punjab water allocation

The water allocated to Punjab by Pakistan's WAA is 69.001 BCM/yr, of a total Pakistan allocation of 144.749 BCM/yr. The minimum received in the 1993-2015 period was 45 BCM in 2001 (Anwar and Bhatti, 2017).

The apportioned canal supplies are usually not supplied, and any shortages are shared between provinces as per apportioned allocations. **Figure 5-11** shows the Punjab canal diversion annual flow variability.

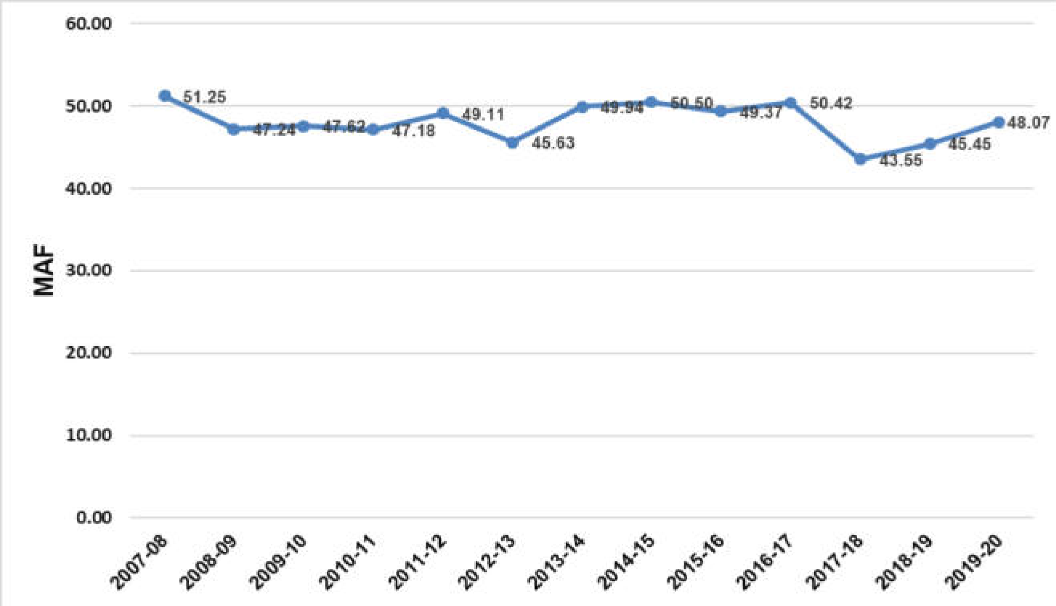


Figure 5-11: Punjab water diversions

5.5.2 WATER SHARING THROUGH LINK CANALS

Link canals are used principally for transferring water from the western rivers, especially the Indus, to the eastern rivers and irrigation command areas. They are nevertheless multi-purpose and supply water for other sectors including urban water supply and industry. As the economy develops further and Punjab increasingly urbanises, these canals will play an increasingly important role for the supply of water to non-irrigation sectors. The operation of the canals will also need to offset the impacts of falling groundwater levels and climate change. The link canals are listed in **Table 5-10**.

Table 5-10: Link Canals in Punjab

Link canal	Water Source	Water Outfall	Discharge capacity (Cs)
CJ Link canal	Chasma Barrage	Jhelum River	21,700
Rasul Qadirabad Link	Rasul Barrage	Qadirabad Barrage	19,000
Qadirabad Balloki Link	Qadirabad Headworks	Baloki Headworks	25,000
Ballaki Sulemanki II Link	Baloki Headworks	Sulemanki	24,500
Trimmu Sidhnai Link	Trimmu Barrage	Sidhnai Headworks	12,500
Sidhnai Mailsi Link	Sidhnai Headworks	Satluj River near Malsi	11,300
Mailsi Bahawal Link	Mailsi	Bahawalpur	6,730
Chashma Jhelum Link	Chasma Barrage	Jhelum River	21,700
Taunsa Panjnad Link	Taunsa Barrage	Chenab River	12,000
Marala Ravi Link	Marala Barrage	River Ravi	22,000

In winter months for Rabi and early Kharif, when flows in Chenab River downstream of Khanki Barrage diminish, delivering water to the Sutlej valley canals depends almost entirely on three link canals.

5.5.3 OTHER SOURCES OF WATER SUPPLY

Other sources of water considered in the ITPID reports are:

(a) Groundwater: Groundwater provides approximately 50% of water supply (53.8 BCM) for urban, industry and irrigation uses. Groundwater levels initially rose with the introduction of irrigation, but they are now declining in most command areas, due to a significant increase in groundwater usage. However, groundwater levels do vary across command areas with shallow water tables in some locations.

Groundwater policy and management needs to be carefully planned as there are both positive and negative aspects that affect its sustainable use: (i) major improvements to irrigation efficiency will reduce groundwater availability as much of its supply is from irrigation canal and field losses. (ii) groundwater as a source has an advantage in that it provides storage and can be tapped during low supply periods, (iii) the farmer determines when it is used and so it can better meet crop demand rather than being tied to a warabandi delivery system. (iv) recharging groundwater for later use has the disadvantage of activating salts and pollutants stored in the geological system thereby affecting crop yields and downstream water quality.

Groundwater is addressed in a later chapter and in the detailed ITPID reports.

(b) Domestic wastewater: About 4.1 BCM of water is supplied for urban drinking water each year. Approximately 80% could theoretically be recovered as effluent from domestic water, if the sewerage network is not leaky or is the effluent is not transferred to groundwater through soaking pits. This would result in 3.26 BCM being recovered for reuse for irrigation or industrial water supply.
Currently, a significant proportion of cities and villages are unsewered and the untreated sewerage and industrial effluents discharged into surface drains and rivers. Thus, the timeframe in which this water can be recovered is uncertain.

(c) Industrial and commercial wastewater: Approximately 2.0 BCM are used for industrial and commercial purposes and 60% could be recovered from the industrial and commercial uses (PWP and GWP 2000[16]) resulting in a recovery of 1.2 BCM.

(d) Agricultural drainage: WAPDA (2005[17]) estimated that 1.43 BCM of agricultural drainage effluent is likely to be available.

(e) Stormwater: In urban areas, storm water, sewage and industrial effluents are not separated and thus treatment of sewage is difficult. If collected, stormwater has a quality that makes it suitable for recharging groundwater aquifers and for non-potable uses, such as irrigation of sports oval, gardens etc. In rural areas stormwater is largely used for agriculture and is captured as effective rainfall runoff in the water balance.

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16 PWP and GWP. 2000. Framework for Action. Pakistan Water Partnership, Global Water Partnership

17 WAPDA. 2005. Drainage Master Plan of Pakistan. Water and Power Development Authority, Lahore, Pakistan

(f) Total availability of wastewater: The total volume of wastewater potentially available for reuse in Punjab is approximately 4.77 BCM. This volume is only slightly less that the current total water imbalance. However, this resource is not spread uniformly across Punjab and is mainly located in the large cities.

(g) Recovery of Non beneficial Uses: There is scope to reduce the water supply-demand gap by reducing losses by lining canals and using more efficient irrigation application methods. However, it needs to be acknowledged that a significant portion of these current losses ends up in the groundwater aquifer and is recovered for use. Most of the losses from seepage from canals contributes to groundwater. A portion of the losses to inefficient irrigation practices joins the groundwater and a portion is lost to evaporation. Reducing these losses will generate a genuine gain in water availability. Detailed analysis is required to quantify the potential gains from reducing losses.

(h) Management needs: There are a range of issues associated with recovering wastewater which need to be considered in developing policies and plans. (i) In the rural areas, domestic, commercial, industrial and storm water wastes are disposed by discharging into village ponds, which were initially developed for stock watering. This results in transmission of disease to stock. To prevent this it is important to treat sewage and commercial effluents separately. (ii) urban stormwater is currently mixed with sewage which diminishes the water quality rendering it unsuitable for many potential uses without expensive treatment. Hence stormwater should be separated from sewerage and industrial effluent. (iii) the extent and condition of the sewerage and stormwater systems is likely to be a significant constraint to sewerage and stormwater collection and a significant budget is required would be required to develop adequate collection services. (iv) The government should undertake a detailed review of the subject and develop a feasible strategy, plan and financing to collect, treat and re-use sewerage effluent, industrial effluent and stormwater. The lead agency for this would be the Department of Punjab Public Health Engineering Department (PPHED) for major cities and with the Department of Local Government smaller, habitations. The PID/WRD would have a role to facilitate this through a Provincial Water Management Strategy.

5.6 LAND MANAGEMENT UNITS, DOABS AND COMMAND AREAS AND THEIR WATER USE

The Indus River basin within Punjab comprises 5 Doabs, 2 use zones and 1 river sub-basin, which are listed below.

Five Rivers Area

a) Thal Doab- Command Areas
b) Chaj Doab- Command Areas
c) Rechna Doab- Command Areas
d) Bari Doab- Command Areas
e) Bahawalpur land use zone- Command Areas

Hill torrents Areas

f) DG Khan Hill torrent area- Command Areas
g) CRBC torrent area- Command Areas

Pothohar river sub-basin

h) Pothohar river sub-basin

The PID is an irrigation management department and because of this it has focussed on supplying water to the irrigation command areas, although PID have other water resource management responsibilities including flood control, operation and maintenance of river infrastructure, hill torrent management. Current water resources assessments focus on the irrigation commands, rather than the whole landscape (including rivers and rainfed areas), which has implications for downstream flows and water quality.

5.6.1 THE CURRENT WATER BALANCE FOR DOAB AND HILL TORRENT AREA (COMMAND AREA BASIS)

The ITPID project analysed the water balance for the command areas in the 5-rivers and hill torrent areas. A summary of the results for current conditions is provided in **Table 5-11**.

Table 5-11: Current Water Balance for Doab and Hill Torrent Areas (command area basis)

Item	Doab and Hill Torrent Area (command area basis)							
	Thal	Chaj	Rechna	Bari	BWP	DG Khan	CRDB	Total
Population (million)	11.35	9.01	29.07	34.23	11.46	4.19	0.68	100.00
CCA (M ha)	1.43	.83	1.90	2.40	1.52	0.36	0.10	8.55
GW usage BCM	8.30	5.73	13.48	13.29	10.02	2.20	0.76	53.79
Inflows								
Effective rainfall, BCM (50% mean annual)	2.41	1.95	4.61	4.12	1.07	0.43	0.09	14.69
Canal head inflow, BCM	9.27	4.95	13.52	14.58	14.58	3.39	0.90	61.18
Other	(1)	(1)	(1)	(1)	(1)	(1)	(1)	
Total Inflows, BCM	11.68	6.89	18.12	18.71	15.65	3.82	0.99	
Outflows								
Crop consumption, BCM	11.37	7.41	18.27	18.27	13.92	3.28	0.98	73.50
Domestic, BCM	0.47	0.37	1.20	1.41	0.47	0.17	0.03	4.11
Industry, BCM	0.22	0.18	0.57	0.67	0.23	0.08	0.01	1.97
Non beneficial loss	0.16	0.13	0.42	0.49	0.16	0.06	0.01	1.44
Other	(2)	(2)	(2)	(2)	(2)	(2)	(2)	
Total Outflows, BCM	12.22	8.09	20.46	20.85	14.79	3.60	1.03	81.02
Balance	(0.54)	(1.19)	(2.33)	(2.14)	0.87	0.23	(0.03)	(5.15)

BWP= Bahawalpur

(1) There are other inflow quantities that are not included here as they are likely relatively small in the overall total. This includes losses from rivers, and recharge from rain fed areas outside command areas.

(2) There are other potential outflows via the river system. These include from surface drainage (an empirical allowance for this is made in the calculation of crop consumption), and water discharged into the rivers for river and floodplain ecological, recreational and heritage reasons. This might or might not be considered a consumptive or non-consumptive use depending upon its specific purpose and rules regarding its supply and flow through the river system.

5.6.2 THE 2050 WATER BALANCE FOR DOAB AND HILL TORRENT AREA (COMMAND AREA BASIS)

The ITPID water balance study assessed the water balance for the year 2050 according for the scenarios described below:

- 2050 Base – Domestic and industrial demands increased with no increase in agricultural demand

- 2050 Scenario 1– All demands increase as per future demand projections. The irrigated area was increased by 26%.
- 2050 Scenario 2– All demands increase as per future demand projections and climate change as a result of temperature increases by 1 degree in 2050 (Amir and Habib 2015[18]). Irrigated areas were increased by 26%. Demands were increased by 6%, 2% and 15% for crop, domestic and industry
- 2050 Scenario 3– All demands increase as per future demand projections and climate change as a result of temperature increases by 3 degrees in 2050 (Amir and Habib 2015[19]). Irrigated areas were increased by 26%. Demands were increased by 8%, 6% and 29% for crop, domestic and industry.

Table 5-12 and **Figure 5-12** summarise the results of the ITPID water balance assessment for the command areas. This shows the current water supply deficit to be 5.13 BCM/y (7.4 % of the Punjab WAA allocation; 8.4 % 0f the current average canal head inflow shown in Table 5-11), which this increases to 43.95 BCM/y (64%; and 72% respectively) by 2050.

Table 5-12: Scenario Water Balances for Doab/Hill torrent areas (command areas)

Doab/Hill Torrent Ca	Current Situation		2050 Base		2050 Scenario 1		2050 Scenario 2		2050 Scenario 3	
	BCM	mm	BCM	mm	BCM	mm	BCM	mm	BCM	mm
Thal	-0.54	-46.19	-1.08	-75.02	-3.62	-207.61	-5.58	-307.34	-6.24	-343.25
Chaj	-1.19	-112.4	-1.62	-194.1	-3.2	-272.48	-4.48	-424.84	-4.91	-465.55
Rechna	-2.33	-85.01	-3.7	-194.67	-7.75	-284.62	-10.92	-454.22	-12	-499.03
Bari	-2.14	-56.75	-3.75	-156.21	-8.01	-231.33	-11.18	-368.41	-12.27	-404.36
Bahawalpur	0.87	107.75	0.33	21.6	-3.25	-118.66	-5.65	-294.37	-6.45	-335.64
DG Khan	0.23	111.2	0.03	7.91	-0.79	-121.87	-1.36	-294.27	-1.55	-335.65
CRBC	-0.03	15.67	-0.06	-65.82	-0.31	-201.69	-0.48	-387.16	-0.53	-432.05
TOTAL	-5.13		-9.85		-26.93		-39.65		-43.95	
% of average canal head inflow	8.4%		16.1%		44.0%		64.8%		71.8%	

18 Estimating the impacts of climate change on sectoral water demand in Pakistan, Amir and Habib 2015

19 Estimating the impacts of climate change on sectoral water demand in Pakistan, Amir and Habib 2015

Doab/Hill Torrent Ca	Current Situation		2050 Base		2050 Scenario 1		2050 Scenario 2		2050 Scenario 3	
	BCM	mm	BCM	mm	BCM	mm	BCM	mm	BCM	mm
% of Punjab WAA share	7.4%		14.3%		39.0%		57.5%		63.7%	

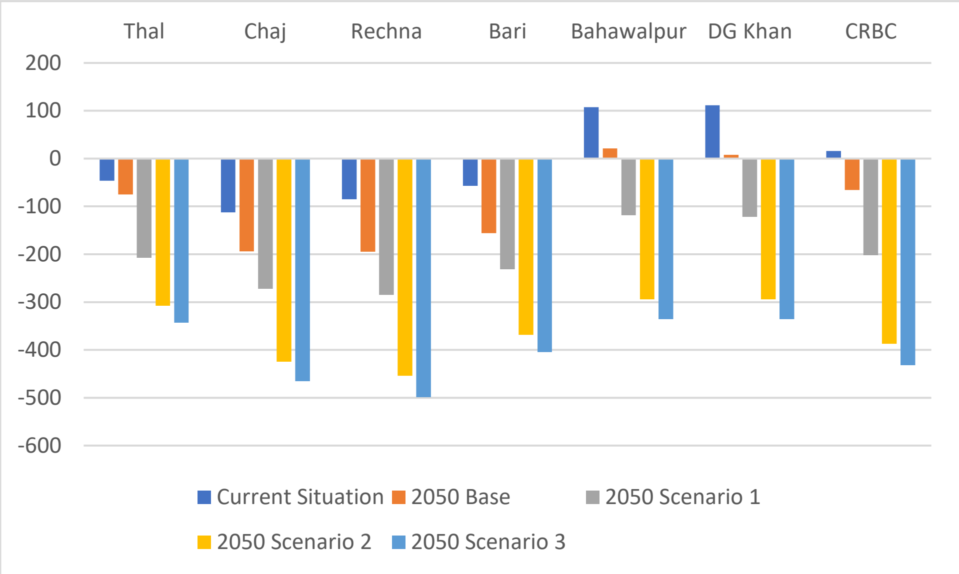

Figure 5-12: Doab/hill torrent CA water balance scenarios (mm)

5.7 RIVER BASIN WATER BALANCES

With the exception of Pothohar Plateau basin, all other areas of runoff in Punjab are sub-basins with part of the runoff coming from upstream Provinces or countries.

The 5-river area is a flat geographic area without any hydrological boundary between rivers as a result flooding can spread across rivers. These rivers are also highly interconnected by the link canal system.

The river (sub) basins within Punjab are:

1. The Indus Basin in Punjab: Inflow enters from upstream jurisdictions, whilst outflow leaves the Province.
2. The 5-rivers area (Panjnad basin): Inflows from upstream jurisdictions. Outflow to the Indus River
3. The Pothohar river basin: No inflow from upstream jurisdictions, with all flow generated within Punjab. Outflow through the Soan and Haro Basins. Depending upon the significance of the issues these could be treated as 2 separate basins however, at this stage and for simplicity they are treated as one.
4. The right bank hill torrent areas: Inflow: Hill torrent runoff and diversions from Indus River (DG Khan and (b) CRBC areas. There is very little outflow to the Indus river.

The River Basin Water Balance is calculated by the following formula:

River Basin Water Balance Δ = I - O

Where:

I = Inflows to the 'river basin': rainfall + surface water inflows (e.g. from upstream jurisdictions, inter-basin transfers)

O = Outflows from the 'river basin': surface water discharge (e.g. to downstream jurisdiction, ocean, terminal lake system + ET (crop/vegetation ET, evaporation from large water bodies) + consumption associated with urban , industry , thermal power plants

The water balances for the Indus River basins are as follows:

Table 5-13: Water Balances for River Basins

PUNJAB INDUS RIVER BASIN	Value
Basin Area (205,034 km^2)	205,034
Inflow (BCM)	
Canal Head+ Hill Torrent+ Pothohar (BCM)	80.30
Rainfall (mm)	535
Effective Rainfall (BCM)	45.19
Outflow (BCM	
Crop Consumption (Canal)	26.91
Crop Consumption (GW)	36.31
Crop Consumption (Rainfall+ Hill Torrents)	10.58
Net consumption (domestic, urban, industry, power plants, non-beneficial)	8.98
Total Outflow	83.28
Water Balance (BCM)	-2.48

5.8 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are made from the water budget analysis:

i) There is insufficient water to meet all water demands at present. All sub-basins have shortfalls in water supply, except for DG Khan sub-basin, Pothohar and the Hill torrents
ii) Inflows and outflows have been estimated for each sub-basin including canal command areas, rain fed, hill torrent and Pothohar region.
iii) The water budget for the seven sub-basins indicates a water deficiency, which agrees with past studies. However, this doesn't give a true picture, as most of the water balance components are estimates and they have a high degree of uncertainty. This highlights the need to invest in improved analysis of the water budget for each sub-basin through the development of computer models.

iv) Water balances at basin and sub-basin levels do not identify issues such as ‘tail end supply shortfalls’, capacity constraints and water seeping to saline aquifers etc. A detailed canal level water balance is required to identify these issues.
v) Water supply sources are likely to decrease due to factors such as: climate change; siltation of dam storages and canals; and deteriorating irrigation asserts. These issues need to be considered in the water budget.
vi) A holistic approach towards water management and conservation needs to be implemented.
vii) Surface drainage outflows are not properly gauged and have been ignored in the water budget analysis.
viii) Models at the Doab scale are useful for the Irrigation Department to improve planning and management of surface and groundwater resources. This will require increased capacity for irrigation agencies, as well as institutional reform.
ix) Expansion of the irrigation area is desirable but is currently constrained by limited water resources. The sustainable and cost-effective option to facilitate expansion is to enhance water productivity. This requires enhancement of crop productivity and reductions in crop water use. This is possible by adoption of water efficient technologies, improved production practices, more productive and higher value crops and varieties, improved operation and maintenance of irrigation systems, and reduced non-beneficial losses of water.
x) The PID is an irrigation department with a focus on supply of water to irrigation command areas, although it has other responsibilities including flood control, operation and maintenance of river infrastructure and hill torrent management). A result of this focus is that information on water balances has been focused on command areas, rather than the overall water resources of the Province.
xi) A Water Resources Department would have a stronger recognition of rivers and their values and uses including environmental, recreational, heritage and cultural uses, as well as traditional irrigation, drinking water and industrial water uses.

5.8.1 WATER AVAILABILITY ACTIONS PROPOSED IN THE PUNJAB WATER POLICY, 2018

The Punjab Water Policy includes actions to enhance the management, availability and efficiency of use of water. Those most relevant to this chapter, and not included in other chapters, are:

(b) to enhance the availability of surface water, the following policies should be adopted:

- Continue efforts vigorously for construction of Kalabagh, Bhasha and other mega projects within the Indus Basin.
- Enhance canal capacities to regulate flows.
- Harness information technology including expanding data monitoring sites, collecting real time data, utilising numerical models and utilising expert systems.

(c) For water use and allocation, the following policies should be adopted:

- Assess the water requirements for different sectors and allocate water for various sub-sectors based on the following order of priority: domestic water, livestock, water for agriculture, water for industry and commercial uses, water for environment, forestry and recreational uses.
- Re-assess the water allocations for different canal systems to provide more equitable supply.
- Enforce measures to reduce, reuse and recycle water in domestic, commercial and industrial sub-sectors.
- Harness information technology as above.

(d) To adapt for climate change, following policies should be adopted:

- Local Climate Models or statistical downscaling techniques[20] should be applied to better understand the local impacts of Climate Change.
- Better utilise surface and groundwater storages to survive extended drought, including large new surface storages.
- Adaptive measures be developed out to mitigate impacts of Climate Change.

(e) For water governance, the following policies should be adopted

- IWRM support tools should be developed including:
    - GIS database for water & environment,
    - water balance models,
    - water quality models,
    - decision support tools.
- A state of the art Water Resources Management Information system (WRMIS) needs to be developed

5.8.2 RECOMMENDATIONS

The following recommendation should be considered to better manage the water allocation and balance to be undertaken into the future:

- Develop and implement a comprehensive water monitoring system for the Indus River basin to monitor rainfall, evaporation, surface flows, canal levels, storage levels/volumes, groundwater levels, water quality, water supply volumes, effluent discharges, including web-based data sharing arrangement.
- Undertake more holistic water balance analysis using water balance models such as WEAP or Source.
- Undertake further analysis on ecological requirements for water, particularly considering the revival of dry rivers such as Ravi, Beas and Sutlej.
- Enhance existing WRMIS capability to analyse and prepare water balance and availability reports for the entire system down to farm outlet level.
- Develop policies and action plans for the management of storm water (urban and rural) and treatment of sewage and industrial effluents.
- The PID/WRD will need to develop policies and action plans to separate sewage from stormwater and stock water ponds. Alternative treatment measures include construction of artificial wetlands for sewage treatment and landscaping around stock ponds to reduce sediment inflows.

[20] Downscaling techniques use the results from coarse global climate models to develop estimates of future climate at finer grid spacings to provide more detailed local information on climate change projections.

5.9 INDICATIVE ACTION PLAN

Table 5-4 provides a summary of action plans and studies required for implementation of a comprehensive water quality monitoring program for the Punjab River basin.

Table 5-14: Indicative Action Plan

Sr. No	Project/Activity	Year 0-1	Year 1-5	Year 5-10	Lead Agency	Involved Agencies
1)	Improving streamflow, rainfall and climatic data Measurement Accuracies.	√	√		PID/WRM	PID
2)	Setting up water accounting framework	√	√		PID/WRM	PID
3)	Undertake more holistic water balance analysis using water balance models such as WEAP or Source.		√	√	PID/WRM	PID
4)	Enhance existing WRMIS capability to analyse and prepare water balance and availability reports for the entire system down to farm outlet level.	√	√		PID/WRM	PID
5)	Develop policies and action plans for the management of storm water (urban and rural) and treatment of sewage and industrial effluents.		√	√	PID/WRM	EPD, WASA /Local governments
6)	The PID/WRD will need to develop policies and action plans to separate sewage from stormwater and stock water ponds. Alternative treatment measures include construction of artificial wetlands for sewage treatment and landscaping around stock ponds to reduce sediment inflows.		√	√	PID/WRM	PID

6 WATER QUALITY IN THE BASIN'S RIVERS

6.1 GENERAL

Surface water from the contiguous part of the upper Indus basin is the main water resource in Punjab province. Surface water sources in the province controlled by 12 link canals, 13 major barrages, two siphons and 24 canal commands. Surface waters in the Punjab River basins (Indus, Chenab, Jhelum, Ravi and Sutlej) and irrigation sub-basins (canal commands) are often under duress and subject to change, due to human activities. These activities often lead to degradation of water quality which can have significant negative impact on public health.

Water pollution in the Indus River system results from three major sources: i) entry of untreated domestic effluents and stormwater from the large urban towns; ii) untreated industrial effluents; and iii) return-flows from agricultural lands through agricultural drainage systems. Most cities and towns dispose their untreated domestic effluents into the river system. Even in areas where treatment facilities are provided, lack of monitoring and rehabilitation of the systems minimizes the effectiveness of the treatment process. None of the treatment plants in Punjab provide 'Zero-Risk Treated Water' and consequently they are not fit to be safely disposed into freshwater bodies. Currently, there are no standards established in Punjab Province for disposal of treated wastewater to freshwater bodies.

6.2 AGENCIES INVOLVED WITH WATER QUALITY MANAGEMENT AND MONITORING

Key Institutions involved in Water quality and pollution control in Punjab Province are:

- **EPD** Environment Protection Department;
- **EPA** Environmental Protection Agency; and
- **LGCD** Local Government and Community Development Department.

6.2.1 OPERATIONAL GAPS

- Water supply delivery is neglected in towns;
- Low staff capacity for planning, design, or monitoring planning;
- Low capacity for review of Environmental Impact Assessments (EIAs), Initial Environmental Examinations (IEEs) and Environmental Management Plans (EMPs);
- Lack of research/analysis facilities and resources within EPD and EPA;
- Low staff capacity for solid waste or storm water management; and
- Budget constraints.

6.2.2 POLICY GAPS

- Outdated water quality standards;
- No policy for surface water quality standards or control; and
- Inadequate implementation of current legislation.

6.3 CURRENT POLLUTION SOURCES (URBAN, AGRICULTURE, INDUSTRY)

Wastewater from Punjab's cities mostly remains untreated and is discharged directly into the nearby water bodies. Surface water supplies are increasingly threatened by wastewater pollution. In 2013, only 50 percent of the effluents were being collected and only 10 percent of those collected were treated.[21] The major water pollutants include heavy metals, faecal coliforms, phosphorous, sodium, nitrogen, and sediments, as well as pathogenic bacteria and viruses. For instance, wastewater from Lahore City remains virtually untreated and is discharged into Ravi River which is a source of drinking water for downstream communities. Discharge of untreated wastewater into canals and rivers is also a major cause of groundwater pollution due to seepage of polluted surface waters into the underlying aquifer, making such groundwater unfit for human consumption. This is a significant concern for neighbouring communities and cities that depend on groundwater as a drinking water source. According to a 2017 study, groundwater in the Indus plain contains five times the arsenic limit established in the WHO guidelines, putting 50 to 60 million people who are dependent on this water resource at risk.[22] Open defecation (OD) is another source of contamination of surface and groundwater, causing many bacterial diseases, diarrhoea, and other health-related issues.[23]

Industrial effluent is another major source of Pakistan's surface and groundwater pollution. The major industries causing water pollution in Punjab include textiles, pharmaceuticals, tanneries, cement factories, electrical equipment, glass and ceramics, pulp and paper board, petroleum refineries, fertilizers, and pesticides. Such industries generally have no mechanisms for treating wastewater before disposal into the municipal sewage network or directly into a nearby drain.

Agriculture is also a major contributor to water pollution in Punjab province. Effects of agriculture on water quality is mainly due to over application of fertilizers, use of highly toxic, sometimes banned agrochemicals, and secondary salinization as well as leaching of salts into groundwater. Runoff from agricultural fields carry phosphorus-based fertilizers, while over application of nitrogen fertilizer and highly toxic pesticides causes leaching of nitrates, nitrites and pesticide residues into groundwater. The presence of agrochemicals in groundwater, especially pesticides, is a major source of human poisoning in Pakistan. It is estimated that in 2015 alone, around 500,000 Pakistanis suffered from agrochemical poisoning, out of which around 10,000 died.

[21] Sánchez-Triana, Ernesto, Santiago Enriquez, Bjorn Larsen, Peter Webster, and Javaid Afzal, with contributions from Elena Strukova Golub, Hammad Raza, Mosuf Ali, and P. S. Rajani. 2015. "Sustainability and Poverty Alleviation: Confronting Environmental Threats in Sindh, Pakistan." Directions in Development. Washington, DC: World Bank

[22] World Bank. (2019). Opportunities for a Clean and Green Pakistan: A Country Environmental Analysis.

[23] Podgorski, J. E., S. A. M. A. S. Eqani, T. Khanam, R. Ullah, H. Shen, and M. Berg. 2017. "Extensive Arsenic Contamination in High-pH Unconfined Aquifers in the Indus Valley." Science Advances 3 (8): e1700935.

6.4 COMPARISON OF INTERNATIONAL AND LOCAL ENVIRONMENTAL LEGISLATIONS

The ADB's SPS 2009 requires application of pollution prevention and control technologies and requires consistency with international good practice and standards. It clearly states that when host country regulations differ from the international standards, the Environmental Agency (EA) and Environmental management Plan (EMP) should use whichever is more stringent.

Hence, the local regulations of Punjab Environmental Quality Standards (PEQS) should be adopted, since they are more stringent than those recommended by THE World Health Organisation (WHO) and/or International Finance Corporation (IFC).

Table 6-1 provides a comparison of drinking water quality requirements of PEQS for biological and physical parameters and the WHO standards. The table indicates that PEQS standards for chemicals, toxic inorganic and organic parameters are similar to WHO, while WHO standards for Pb and Zn are more stringent. Standards for residual chlorine, phenolic compounds and poly aromatic hydrocarbons (as PAHs) are provided either in Punjab or WHO guidelines, but not both.

Table 6-1: Comparison of Drinking Water Standards of Punjab and WHO

PROPERTIES/PARAMETERS	PUNJAB STANDARD	WHO STANDARDS	REMARKS
BIOLOGICAL			
ALL WATER INTENDED FOR DRINKING (E. COLI OR THERMO -TOLERANT COLIFORM BACTERIA)	Must not be detectable in any 100 ml sample	Must not be detectable in any 100 ml sample	Most Asian countries follow WHO standards
TREATED WATER ENTERING THE DISTRIBUTION SYSTEM (E. COLI OR THERMO TOLERANT COLIFORM AND TOTAL COLIFORM BACTERIA)	Must not be detectable in any 100 ml sample	Must not be detectable in any 100 ml sample	Most Asian countries follow WHO standards
TREATED WATER DISTRIBUTION SYSTEM (E. COLI OR THERMO TOLERANT COLIFORM AND TOTAL COLIFORM BACTERIA)	Must not be detectable in any 100 ml sample in case of large supplies, where sufficient samples are examined, must not be present in 95% of the samples taken throughout any 12-month period.	Must not be detectable in any 100 ml sample in case of large supplies, where sufficient samples are examined, must not be present in 95% of the sample taken throughout any 12-month period.	Most Asian countries follow WHO standards
PHYSICAL			
COLOUR	≤15TCU	≤15TCU	
TASTE	Non objectionable/ Acceptable	Non objectionable/ Acceptable	
ODOUR	Non objectionable/ Acceptable	Non objectionable/ Acceptable	
TURBIDITY	<5NTU	<5NTU	
TOTAL HARDNESS AS CACO3	<500mg/l	---	
TDS	<1000	<1000	

PROPERTIES/PARAMETERS	PUNJAB STANDARD	WHO STANDARDS	REMARKS
PH	6.5 – 8.5	6.5 – 8.5	
CHEMICAL			
ESSENTIAL INORGANIC	mg/Litre	mg/Litre	
ALUMINUM (AL) MG/L	≤0.2	≤0.2	
ANTIMONY (SB)	≤0.005 (P)	≤0.02	
ARSENIC (AS)	≤0.05 (P)	≤0.01	Pakistan standards are similar to most other Asian countries
BARIUM (BA)	≤0.7	≤0.7	
BORON (B)	≤0.3	≤0.3	
CADMIUM (CD)	≤0.01	≤0.003	Pakistan standards are similar to most other Asian countries
CHLORIDE (CL-)	<250	<250	
CHROMIUM (CR)	≤0.05	≤0.05	
COPPER (CU)	≤2	≤2	
TOXIC INORGANIC	mg/l	mg/l	
CYANIDE (CN)	≤0.05	≤0.07	Pakistan standards are similar to most other Asian countries
FLUORIDE (F)*	≤1.5	≤1.5	
LEAD (PB)	≤0.05	≤0.01	Pakistan standards are similar to most other Asian countries
MANGANESE (MN)	≤0.5	≤0.5	
MERCURY (HG)	≤0.001	≤0.001	
NICKEL (NI)	≤0.02	≤0.02	
NITRATE (NO3)*	≤50	≤50	
NITRITE (NO2)*	≤3 (P)	≤3	
SELENIUM (SE)	≤0.01 (P)	≤0.01	
RESIDUAL CHLORINE	≤0.2-0.5 at consumer end ≤0.5-1.5 at source		
ZINC (ZN)	≤5.0	≤3	Pakistan standards are similar to most other Asian countries
ORGANIC (PSQCA NO 4639-2004, PAGE NO. 4 TABLE NO. 3 SERIAL NO. 20-58 MAY BE CONSULTED.)			
PESTICIDES, MG/L			
PHENOLIC COMPOUNDS (AS PHENOLS), MG/L		≤0.002	

PROPERTIES/PARAMETERS	PUNJAB STANDARD	WHO STANDARDS	REMARKS
POLY-NUCLEAR AROMATIC HYDROCARBONS (AS PAHS), G/L		≤0.01 (By GC/MS methods)	
ALPHA EMITTERS BQ/L OR PCI	≤0.1	≤0.1	
BETA EMITTERS	1	1	

There are no national standards for surface water quality. However, standards are established for drinking water quality and effluent discharge (to inland waters). The latter standard assumes a dilution factor of 10 to 1 at discharge and at this dilution is taken as an indicator of acceptable surface water quality.

6.5 WATER QUALITY IN RIVERS OF PUNJAB

A number of studies have been conducted on surface water quality of the major rivers (Indus, Jhelum, Chenab, Ravi, and Sutlej) in Punjab. A summary of their findings is presented in the following sections.

6.5.1 RAVI AND SUTLEJ BASINS

6.1.1.1 Directorate of Land Reclamation, PID

A surface water quality monitoring program was initiated in 2017-18 by the Directorate of Land Reclamation, Punjab Irrigation Department Punjab,[24] to tackle the alarming scenario of water quality of rivers, canals and drains that are receiving pollution from different industries and cites. Samples were collected from Ravi and Sutlej rivers, as well as 18 canals & distributaries in the Punjab section of the river basin in the months of January, April, July and October of 2017 & 2018 by the field staff of the Directorate. The samples were analysed at the central Directorate of Land Reclamation (DLR) laboratories.

The water quality of all rivers and canals was within the prescribed limits of Punjab Environmental Quality Standards (PEQS) with respect to pH, TDS and hardness, however, turbidity (NTU) in all samples exceeded the permissible limit (<5) throughout the monitoring period. High turbidity values determine all surface waters as unfit for drinking. Results of water samples collected from the Sutlej, Ravi and Lower Jhelum canals are provided in **Table 6-2**.

[24] Khan, Tashkil-ur-Raza and Sarwar *Zahid. (2018).* Surface Water Quality Monitoring (Drinking) in Punjab 2017-18. Directorate of Land Reclamation Punjab, Irrigation Department Canal Bank Moghalpura Lahore

Table 6-2: Water Samples Collected from Sutlej, Ravi and Lower Jhelum canals

SAMPLING SEASON	REFERENCE VALUES	PARAMETERS						
		pH	Turbidity (NTU)	TDS (mg/L)	Hardness (mg/L)	Cu (mg/L)	Zn (mg/L)	Ni (mg/L)
	WHO	6.5-8.5	< 5	< 1000	-	2	3	0.02
	NEQS	6.5-8.6	< 5	< 1000	< 500	2	5	≤ 0.02
2017	Jan	7.76	71	768	200	0.06	0.03	0.01
	Apr	7.3	344	172.8	95	0	0	0.01
	Jul	7.4	938	192	115	0.06	0.05	0.01
	Oct	7.08	45	217.6	115	0.03	0.08	0.01
2018	Jan	Canal Closed						
	Apr	7.32	11.5	249.6	100	0.03	0.03	0.01
	Jul	7.2	878	198.4	95	0.06	0.03	0.01
	Oct	Canal Closed						

The samples collected were analysed for physical, chemical, microbiological, trace metals, pesticides and persistent organic pollutants (POPs). The physical and chemical properties of the water at the sampling locations were mostly found to be within the permissible limits during high flow with the exception of turbidity that was particularly high in August and September due to flood. However, during the low-flow season (October onwards), there were significant increases in pollutant concentrations and oxygen demand. The Manga Mandi and Chichawatni sampling sites at Ravi failed to meet water quality standards for effluent waste streams, with high Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). In most cases the dissolved oxygen (DO) level approached zero, the level at which no aquatic life can exist. Contamination was further increased downstream due to reduced river flow.

Physical and chemical contamination were generally higher in the Ravi River compared to Sutlej River. All collected samples in Ravi River were found to be contaminated with POPs during high-flow season. High concentrations of POPs such as BHCs, Hexachlorobenzene (HCB) Heptachlor, DDT and its degradants were found at Ravi Syphon, the first monitoring point upstream, where the river enters Pakistan. Chlorpyrifos methyl was detected at one site (upstream of Qadirabab-Baloki confluence). However, concentrations of POPs decreased downstream. Similarly, very high concentrations of POPs, especially DDT degradants and Chlorpyrifos methyl, were detected in Sultej River, where the river enters Pakistan. Most of the shallow groundwater sources near the drains, carrying both urban and industrial waste as well as agricultural contaminants, were found to be contaminated microbiologically as well as with POPs and heavy metals. The shallow groundwater source of Khudpur village near Hadiara drain and the Rangwala shallow source near Kasur Nullah were found to be highly contaminated with degradants of DDT and heavy metals. The groundwater sources were also found to be contaminated, apparently due to recharge from river and drains. The pollution levels in all drains were much higher than Pakistan National Environmental Quality Standards (PNEQS) permissible limits. The discharge of untreated wastewater into these rivers through drains and inadequate dilution flow has converted them into sewage carriers with a highly significant impact on the downstream users and the ecosystem. This assessment can be considered as a warning to stakeholders and should be used as motivation for initiation of proper actions to improve water quality and the health of the Punjab rivers. It is recommended to use these findings as a baseline in any future water quality monitoring study.

6.1.1.2 Pollution Sources in Ravi and Sutlej Rivers

The Sutlej enters Pakistan in Kasur district. The Bulloki-Sulemanki Link Canal and Pakpattan Islam Link Canal, join the river to augment its flow. Both link canals carry industrial and municipal wastewater to the river from nearby urban and industrial areas, including the Kasur and Pakpattan districts. The Pandoki drain in the Kasur district, is the main source of pollution in Sutlej River (Pak EPA, 2008). Municipal wastewater from Bahawalnagar, Okara, Bahawalpur and Vehari districts also end up in the Sutlej River. These districts are mostly agricultural, with high use of fertilizers and pesticides.

The Ravi is the smallest of five tributaries of the Indus River. It is used as a dumping channel for municipal and industrial wastewater. In total, 12 drains release industrial and municipal wastes of the provincial capital into this river. More than 450 industrial units pump untreated toxic wastewater into the drain at different entry points. These drains dump some 15 =m3/s of wastewater everyday into the river (JICA, 2010). In addition to the provincial capital, other drains from Faisalabad, Sahiwal and Toba Tek Singh districts also release wastewater into the Ravi (Munir et al., 2005). Near Lahore, the wastewater carrying drains add more than 594 tons per day of organic load into Ravi River during the low-flow season (Pak EPA, 2010).

6.1.1.3 Ravi River Eco-Revitalization Master Plan[25]

The Ravi River is currently in a highly deteriorated state. Ecological revitalization of the river ecosystem can only be achieved if the local habitants as well as public and private organizations play their part in improving the river water quality. ADB (2020) has prepared the Ravi River Eco-Revitalization Master Plan as a detailed road map for achieving the collective vision. According to their findings, the Ravi River water quality is 400% below the minimum requirement to sustain aquatic life. The DO levels in the river drops to 1.5 mg/l in winter whereas US EPA criteria sets 6.5 mg/L as the minimum level to sustain aquatic life. River sediments are highly contaminated and considered a secondary source of pollution. Highly toxic pesticides and other persistent organic pollutants are present in several parts of the river despite being banned for almost 20 years.

Levels of COD, BOD, and E. coli in the Ravi significantly exceed the allowable wastewater discharge levels, approved in Pakistan. COD levels range between 63 and 135 mg/L and BOD levels range between 27 and 71 mg/l. The maximum E. coli levels around Lahore were found to be 3,000 CFU/100 ml (that is 30 times higher than the US standards). 40 % of respondents of Punjab, reported E. coli infection, 19 % tested positive for deadly waterborne pathogens such as typhoid, diarrhoea, and hepatitis, while 3% had potentially fatal water-vector diseases such as malaria and dengue fever. In addition, 17 % reported to being afflicted by water-washed (e.g., skin) diseases. The presence of highly toxic pesticides can potentially cause significant diseases and long-term impact on the health and lifespan of local inhabitants that use river water for human and livestock consumption.

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[25] Asian Development Bank (2020). Pakistan's River Ravi Eco-Revitalization Master Plan: A Road Map to Rescue and Revitalize the River Ravi and Its Tributaries. https://www.adb.org/sites/default/files/publication/663441/pakistan-river-ravi-eco-revitalization-master-plan.pdf

6.5.2 WATER QUALITY IN CHENAB RIVER BASIN

Water quality of the Chenab River was evaluated for its suitability for drinking, livestock and irrigation purposes[26]. Water samples were collected from nine stations through a stretch of the river within Punjab province, as shown in **Figure 6-1**. Sampling was done in two distinct phases, i.e. March–April representing pre-monsoon and September monsoon season over a period of three years (2012–2014).

Chenab River traverses some areas with brackish groundwater. Many people use river water for drinking and livestock. The suitability of Chenab River water for drinking purposes was evaluated using WHO Guidelines (2011) and National Drinking Water Quality Standards (NDWQS), presented in Table 6.3. Physical and chemical parameters of water quality were within allowable limits, with the exception of a few heavy metals.

Cadmium levels in Chenab River water exceeded the WHO limit value of 0.003 mg/l in 55% of the samples. Cadmium is extremely toxic to human health and may lead to renal failure. Similarly, chromium levels in 24% of water samples exceeded the WHO and NDWQS limit of 0.05 mg/l. The maximum concentration of lead was 0.98 mg/l, which significantly exceeds WHO standard limit of 0.01 mg/l. Similarly, Fe levels of a number of samples were found to be high in surface water when compared to WHO limits.

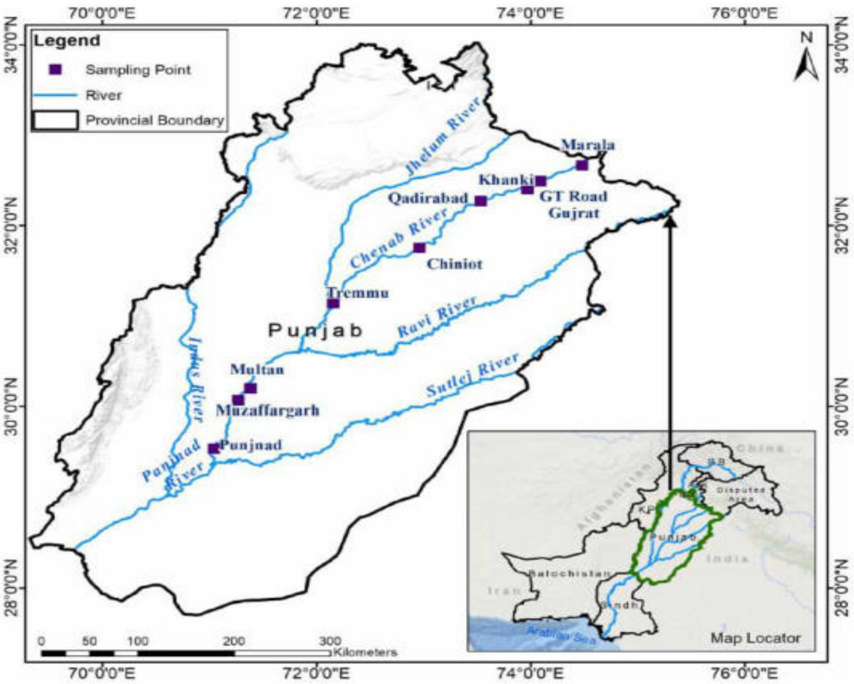

Figure 6-1: Observation Points of Chenab River

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[26] Kausar, F., Qadir, A., Ahmad, S. R., Baqar, M., & Sardar, F. (2020). Evaluation of River Chenab water quality with respect to its users, using different classification schemes. *Water Supply*, *20*(8), 2971-2987.

The water quality index rating revealed that the water of the Chenab River is less than the marginal category for drinking and livestock, due to the presence of heavy metal pollution above safe limits. Irrigation suitability parameters, such as the sodium absorption ratio (SAR), residual sodium carbonate (RSC), Na (%), Kelley's ratio (KR), magnesium hazard (MH) and the permeability index (PI) were also measured, and most samples were found to be within the safe limits as shown in **Table 6-3**.

Table 6-3: Water Quality Index of Chenab River

Parameter	WHO	NDWQS	Minimum	Maximum	Std. Dev.
pH	6.5-8.5	6.5-8.6	7.02	8.64	0.34
TDS (mg/L)	1,000	1,000	110	550	95
BOD (mg/L)	6		1.6	24	3.58
Cl (mg/L)	250	250	10	220	55
SO4 (mg/L)	500		18	240	43.9
F (mg/L)	1.5	1.5	0.15	1.02	0.24
Mg (mg/L)	50		0	32	7.09
Na (mg/L)	200		250	145	38.24
Ca (mg/L)	75		12	65	10.21
K (mg/L)	10		1.5	8	4.27
Cu (mg/L)	2	2	0.02	0.36	0.06
Cr (mg/L)	< 0.05	0.05	0.001	0.38	0.07
Cd (mg/L)	0.003	0.003	0	0.74	0.12
Fe (mg/L)	0.3		0.08	4.12	0.97
Pb (mg/L)	0.01	0.05	0.0022	0.98	0.15

Temporal variations in the water quality index of the Chenab River during the study are presented in **Figure 6-2**. Spatio-temporal distribution of the pollutants highlighted minimal pollution until the Qadirabad, Water quality gradually worsens downstream of Qadirabad. Water quality deterioration is believed to be from both point and nonpoint sources, and also due to diversion of water through canals. In order to manage the water quality of the Chenab River it is necessary to enforce current environmental laws, especially for point source pollution.

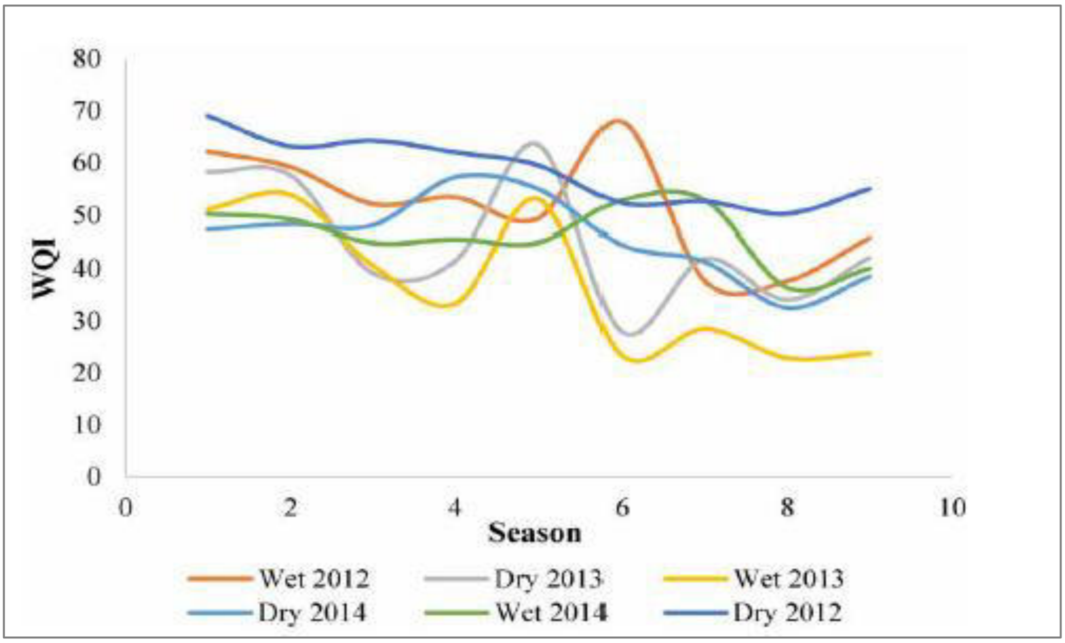

Figure 6-2: Temporal variation in the water quality index of Chenab River during study

Hussain at. al. (2018) assessed the seasonal impact of industrial and sewage waste disposal in water quality of the Chenab River, upstream of Trimmu Head[27]. Considering the significance of the river, Chakbandi main (CBM) drain wastewater was analysed during the summer and the winter seasons from pre-determined locations. Water quality parameters were found to be higher than the maximum permissible limits prescribed by WHO for freshwater bodies. The level of these Physio-chemical variables (level of TDS, TSS, and salinity) were higher in the winter, due to the lower amount of water released from domestic sewage.

In summer, Mn, Pb, and Sn levels were very high in sediments in the drain and Chenab River. In winter, almost all metals were found at higher concentration levels than during the summer season. Pb, Mn, Cr, and Cu concentration levels were 33% higher in winter, indicating higher metal load. At three sampling sites during the winter season, the level of these metal concentrations was found to be as high as double the values in summer, potentially having significant negative impact on aquatic fauna and flora in the riverine environment.

[27] Hussain, B., Sultana, T., Sultana, S., Al-Mulhim, N., & Mahboob, S. (2018). Pollutant fate and spatio-temporal variation and degree of sedimentation of industrial-and municipal wastes in Chakbandi drain and River Chenab. *Saudi journal of biological sciences*, *25*(7), 1326-1331.

6.5.3 WATER QUALITY IN JHELUM RIVER BASIN

Yasara at. al. (2019) sampled surface water from three sampling locations in Mangla Dam, Rasul Barrage, and Trimmu Barrage along the Jhelum River and analysed the samples for Pb, Zn, Mn, and Cr[28]. Concentrations of Pb, Zn, Mn, and Cr were found highest in surface water samples collected from Trimmu Barrage and lowest in Mangla Dam. These results showed that the downstream sampling site of Jhelum River had higher concentrations of heavy metals than the upstream sampling sites. The reason is believed to be the discharge of many drainage canals, emptying municipal waste to the river as well as irrigation drainage canals along its pathway, causing higher pollution loads in downstream areas. The report concluded, that with the exception of lead levels, all other physicochemical and inorganic levels in the samples are within the permissible limits of PEQS and WHO standards for drinking water (**Table 6-4**).

Table 6-4: Comparison of mean values of physicochemical parameter of Jehlum water samples with NEQS

Parameters	Sampling Sites			
	Mangala Dam	Rasul Barrage	Trimmu Barrage	NEQS
pH	7.63	8.0	6.86	6–9
TDS (mg/L)	143.67	109.83	381.67	1,000
TSS (mg/L)	20.67	23.0	46.3	150
EC (µS/cm)	223.3	171.67	600.0	–
DO (mg/l)	7.167	7.56	6.07	–
Ca+2 (mg/l)	31.3	14.67	44.67	–
Mg+2 (mg/l)	6.4	4.0	9.2	–
Na+ (mg/l)	3.07	15.3	66.3	–
K+ (mg/l)	0.39	0.91	3.25	–
Chloride (mg/l)	5.3	3.57	79.27	–
HCO3 (mg/l)	124	42.7	156.57	–

[28] Yasara, A., Farooqa, T., Tabindaa, A. B., Sohailb, M. T., Mahfooza, Y., & Malika, A(2019). Macrophytes as potential indicator of heavy metals in river water. Desalination and Water Treatment. 142 (2019) 272–278

In another study by Iqbal at. al. (2017), a total of 18 samples were taken from six sampling sites on Rasul Barrage in the Jhelum River[29]. Water samples were collected at two locations from the old headworks (right and left banks), two from downstream (right and left banks), and two from the upstream pond area on April 10, 2013 to investigate water quality and fish diversity at Rasul Barrage. Water samples at six sampling sites were assessed for pollution levels and fish fauna of the Barrage. Physicochemical parameters such as turbidity, BOD, and COD were above the permissible limits of fresh water set by the U.S. EPA but met the criteria of NEQS. Temperature, pH, EC, TDS, TSS, Na, and Cl were found to be below the permissible limits of NEQS, but the TSS level was above EPA standards. However, the concentrations of metals such as iron (2.62-3.98 mg/l), chromium (0.03-0.59 mg/l-1), and nickel (0.49-1.71 mg/l) were above the permissible limits for drinking and irrigation waters. Due to high concentrations of BOD, COD, and metals in all samples, they concluded that surface water quality is poor for fish diversity and drinking water within the barrage. They recommended urgent measures are required to prevent such contamination and stressed, the need for regular monitoring of water quality in the study area.

Total hardness was found to be within standard limits of the Pakistani EPA (500 mg/l), whereas the average Na concentration (32 mg/l) exceeded the drinking water standard limits established by the U.S. EPA (26 mg/l). The study indicated that river water was suitable for irrigation, according to FAO guidelines (<69 mg/l). In addition, concentration of some anions such as carbonates, bicarbonates, and chlorides ranged between 3 to 9 mg/l, 6 to 14 mg/l, and 33 to 49 mg/l, respectively, being within permissible limits set by the U.S. EPA, the Pakistani EPA, WHO, and NEQS for drinking water, and FAO guidelines for irrigation water.

Concentration of heavy metals (Cr, Cu, Ni, and Fe) were found to be higher than permissible limits. Cr and Ni were recorded in the range 0.03 to 0.59 mg/l and 0.49 to 1.71 mg/l, respectively, exceeding the standard limits set by the U.S. EPA, the Pakistani EPA, and WHO. However, the Cr concentration was less than the limit established by NEQS for drinking water. Furthermore, according to the FAO guidelines, the levels of these metals were not suitable for irrigation purposes. The high concentration of Cr is either due to anthropogenic activities such as release of effluents from dyeing and tanning industries or natural occurrence due to weathering of parent rocks. The high concentration of Cr in Rasul Barrage water makes it unsuitable for drinking and/or irrigation.

The average concentration of Fe (3.52 mg/l) exceeded the U.S. EPA standard limits for drinking water for human and livestock, however, it is suitable for irrigation. The study suggested that the high concentration of Fe is either from weathering of parent rock or release of industrial effluents and municipal sewage from nearby cities.

The study found copper content ranging from 0.33 to 0.69 mg/l, with an average of 0.52 mg/l, exceeding the permissible limits of Pakistani EPA and WHO standard values for drinking water, and FAO guidelines (0.20 mg/l) for irrigation. The study recommended that long-term irrigation from Rasul Barrage water should be avoided. They stated that continuous irrigation of polluted water in terms of heavy metals may increase metals concentration in plants, affecting activities of soil microorganisms in soils as well as impacting human health (**Table 6-5**).

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[29] Iqbal, H. H., Shahid, N., Qadir, A., Ahmad, S. R., Sarwar, S., Ashraf, M. R., & Masood, N. (2017). Hydrological and Ichthyological Impact Assessment of Rasul Barrage, River Jhelum, Pakistan. *Polish Journal of Environmental Studies*, *26*(1).

Table 6-5: Heavy metals concentrations in Rasul Barrage water in the Jhelum River

Location	Iron (mg/l)	Chromium (mg/l)	Copper (mg/l)	Nickel (mg/l)
S1(upstream pond area-Right)	3.98	0.59	0.69	1.71
S2 (upstream pond area-Left)	3.90	0.49	0.51	1.59
S3 (old headworks-Right)	2.62	0.03	0.33	0.49
S4 (old headworks-Left)	2.84	0.04	0.42	0.01
S5 (Downstream-Right)	3.86	0.38	0.62	1.64
S6 (Downstream-Left)	3.93	0.48	0.58	1.03

6.5.4 WATER QUALITY IN INDUS RIVER

Ghanim et al (2016)[30] conducted a water quality assessment study at three sites: Kundian (upstream), Chashma (middle stream) and Kalabagh (downstream) along the stretch of the Indus River in Mianwali, over a reach of 80 km. Water samples were taken from all sampling stations. Laboratory results indicated that Cd, Ni, Zn and Co concentrations were all within the maximum permissible limits of FEPA (2003). The range for other parameters were TDS 158 ± 0.57 to 312 ± 0.57 mg/ml, EC 1.95 ± 0.00 to 3.89 ± 0.03 mS/cm, DO 5.1 ± 0.05 to 8.2 ± 0.057 mg/l and pH 7.06 ± 0.03 to 9.6 ± 0.57.

Javed et.al. (2020) collected water samples from three major stations along the Indus River in Pakistan, i.e., Kalabagh, Chashma Barrage and Taunsa Barrage[13]. The study indicated that Zn concentration was highest at the Kalabagh sampling location. Metal concentration was highest at Kalabagh and lowest at the Chashma barrage. The order of metals concentration in in water samples collected from Indus River fishing sites were Zn > Ni > Cu > Cr > Co (**Figure 6-3**).

[30] Al-Ghanim, K. A., Mahboob, S., Seemab, S., Sultana, S., Sultana, T., Al-Misned, F., & Ahmed, Z. (2016). Monitoring of trace metals in tissues of Wallago attu (lanchi) from the Indus River as an indicator of environmental pollution. *Saudi journal of biological sciences*, *23*(1), 72-78.

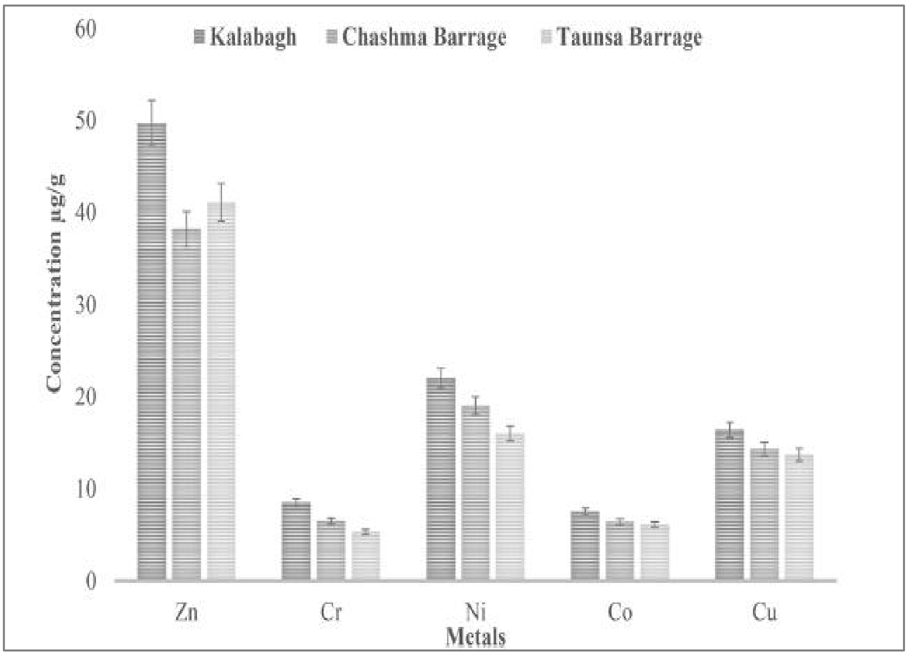

Figure 6-3: Concentration of Metals in Water samples along Indus River

a) Taunsa barrage along Indus River

In another study, water and fish samples were collected from a fish farm hatchery in Taunsa barrage along the Indus River in 2016[31]. Maximum values of all the physio-chemical parameters were determined in water samples collected from the river. The highest values of Zn, Cu and Ni were found in water samples from the Indus River and the lowest values were found in water samples collected at the fish farm (Table 6.6). Among metals, the concentration of Zn was highest in all water samples followed by Ni and Cu.

6.5.5 LOWER JHELUM CANAL[32]

The Lower Jhelum canal (LJC) receives Jhelum River water at Rasul head Barrage and irrigates the area of Chajj Doab in Sargodha, Mandi Baha-ud-din, and Jhang districts. Currently, the discharge rate of LJC is 156 m3/s during Kharif and 120 m3/s during Rabi. The gross command area (GCA) of LJC is 660,406 ha. Bashir et.al. (2020) conducted a study to assess the water quality of LJC and its suitability for irrigation and livestock drinking. They tried to develop a methodology

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[31] Bano, Z., Abdullah, S., Ahmad, W., Zia, M. A., & Hassan, W. (2017). Assessment of heavy metals and antioxidant enzyme in different organs of fish from farm, hatchery and Indus river of Pakistan. *Pakistan Journal of Zoology*, *49*(6).

[32] Bashir, N., Saeed, R., Afzaal, M., Ahmad, A., Muhammad, N., Iqbal, J., & Hameed, S. (2020). Water quality assessment of lower Jhelum canal in Pakistan by using geographic information system (GIS). *Groundwater for Sustainable Development*, *10*, 100357.

by integrating a water quality index with GIS for interpretation of LJC water quality. They claimed, based on the data collected during the rainy season, that the majority of the water (55%) is of excellent quality, (5%) of good quality, (30%) of inferior quality, (5%) of poor quality and (5%) unfit for irrigation and requiring “special treatment”. The study stated that E. coli, the biological parameter, is elevated at nearly all sampling points due to faecal contamination. Additionally, they stated that all other parameters (turbidity, carbonate, bicarbonate, calcium, magnesium, pH, EC, TDS, TSS, Ca, Mg K, Na, Fe, Zn, Cu, sulphate) were within permissible WHO and NEQS limits.

Table 6-6: Different parameters of water analysis from three water bodies (Mean ± SD)

PARAMETERS		SAMPLING SITES		
		Fish Farm	Hatchery	Indus River
PHYSICO-CHEMICAL PARAMETERS	Temperature (^{0}C)	29.86 ± 0.49b	29.93 ± 0.55b	31.833 ± 0.83a
	pH	7.9 ± 0.152b	7.73 ± 0.21b	8.03 ± 0.12a
	Dissolved Oxygen	7.66 ± 0.12a	6.7 ± 0.17b	5.63 ± 0.152c
	Electrical Conductivity (mS cm^{-1})	2.16 ± 0.02c	2.59 ± 0.06b	2.66 ± 0.10a
	Carbonates (mg L^{-1})	26.0 ± 0.81c	67.66 ± 0.58b	68.33 ± 2.082a
	Bicarbonates (mg L^{-1})	119.4 ± 0.62c	191.33 ± 1.52b	300.86 ± 4.25a
	Total alkalinity (mg L^{-1})	145.23 ± 0.42c	258.9 ± 4.04b	369.2 ± 6.298a
	Total Hardness (mg L^{-1})	112.0 ± 5c	196.33 ± 7.64b	238.33 ± 7.64a
METALS	Zn (mg L^{-1})	0.05 ± 0.02b	0.06 ± 0.04b	2.11 ± 0.05a
	Cu (mg L^{-1})	0.007 ± 0.01b	0.008 ± 0.02b	1.02 ± 0.02a
	Ni (mg L^{-1})	0.01 ± 0.005c	0.05 ± 0.07b	1.23 ± 0.22a

6.5.6 D.G. KHAN CANAL

A study was carried out to investigate the seasonal variations in limnological characteristics and planktonic diversity of D.G. Khan Canal water which is affected by sewage at D.G.Khan[12]. Water samples were collected on a monthly basis and analysed for water temperature, light penetration, turbidity, boiling point, surface tension, viscosity, density, specific gravity, pH, EC, dissolved O_2, Free CO_2, alkalinity, carbonates, bicarbonates, sodium, chlorides, acidity, hardness, total solid, total volatile solids, total dissolved solids and total volatile dissolved solids. An attempt was also made to assess the biological parameters including the frequency of occurrence, relative abundance and diversity index of plankton life.

6.5.7 WATER QUALITY OF CHASHMA RIGHT BANK CANAL NEAR TAUNSA TOWN

The Chashma Right Bank Canal commences at the Chashma Barrage and cultivates the area of Tehsil Taunsa Sharif, District DG Khan. The canal was closed in January and July of 2017-18. It was sampled near Taunsa Town and overall water quality for drinking was found to be unfit due to high turbidity above permissible limits of PEQS (**Table 6-7**). Parameters for TDS, hardness, pH, Cu (II), Ni (II) and Zn (II) were in the fit range.

Table 6-7: Analysis of Chashma Right Bank Canal near Taunsa Town

Sampling Season	Reference Values	Parameters						
		pH	Turbidity (NTU)	TDS (mg/L)	Hardness (mg/L)	Cu (mg/L)	Zn (mg/L)	Ni (mg/L)
	WHO	6.5-8.5	< 5	< 1000	-	2	3	0.02
	NEQS	6.5-8.5	< 5	< 1000	< 500	2	5	≤ 0.02
2017	Jan	Canal Closed						
	Apr	7.69	198	192	120	0	0.01	0.01
	Jul	Canal Closed						
	Oct	7.8	19	211.2	110	0.09	0.01	0.01
2018	Jan	Canal Closed						
	Apr	7.3	254	256	130	0.06	0.07	0.01
	Jul	Canal Closed						
	Oct	7.6	64	268.8	145	0.06	0.04	0.01

6.6 SURFACE WATER QUALITY STANDARDS, MONITORING NETWORKS, DATA MANAGEMENT AND DISSEMINATION

There is very little separation of municipal wastewater from industrial effluents in Pakistan. Both flow directly and merge into open drains flowing into the nearby natural water bodies. There is no established water quality monitoring programme for assessing water quality of surface waters in Punjab province. In fact, no surface water quality standards have been established in Pakistan for use throughout the country.

Environmental monitoring of surface water quality in Punjab is fairly random and available data is very scattered. There are no organized and long-term environmental monitoring programs to determine the potential environmental impact of water quality on flora, fauna and local inhabitants, downstream of discharge points. Even if some institutions are studying water quality, there is not any information available on what kind of environmental monitoring programs exist in Punjab province. Our observation and literature review indicate that most of the datasets, if present, are not publicly available. The environmental monitoring and reporting process is not functional due to the following:

- No comprehensive and coherent monitoring plans have been developed to assess all relevant aspects of the environment (air, noise, water, wastewater, etc.), industrial sectors, geographic regions in order to assess and enforce compliance with notified EQS and conditions set out in EIA and EMP.
- Monitoring data, if collected, is not used for data analysis to identify synergies and develop correlations to reach meaningful and logical conclusions.
- The Punjab Environment Protection department does not monitor biodiversity (endangered species and habitats, migratory birds, forests, fish and other flora and fauna) within the riverine environment. They also do not consider the effects of climate change, use of Persistent Organic Pollutants (POPs), and hazardous waste. Water quality data has made a very limited contribution in protecting and conserving environmentally sensitive areas of Punjab, such as RAMSAR sites, or other significant wetlands that can have significant impact on flood attenuation and are also

spawning areas for aquatic fauna.

- PID has limited collaboration with other government departments to jointly monitor and utilize environmental data from other sources (forest, groundwater table, weather data or information related to the ecology of national parks, riverine and protected areas).
- EPD should be the custodian of all environmental data; irrespective of the organization who does the actual water quality or environmental monitoring. However, this logical role has not yet been established, although EPA has the obligation to prepare State of the Environment reports (SOER's).
- Currently, the EPD inspection process being employed for compliance checking and enforcement, is random and incoherent, and mainly undertaken when a complaint has been received.
- The involvement of private sector environmental consultants and laboratories and quality assurance/quality control (QA/QC) processes to determine their competencies, has not been developed and organized.
- The quality of available data is questionable, since no Standard Operating Procedures (SOPs) have been developed for sampling of water quality parameters. Also sufficient training for water sampling has not been undertaken.
- Scientific procedures are not followed when collecting samples, to ensure samples are representative. Statistical analysis cannot be performed on the basis of a single reading.
- There is no data management strategy in place to ensure that relevant data is assimilated in a coordinated manner, on a unified platform, that can later be available in a useable form to potential users.
- Modern technologies such as: modelling; GIS techniques; or on-line measurement technologies are not sufficiently used.

Therefore, it is necessary to establish a comprehensive Environmental Monitoring Framework to:

- serve the operative needs of Environmental permitting, EIAs, IEEs, EMPs and Complaint handlings;
- along with assessment of environmental trends through monitoring of indicators defined in Sustainable Development Goals (SDGs); and
- for provincial purposes through setting of core environmental indicators for the province.

6.7 OPPORTUNITIES AND MEASURES TO IMPROVE WATER QUALITY. INCLUDING ANY INFRASTRUCTURE PLANS AND INDICATIVE INVESTMENT NEEDS

Enhancing the water quality in Punjab Rivers, canals and nullahs is essential for successful revitalization of the river ecosystems. Water quality can be improved by adopting following plans and measures:

- Proposed Surface Water Quality Monitoring Plan
- Wastewater Treatment Plants, and
- Management Measures.

6.7.1 PROPOSED SURFACE WATER QUALITY MONITORING PLAN

The **best model** for a single system of water management is management by the river basin - the natural geographical and hydrological unit - instead of adopting administrative or political boundaries. For each river basin district - some of which will traverse provisional or even national frontiers – a "river basin management plan with rivers as the unifying unit" will need to be established and updated periodically, e.g. every five years.

An attempt has been made to develop a monitoring plan for the five river basins of Punjab i.e. Indus, Sutlej, Ravi, Jhelum and Chenab, including main canals, link canals, etc. These rivers originate from mountain ecosystems and deliver a major part of their water resource to the plain areas of the province. All of these rivers are tributaries of the Indus River. The main steps for developing a surface water quality plan should be the following.

I. Preliminary Surveys

Walkthrough surveys of the Indus, Chenab, Ravi, Jhelum and Sutlej rivers, all main canals and link canals would be done. The names of all point and non-point sources of water pollution will be noted and their confluence point with River/canal will be marked using a GPS (Global Positioning System, Garmin) for future sampling visits. Preliminary surveys will also help to refine the logistical aspects of monitoring. For example, access to sampling stations will be tested and can indicate whether refinements are necessary to the site selection. Sampling sites could also be found to be impractical for a variety of reasons, such as transport difficulties. Similarly, operational approaches may be tested during the pilot project and aspects such as the means of transport, on-site testing techniques or sample preservation and transport methods, can be evaluated. A map of each district should be prepared as presented in the sample in map (**Figure 6-4**).

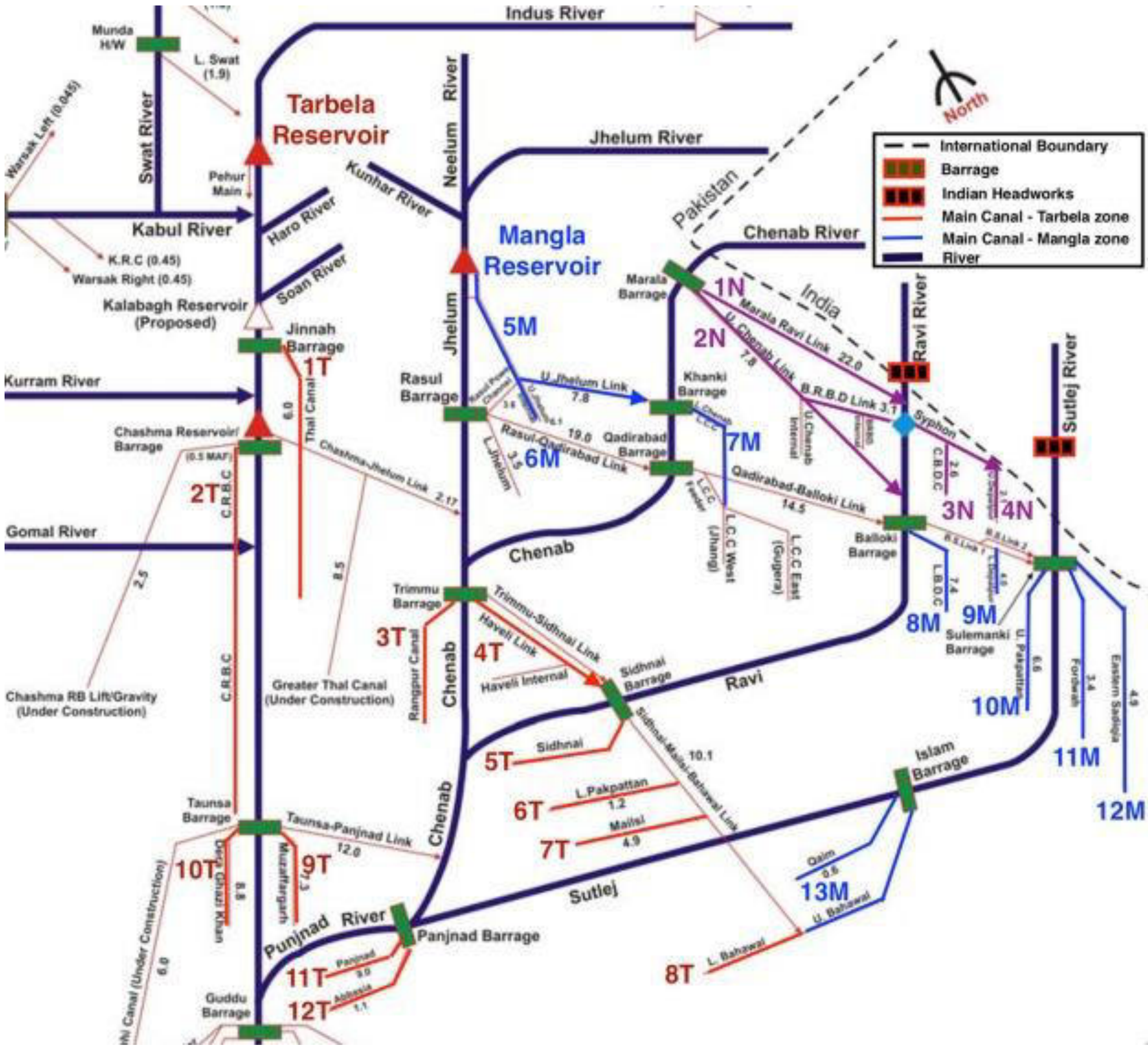

Figure 6-4: General Map showing Rivers, Main Canals and Link Canals of Punjab

II. Mapping of sampling locations

The preliminary survey should be followed up with production of GIS maps of each river basin/sub-basin, using GPS coordinates noted during field visit. All river/main canal/link canals with each point/non-point source will be labelled and marked on GIS Maps.

III. Sampling Design.

A basic river monitoring network will comprise sampling sites on major tributaries at their confluence and at major discharges locations of sewage or industrial effluents.

Samples for surface water quality analysis will be collected from each site as under:

- From each of drains/ sources of pollution just before joining river/ canal,
- After joining River/ canal,
- Upstream of joining river/canal.

Sampling will be done in low flow and high flow seasons. A detailed weather forecast for the study area will be reviewed to avoid rainy days or unusual flows. All samples are to be taken during sunny days and when the stream flow is at normal levels.

IV. Establishing Sampling Point on Major Rivers / Canals

To verify that there is complete mixing (of drain/point source of pollution & river/canal water) at a sampling station, it is necessary to take several samples at points across the width and depth of the river/canal and to analyse them. If the results do not vary significantly, a sampling station (or sampling point) can be established at mid-stream or some other convenient point. If the results are significantly different it will be necessary to obtain a composite sample by combining samples taken at several points in the cross-section of the stream. Generally, the more points that are sampled, the more representative the composite sample will be. Sampling at three to five points is usually sufficient, whilst fewer points are needed for narrow and shallow streams.

A bridge is an excellent location for a sampling station (provided that it is located at a sampling site on the river). It is easily accessible and clearly identifiable, and the station can be precisely described. Usually, a sample taken from a bridge at mid-stream or in mid-channel, in a well-mixed river, will adequately represent all of the water in the river.

A sampling site is the general area of a water body from which samples are to be taken and is sometimes called a "macro-location". The exact place at which the sample is taken is commonly referred to as a sampling station or, sometimes, a "micro-location".

V. Responsibilities of Organizations regarding surface water quality monitoring:

The monitoring of surface waters should serve objectives of river basin management, which includes minimisation of downstream impacts, as well as management of flows such as for dilution and flushing. Monitoring of surface waters is based on long-term monitoring of the ambient environment by government (Environment Protection Department, Irrigation Department and WASA) and self-monitoring by polluters for point sources, such as industry and city wastewater disposal points (complemented with government check-ups and verification). The latter will be based on obligations given to industries and municipalities in permitting conditions. Industries in certain areas can be given an obligation to form "Water Protection Associations", which do the monitoring on behalf of the industries. Water Protection Associations must have ISO 17025 certified laboratories and certified personnel for sample taking and field measurements. Industries will pay the costs of the monitoring to the associations as membership fees. Pollution from irrigated agriculture, being a non-point source should be monitored by the responsible government agencies upstream and downstream of irrigation blocks, both spatially and temporally. PID should collect samples from rivers, canals and drains for analysis.

Punjab EPD should have the lead pollution regulatory role and should be responsible for monitoring of background values and general water quality of all waterways; checking through periodic sampling, based on statistical analysis, auditing the discharges of waste waters and gradients outside industries and verifying results of private environmental firms; licencing of pollution discharge to rivers including from irrigation drains, polluters including and Water Protection Associations of polluters (industries and municipalities).

Industries, through their Water Protection Associations or separate private environmental monitoring firms, are responsible for monitoring and reporting to EPD the concentrations and loads of pollutants:

a) At the discharge point (and parts of processes, if stipulated in permits); and

b) at several stations (5-10) downstream of the discharge point to indicate changing concentrations downstream of the discharge location.

The parameters necessary for the surface water monitoring sampling plan should be developed based on an annual monitoring program in each district and ensure that multiple tasks are performed during each field visit to optimize the sampling program, reduce cost and maximize program efficiency.

PID has responsibility for controlling discharge into canals to protect water quality so that it is suitable for irrigation and use by downstream communities. A WRD would ensure PID zones compliance with this requirement through operating agreements. WRD would also coordinate with EPD the monitoring of ambient water quality in rivers and at canal offtakes and the role of the irrigation zones in undertaking the monitoring. WRD would also include flow needs such as for water quality management in its annual river basin based, water allocation and river operations plans and assess the impacts of pollution loads, existing and from proposed projects, on river and canal water quality.

6.7.2 WASTEWATER TREATMENT

The plan promotes localized, municipal wastewater treatment linked with strategically placed, centralized, end-of-pipe wastewater treatment facilities serving the major urban areas. Wastewater treatment works best with local control and accountability, while being integrated with the basin-wide system. This reflects the inherent interconnectivity, protecting the water quality upstream, downstream, and throughout the nullahs. Healthy functioning river ecosystems can process some pollutants through natural processes. If the ecological condition of the Punjab rivers, canals and their nullahs is improved, as well as the quality of the water discharged into them, the river and nullahs themselves will help clean effluents.

There are three main methodologies that are internationally accepted for treatment of industrially produced wastewater and are recommended for the treatment of industrial and municipal wastes in Punjab province:

- In-house treatment of industrial effluents;
- Treatment plants at the cluster of the industries; and
- Joint treatment plant for the entire drain/region.

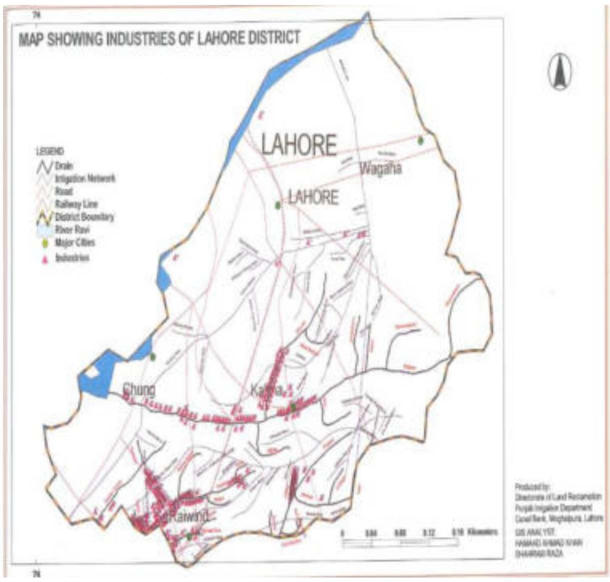

Figure 6-5 Industrial setup of Lahore

The most feasible option for wastewater treatment in Punjab province is believed to be the use of in-house treatment of industrial effluents due to the wide distribution of industries within the province. The second and third options are useful if the industries were in clusters such as industrial parks. There are very few industries that are located in close proximity of

each other along the drains or rivers to allow the installation of cluster-based treatment plants. If a cluster-based plant is feasible, the running cost of- the treatment plant should be borne by each industry on the basis of quality and quantity of the produced effluent by each industry. The cluster-based treatment plant should be installed outside the industrial area before the discharge point to the drain.

WASAs and TMAs should install wastewater treatment plants to treat urban produced sewage in accordance with prescribed standards provided by Punjab EPA.

6.7.3 MANAGEMENT OPTIONS

For sustainability of a water quality monitoring and management program, a mechanism of implementation of legal powers and jurisdictions of various institutions should be developed. Water samples should be collected for baseline water quality data collection at each identified location for point and non-point source pollution on at least a bi-annual basis (low flow and high flow seasons), preferably once before the commencement and once after the end of the flow season. Development of an environmental evaluation and performance assessment system to effectively maintain the Water Quality Management Plan should be followed. The overall sustainability of the water quality management plan can only be achieved if objectives are clearly defined at the onset of the program, policies are clearly developed, combined with clear identification of responsibilities of each line agency with a clear definition of their mandates and roles, development of procedures and standards for the plan and identification of resources and sources of funding for the implementation of the management plan. **Table 6-8** provides a summary of action plans and studies required for implementation of a comprehensive water quality monitoring program for the Punjab River basin.

Table 6-8: Indicative Action Plan for further studies, thematic and hot spot plans and projects

NO	PROJECT/ACTIVITY	YEAR 0-1	YEAR 1-5	YEAR 5-10	LEAD AGENCY	INVOLVED AGENCIES
1	Field surveys for recording information about industries & WASA discharging effluent into irrigation channels/drains (as per table 12)-District wise (Duration: 1 to 1.5 year)	√	√		Irrigation Department	Environment Protection Department, Punjab, WASA
2	Preparation of comprehensive report on water sector industrial and municipal pollution in Punjab based on collected information (refer Sr. No 1) (Duration: 6 months)		√		Irrigation Department	
3	Development of surface water quality monitoring network across Punjab on the basis of field surveys (Sr. No 1) and GIS mapping		√		Irrigation Department	Environment Protection Department, Punjab, WASA
4	Surface water sampling and analysis from established monitoring points across Punjab canals/rivers		√		Irrigation Department	Environment Protection Department, Punjab. WASA
5	Preparation of comprehensive report on surface water quality of canals/rivers of Punjab		√		Irrigation Department	Environment Protection Department, Punjab. WASA

NO	PROJECT/ACTIVITY	YEAR 0-1	YEAR 1-5	YEAR 5-10	LEAD AGENCY	INVOLVED AGENCIES
6	Characterization of drains, canals and river waters on the basis of industrial/urban pollution within each river basin.		√		PID	EPD, WASA /Local Governments
7	Setting pollution discharge limits for each point source pollution location as a function of applicable maximum contaminant level at each discharge point.		√		EPD	PID / MH&UD
8	Formulating environmental management plan for each river basin for ambient water quality.		√		PID	EPD / MH&UD
9	Implementation & monitoring of environmental management plan for river basin.		√	√	PID	EPD, WASA
10	Environmental auditing and law enforcement		√	√	EPD	

6.8 RECOMMENDATIONS

Based on the review of available water quality data for different river basins in Punjab province, the following actions are recommended:

- The available water quality data for most canals/drains in different river basins within Punjab province show pollution levels that are well above the permissible limits provided by the Pakistan National Environmental Quality Standards (PNEQS) that have significant impact on the health of downstream water users and ecosystem. It is recommended to develop an action plan for improvement of water quality as is discussed in previous sections. In addition, it is recommended to provide awareness raising programs to increase knowledge of downstream water users on the potential impact of the use of polluted waters from drains and irrigation canals for human and livestock consumption and its potential impact on their health, and also to motivate farming communities and industries to initiate proper actions to improve water quality and health of the Punjab River basins.
- Available studies of water quality of different river basins in Punjab province, discussed in previous section of this chapter clearly demonstrate the significant pollution of waters, especially in irrigation canals and drains by heavy metals, PAHs and other organics and by high concentrations of BOD and COD. Since water flow within the riverbed is relatively low due to its use not only for irrigation, but also due to significant use for industries along the river, the quality of surface water becomes poor for fish populations within the river ecosystem. The high levels of BOD, COD and heavy metals also negatively impacts fish diversity and fish populations within barrage reservoirs. It is highly recommended to implement urgent measures to minimize such contamination and to regulate their levels through regular and systematic monitoring and evaluation of water quality in drains, canals and rivers.
- To minimize the impact of point source pollution sources such as industries along the rivers/canals and urban wastewater discharge points, it is recommended to implement an information sharing process between EPD, WASA and PID to minimize duplication of efforts and to better identify significant point source pollution points and enforce prior treatment of wastewater, industrial effluents before their discharge to surface bodies. Possible plans include establishment of aerobic and aerobic digestion of wastewaters to reduce their physical, chemical and biological pollutant levels to acceptable levels before discharge to the surface water bodies or for use as irrigation water for

conjunctive use. Other potential plans, especially for urban wastewater and small industries effluents is the establishment of created wetlands between point source and surface water bodies to adsorb heavy metals, sediments, etc. Establishment of created wetland where land is available could also act as a means to reduce flood attenuation.

- Directorate of Land Reclamation (PID) of Punjab Irrigation Department (PID) has six soil and water quality testing labs and is involved in surface & ground water quality monitoring with insufficient resources. DLR Capacity should be enhanced in terms of providing Laboratory research assistants and Field staff (for sample collection), purchase of new Lab equipment and maintenance/repair of already available equipment, and purchase of vehicles for field work.

The reviewed water quality data clearly indicate that non-point source pollution of groundwater resources due to irrigated agriculture practices, especially through leaching of nitrogen and highly toxic soluble pesticides from leaky drains and canals, as well as agricultural fields can have significant negative impact on the quality of groundwater resources, mainly due to over application and/or improper timing of agrochemical application. It is important to develop an action plan for monitoring of nutrients and highly toxic agrochemicals impacting surface and groundwater quality. It is also very important to strengthen capacity of regulatory and implementing agencies to raise awareness of farmers on proper use and split application of fertilizers and agrochemicals and to enforce environmental regulations within not only urban and industries, but also in agricultural communities.

7 GROUNDWATER CONDITIONS IN THE BASIN

7.1 INTRODUCTION

The fresh groundwater reservoir underlying the alluvial basin in Punjab has developed as a result of seepage losses from the expanded irrigation network. PID has recognized the need for improving the use and management of groundwater resources in Punjab to meet the growing demand for water for domestic use, industrial use, and urban growth centres, and for irrigated agriculture.

About 90% of all water used in Punjab is for irrigated agriculture, and 70% of drinking water is supplied from groundwater. Annual groundwater abstractions in Punjab are about 53.455.12 BCM (43.65 MAF), which means that present share of groundwater provides approximately 50%for of irrigation water in Punjabis equal to canal supplies.

A detailed report on groundwater management in Punjab was prepared as part of this project and this chapter is based upon the findings of that report.

7.2 IMPORTANCE OF GROUNDWATER IN PUNJAB

Groundwater contributes over just under 50% of the irrigation water to around 16 million ha of cropped area (8.4 million ha irrigated area) and 70% of the domestic water supply to a population of 110 million in Punjab (2017 census). The contribution of groundwater to irrigation has increased steadily from about 10% in the 1960's to more than 50% in 2018. Groundwater pumping by over one million farmer owned wells (tubewells) in Punjab has been the driving factor for increasing the cropping intensity from 67% to around 131%. Moreover, irrigated agriculture in Punjab produces more than 80% of food - surplus to its need, which is exported within and outside the country. Agriculture in Punjab contributes 20% of Punjab's GDP and provides 40% of jobs for skilled and unskilled labour. The dependence of agriculture on different sources of water in Punjab is provided in **Figure 7-1**.

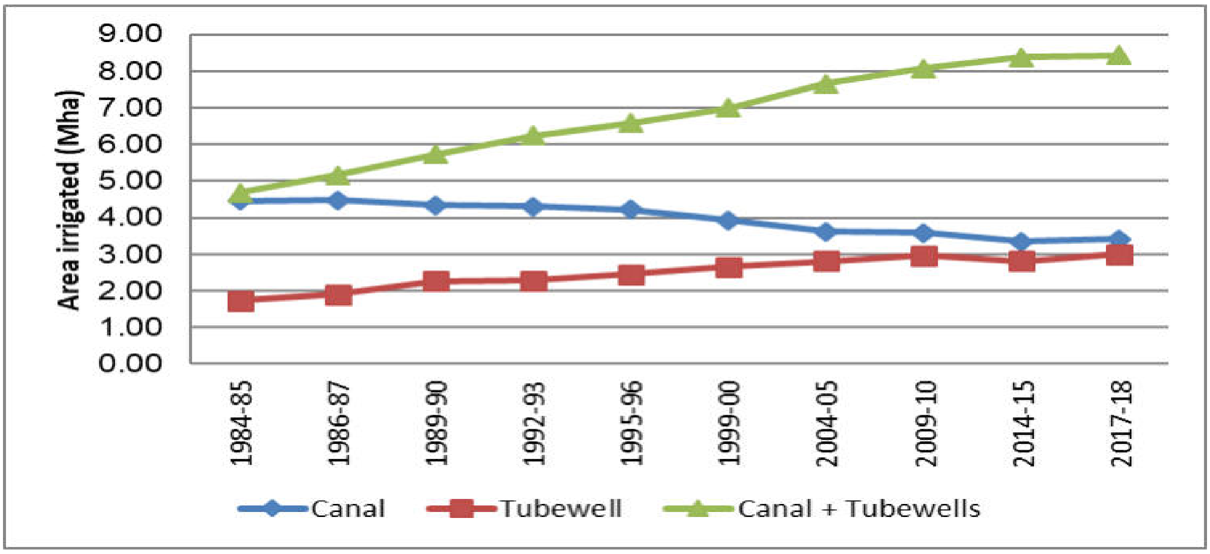

Figure 7-1: Sources of Irrigation Water in Punjab (Source: Agri. Statistics of Pakistan 2017-18)

7.2.1 GROUND WATER USE

The number of tubewells by type of prime movers and annual groundwater pumpage in Punjab are given in **Table 7-1**, including utilization factors and discharges. Pumpage of electric and diesel tubewells for year 2017-18 has been estimated in the table. This also includes tubewells in un-commanded areas. Farmers own and operate the tubewells and pay the full capital, operation and maintenance costs.

Table 7-1: Tubewell Number, Prime Mover type and Annual Pumpage in Punjab

Tubewell Type	Electric	Diesel
Total Number of Tubewells	143,500	944,000
Pump days Per Year	183	124
Hours Per Day	6	5
Discharge (cfs)	1.5	0.7
Pumpage per tubewell (AF)	19,532,600	33,859,174
Total Pumpage (MAF)	**53.4**	

Source: Agriculture Statistics of Pakistan-2017-18

Table 7-2: Summary of water balance for sub-basins in Punjab (MAF)

No	Sub-basin	Canal		Tubewells		Rainfall		Net-recharge
		Diversions	Recharge	Pumpage	Recharge	Volume	Recharge	MAF
1	Bari	11.82	5.343	10.775	3.265	7.796	1.949	-0.218
2	Rechna	10.957	4.953	10.932	3.312	9.537	2.384	-0.282
3	Chaj	4.01	1.813	4.649	1.409	5.314	1.329	-0.099
4	Thal	7.512	3.396	6.731	2.039	4.338	1.085	-0.211
5	Bahawalpur	11.822	5.344	8.12	2.017	1.845	0.461	-0.293
6	DG Khan	2.75	1.243	1.786	0.566	0.787	0.197	0.195
7	CRBC	0.71	0.321	0.617	0.187	0.514	0.129	0.019
	Total MAF	49.581	22.413	43.61	12.795	30.131	7.534	-0.888
	Total BCM	61.157	27.646	53.792	15.782	37.166	9.293	-1.095

7.2.2 PROJECTED SECTORAL DEMANDS

In urban Punjab groundwater is the main source of supply for all major cities in Punjab. The cumulative evidence of declining groundwater levels in major cities is impossible to ignore. Abbas et al. (2012) showed an on-going rate of decline in groundwater levels in Rawalpindi City of 1.7m per year. A similar situation is evident visible for the aquifer that supplies in Lahore City. By 2025, the groundwater levels are expected to have declined by 70m and by 2040 groundwater levels are projected to have declined by 100m. This decline in groundwater levels means a loss in aquifer storage along with a decline. in the quality of groundwater (Qureshi and Sayed 2014), and increased pumping costs and higher water charges for users.

The projected demands for water in Punjab by the major water using sectors is shown in **Figure 7-2**.

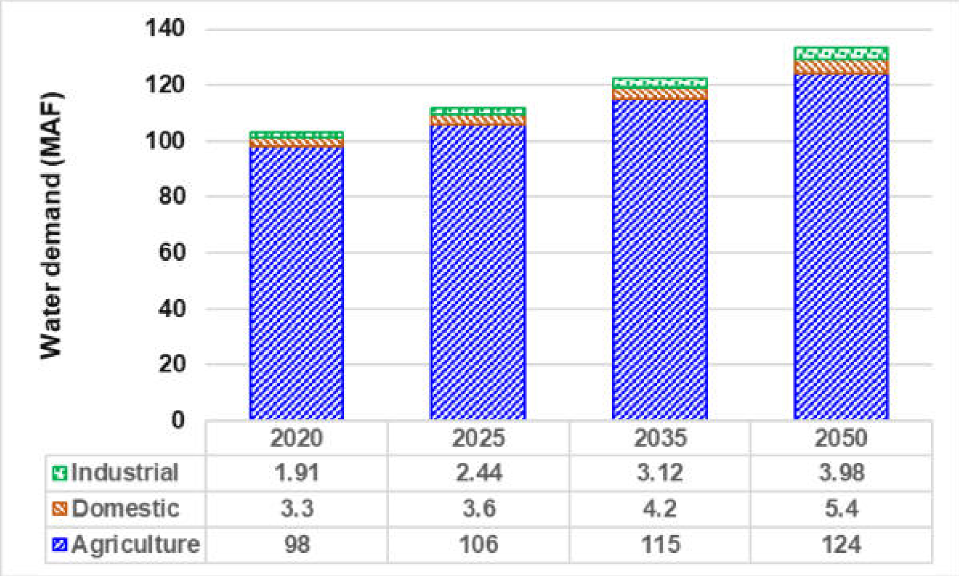

Figure 7-2: Punjab Water Demand Projection

Currently groundwater provides around 50 percent of irrigation water demand in Punjab and about 70 percent of domestic and industrial water demand. It is inevitable that without additional water sources the increase in water use for the industrial and municipal sectors will need to be reallocated from the agricultural sector. This will compound the impacts of climate change on agricultural water demands and inevitably result in a reduction in water available for agriculture. In this case farming communities and irrigators will need to adapt by adopting improved irrigation and groundwater management practices, adopting low water use crops in part of their cropping systems, improving irrigation efficiency, better conjunctive use practices, improved soil and land management, and water conservation practices.

The additional 12.8 BCM needed for the four sectors (by 2050) means additional pressure on existing surface and groundwater sources. The World Bank (2019) report, identifies four priorities to help address this challenge:

- Improved monitoring of the resource and water accounting.
- strengthening institutional capacity to map water use and enforce pricing reforms
- encouraging water savings through improved rates (currently a flat rate Rs/acre differentiated for Kharif and Rabi seasons regardless of water use or consumption), and
- 100% recovery of operating and maintenance costs.

7.2.3 GROUNDWATER MONITORING IN PUNJAB

A robust assessment of groundwater issues and the subsequent implementation of management solutions require both reference data and temporal hydrogeological data. Groundwater monitoring comprises the collection, analysis and storage of a range of data on a regular basis according to specific objectives and management needs. A detailed discussion on monitoring requirements is presented in the GW Management Interim Report. A brief discussion is presented here.

Since 1960, the task of groundwater monitoring was entrusted to Scarp Monitoring Organization (SMO), WAPDA. The SMO-WAPDA monitoring of 4,500 observation wells, open wells, tubewells and a small number of automatic water stage recorders. The average area per observation well is 28 km2. The monitoring program by SMO-WAPDA consists of the following:

- By-annual water level observations.

- Maintaining, 60 automatic water stage recorders
- Periodic water quality sampling and analysis
- Chemical composition of groundwater being pumped through tubewells.
- Monitoring of water bodies, such as rivers, main drains, lakes and ponds, etc.
- Periodic monitoring of surface and soil profile salinity to monitor secondary salinization.

The Directorate of Land Reclamation (DLR), of the PID also monitors groundwater levels and quality in Punjab. It has established a network of monitoring points for depth to water table and groundwater quality (EC) of tubewell water. The monitoring entails the following main objectives:

- Monitoring of groundwater levels and time rate changes.
- Demarcation of zones of saline and fresh water.
- Monitoring of spatial and temporal changes in groundwater quality.

There are 3,319 observation wells and 9,969 water quality monitoring points throughout Punjab which are maintained by DLR, as detailed in **Table 7-3**. However, only 1,284 observation wells are active. Each active observation well represents and area of 86 km2 (8599 ha), which is a very low density of monitoring. Each water quality monitoring point represents 30 km^2 (2975 ha). The data is collected by DLR staff twice a year i.e., Pre-monsoon (May-June) and Post-monsoon (October-November). A report is published by DLR every three years under the title "Groundwater Monitoring in Punjab".

Table 7-3: Groundwater Monitoring Points maintained by DLR

No.	Doab/Area	Areas (000 ha)	Observation wells			
			Total	Functional	Dead	Area per active OW (ha)
1	Bari Doab	2797	881	364	517	7685
2	Rechna Doab	2427	560	340	220	7139
3	Chaj Doab	993	421	159	262	6243
4	Thal Doab	1594	246	116	130	13737
5	Bahawalpur Zone	1750	606	120	486	14582
6	DG Khan	408	605	185	420	2206
	CRBC					
Total			3319	1284	2035	

Improved understanding of the resource condition will require extensive monitoring networks and data interpretation. The primary goal of aquifer management is to control the impacts of groundwater abstraction and pollution loads on the fresh groundwater source. Thus, monitoring water level response and quality trends provides key inputs towards meeting the objectives of groundwater management.

Groundwater water quality monitoring would benefit by the integration of monitoring networks and data of the SMO-WAPDA and the DLR and developing a process for free sharing of data and transparency.

7.3 GROUNDWATER CONDITIONS

Groundwater yield, depth and water quality determine the extent of the resource and the sustainability of resource use. The groundwater resource of the Indus Basin in Punjab contributes over 50% of the irrigation water and 70% of the domestic water supply. There are indications that this level of use is resulting in declining groundwater levels and hotspots in some of the sub-basins.

7.3.1 GROUNDWATER DEPLETION

The water balance of the 7 irrigation sub-basins was assessed in the ITPID (March 2019) and water table information from the sub-basins evaluated[33] and the watertable based information presented in **Table 7-4**.

Table 7-4: Groundwater conditions in irrigation sub-basins

SUB-BASIN	MEDIAN DEPTH TO WATERTABLE	WATERTABLE DECLINE
BARI DOAB	13.29 m	0.213 m/y
RECHNA DOAB	6.43 m	0.062 m/y
CHAJ DOAB	4.21 m	0.015 m/y
THAL DOAB	4.21 m	0.138 m/y
BAHAWALPUR SUB-BASIN	7.22 m	0.108 m/y
DG KHAN SUB-BASIN	4.69 m	-0.014 m/y
CRBC SUB-BASIN	4.388 m	0.328 m/y

In all except DG Khan and CRBC sub basins, water tables are declining and groundwater is being depleted. However, in all sub-basins there are areas where the depletion of the groundwater is more serious, and it is here that remedial activities are most needed. An example to illustrate this variability is shown in **Figure 7-3**.

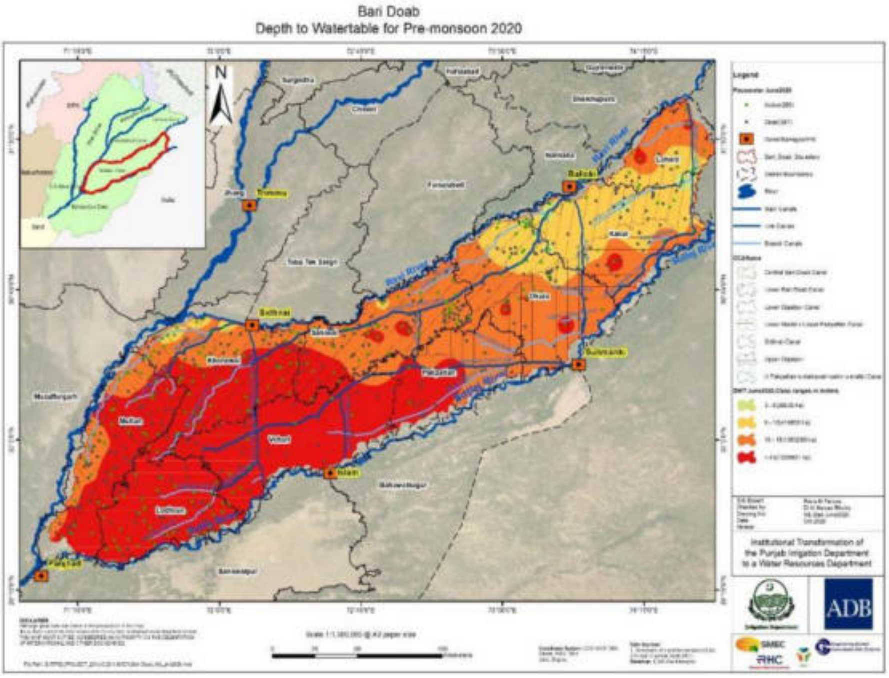

Figure 7-3: Depth to Watertable in Bari Doab for Pre-monsoon 2020

7.3.2 GROUNDWATER QUALITY

Monitoring of water quality in the sub-basins is variable and the following table provides a high-level view of the water quality situation where it is reported. The results show that on average for three of these sub basins, the water quality is deteriorating and its use will affect crop production.

Table 7-5: Proportion of bores with water quality fit for irrigation

SUB-BASIN	2006	2019
BARI	70%	20%
RECHNA	60%	30%
CHAJ	45%	50%
THAL	70%	70%
BAHAWALPUR	80%	25%

7.3.3 GROUNDWATER ISSUES

Groundwater abstractions and groundwater recharge almost balances (Young et al 2019). However critical areas in various sub-basins (e.g., Lower Bari Doab, Lahore and Multan) are water stressed, with groundwater levels and quality declining. This has serious implications for human health and wellbeing and increases cost of abstraction for water suppliers. Groundwater mining of some of the critical aquifers (such as Lahore) has already triggered reallocation from surface water for Lahore city. So, no additional groundwater is expected. Punjab faces major challenges in managing and regulating groundwater, these include:

(i) Growing water shortages which impacts agricultural production, human health and industrial production;

(ii) Progressive deterioration of irrigation infrastructure which has a significant impact on downstream users, such as farmers at the tail end of canals, who resort to exploiting marginal quality groundwater;

(iii) Low water productivity even though agriculture uses over 90% of the available water resource;

(iv) Significant lack of capacity within existing institutions for monitoring, modelling and management of groundwater resources;

(v) A need to strengthen capacity to implement the Punjab water policy and Punjab water act;

(vi) Significant groundwater quality concerns, particularly in urban areas due to disposal of untreated industrial and municipal effluents;

(vii) Over exploitation of groundwater in parts of the doabs of Punjab;

(viii) Prolonged drought in the future will stress the dwindling groundwater resource and can cause serious imbalance. This should be addressed as part of long-term planning;

(ix) Groundwater is dependent on surface water recharge (rivers, canals and irrigation fields) and rainfall. Therefore, surface water and groundwater operate as connected systems and actions on one can impact the other;

(x) Options for additional water are limited (or not existing). Hence, management of all available water resources is critical for all uses and users;

(xi) Water quality has declined, which threatens availability of good quality water in the future;

(xii) Recycling used water and its safe uses has not been explored; and

(xiii) Reallocation from agricultural water use appears to be inevitable in the future (in fact it has already started in some area).

Punjab's water has to be managed within these boundaries.

7.4 GROUNDWATER MANAGEMENT

- As a result of large-scale irrigation losses from unlined canals, which recharged the naturally deep aquifers, some regions experienced shallow groundwater levels and waterlogging resulting in secondary salinity by the 1960s. The World Bank country water resources assistance strategy report (Briscoe and Qamar 2005) claimed that the solution to this crisis was not the obvious and usual one of lining canals and putting less water on the land, but of increasing the use of groundwater. Access to groundwater has filled a gap brought on by increased cropping intensity, but it is not a universal and final remedy, as the uncontrolled use of groundwater for irrigation has now resulted in unsustainable use in many areas due to over abstraction and declining water quality.
- The PWP (2018) has indicated that the safe potential of groundwater abstractions in the province is around 53 BCM (43 MAF), out of which 60% is in the fresh groundwater zone and the rest is within the marginal to brackish quality zones. Close to 50% of irrigation water requirements in Punjab are now being met by groundwater. This means that about 21 BCM (17 MAF) abstractions are from marginal to brackish groundwater. In these areas, improved distribution of surface water supplies, coupled with improved conjunctive use practices, are essential in order to maintain agricultural productivity.
- The PWP also states that around 55.5 BCM (45 MAF) of groundwater is being abstracted annually in the province, indicating net over abstraction of 2.5 BCM (2 MAF). The resultant lowering of the water table is most severe in large urban centres (e.g., Lahore, Rawalpindi, and Multan). To ensure sustainable groundwater abstraction, monitoring measures need to be strategic and the approach to monitoring should be linked to defined objectives.

- Spatial and temporal monitoring data will also provide the means to develop basin scale and sub-basin scale maps for groundwater status reporting and groundwater planning. Monitoring is also essential to enable the WRD to develop a suite of groundwater models, which can provide a basis for developing groundwater budgets at the basin and sub-basin (doab) scale, which will give a much-improved assessment of recharge and discharge for each sub-basin. Monitoring of depth to water (DTW) and electrical conductivity (EC) of the groundwater is required for assessing the lateral and vertical movement of saline zones into freshwater zones, and to ensure the long-term sustainable management of freshwater zones.
- The PWP also calls for appropriate technologies to ensure skimming of fresh groundwater layers overlaying saline zones. The PWP also advocates the promotion of groundwater recharge measures, as 40% of the recharge comes from the irrigation system. PWD recommends that the lining of canals and distributaries should not be undertaken without proper feasibility studies.
- The PWP indicates that regulatory mechanisms are required to be put in place and enforced, to control over-abstraction in critical zones. They recommend a Water Resources Commission should be established which will be responsible for allocation and management of water resources for different purposes.

7.5 DIRECTIONS FOR STRENGTHENED GROUNDWATER MANAGEMENT

Punjab's mid-term development framework, 2015–2018 prioritized reliable irrigation supplies, enhanced agricultural productivity, improved rural economy, and broad-based institutional reforms. In 2015, the 'Punjab-ADB dialogue on water' which considered the impacts of the historic piecemeal reforms and future challenges culminated in a recommendation to transform PID into a Water Resource Department with ADB financial support for the Punjab's reform program.

The Punjab Water Policy (PWP; 2018) provides policy direction for sustainable management of water resources for all type of water uses, at all scales. It covers water availability, water quality, groundwater abstractions, water and sanitation standards, climate change, land resources, water demand management, governance, knowledge and database and capacity building. Punjab Water Act (2019) requires the formation of a provincial Punjab Water Resource Commission (PWRC) and a provincial Punjab Water Services Regulatory Authority (PWSRA) and water and sewerage undertakers.

This section describes the main Activity areas to improve groundwater management and provide a high-level roadmap of this.

7.5.1 GROUNDWATER MANAGEMENT PLANS

Groundwater Management Plans are central to improving the management of groundwater resources under stress, particularly when there is increasing competition for scarce resources. Groundwater planning and management cannot be done in isolation. They require a collaborative approach for the success of the plan. Success will be judged by the Plan's acceptance amongst stakeholders, groundwater users, competing users and water management agencies; and by the Plan's level of adoption and implementation (Punthakey 2016). In the end, by the ownership of the plan by stakeholders. A basin-wide consensus based approach to groundwater resource planning and management increases the chance for successfully implementing groundwater management actions that are equitable, affordable, and provide far reaching benefits locally, regionally, and for the province

Ground water plans components comprise (ITPID GW report Mar 2019):

- Control of declining groundwater levels
- Control of saline water intrusion
- Management of wellhead protection and recharge areas
- Regulation of contaminated groundwater

- Administration of abandoned wells
- Elimination or minimizing groundwater over-exploitation
- Replenishment of groundwater through artificial recharge
- Groundwater monitoring
- Conjunctive water management strategies to minimize impact of land salinization
- The development of groundwater management partnerships
- Coordination of land use planning and groundwater management
- Financing groundwater management projects
- Plan to involve agencies with a stake in groundwater management and use
- Groundwater Management Plan objectives
- Mapping and Modelling of groundwater for the Plan area

The purpose of the Groundwater Management Plan is to review, enhance, assess, and coordinate existing groundwater management policies and programs and to develop new programs and procedures, if necessary, to ensure the long-term sustainability of groundwater resources in a groundwater basin or sub-basin. The vision of the planners for the use and maintenance of groundwater must be made clear, in such a way that community acceptance and involvement is likely to occur. This vision can be expressed in the formulation of objectives. For example, a short-ranged vision might lead to objectives that will have short term benefits but may result in severe problems in the longer term, whereas a longer range vision may lead to objectives that will ensure the resource is maintained indefinitely.

The Plan must also include targets which are used to assess plan implementation, such as:

- Maintain or enhance groundwater levels to meet the long-term needs of groundwater users within the Groundwater Management Area. Establish targets for managing groundwater level decline.
- Maintain or enhance groundwater quality to meet the long-term needs of groundwater users within the Groundwater Management Area. Establish targets for maintaining groundwater quality.
- Minimize impacts on surface water bodies due to continued groundwater pumping and planned conjunctive use.
- Maintain ecosystem health by minimising discharge of sewage and other effluents into surface water bodies.

7.5.2 MANAGED ARTIFICIAL RECHARGE (MAR)

MAR consists of a set of physical infrastructures designed to capture clean surface water and purposefully recharge that water into aquifers, thereby supplementing groundwater storage, improving groundwater quality and maintaining or minimising declining water levels. Criteria need to be developed to ascertain the status of the aquifer and the effectiveness of MAR operations. It requires a collaborative process involving communities, stakeholders and civil society with an interest in improving sustainability of the aquifer.

Flood water can be used to recharge the aquifer through a channel or storage that allows water to seep into the aquifer. Such schemes require planning and detailed studies to establish the effectiveness of the recharge scheme. Abandoned canals and dry riverbeds may be used in recharge schemes. For rivers like the Ravi, floods are rare and recharge schemes may not be effective. Strategies to recharge groundwater using monsoon floods need to be tested. A study of groundwater availability and conjunctive management (ACE et al. 2011) suggested diverting flood waters through BS link to the Sukh Beas area and to use it as storage in drought years. This would also have the added benefit of recharging the aquifer along the mid and western part of Bari Doab.

7.5.3 CONJUNCTIVE WATER USE

Conjunctive water management involves using surface water and groundwater in combination to improve water availability and quality[34].. Monitoring should provide information on surface water flows, groundwater levels and water quality to allow suitable management strategies to be developed at a local level in conjunction with local water users to meet irrigation and environmental objectives. Effective conjunctive use of groundwater and canal water is capable of achieving:

- Much greater water-supply security by taking advantage of natural aquifer storage
- Larger net water-supply yield than generally possible using only one source alone
- Blending of groundwater with canal water in marginal groundwater areas to decrease salinity impacts and improved quality of return flows
- Better timing of irrigation-water delivery as groundwater can be rapidly deployed to compensate for shortfalls in canal-water at critical times in the crop-growth cycle
- Reduced environmental impact, through counteracting waterlogging and salinization of productive land.

In these areas, improved distribution of surface water supplies, coupled with improved conjunctive use practices are essential to maintain agricultural productivity. Presently, more groundwater pumping is required more at the tail of the canal commands to make up supply shortfalls, but the aquifer water quality is generally better in the head reaches. A management option could be to reallocate the canal water by reducing the unit water allowance in the head reaches thus allowing more water to flow towards the tail end. This will encourage tail end farmers to use surface water for irrigation and reduce the use of low-quality groundwater. The farmers in the head reaches can extract a higher volume of groundwater, which is of good quality. This approach makes better use of the available groundwater. Specific technical studies are needed to enable this option.

7.5.4 INDICATIVE ACTION PLAN

The most critical factor in improving groundwater and canal water management is to ensure appropriate institutions are in place to support groundwater management systems. WRD in Punjab would be responsible for groundwater monitoring and evaluation, management and regulation. Achieving groundwater sustainability will require the WRD to achieve the following aims by 2030:

- All major aquifer systems and sub-basins should be properly assessed, with the resulting information and knowledge made available and shared.
- Groundwater management plans to be prepared and implemented for sub-basins and priority canal command areas where groundwater depletion is occurring. Additionally, groundwater management plans need to be

[34] Brackish groundwater that is otherwise unsuitable for irrigation can be combined with fresh surface water to achieve suitable water quality.

developed on a sound basis which requires groundwater models for each sub-basin and estimates of sustainable extraction rates.

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- All major aquifer systems and sub-basins should be properly assessed, with the resulting information and knowledge made available and shared.
- Groundwater management plans to be prepared and implemented for sub-basins and priority canal command areas where groundwater depletion is occurring. Additionally, groundwater management plans need to be developed on a sound basis which requires groundwater models for each sub-basin and estimates of sustainable extraction rates.
- The WRD to be properly resourced for the key tasks of capacity building, monitoring the groundwater resource, groundwater quality monitoring, mapping and modelling.
- Information systems to be upgraded to make use of up-to-date information and users and knowledge products developed to facilitate communication between stakeholders, water users and those with an interest in sustainable groundwater management.
- To promote responsible groundwater, use and management amongst users which is critical for improved productivity, equity, and sustainability.
- To promote groundwater governance by improving conjunctive management of surface water and groundwater and improved blending strategies to manage salinity.
- To promote demand management such as conservation of groundwater resources, improving agricultural water productivity, adopting low delta crops, along with supply-side measures such as increasing canal duties to enhance recharge and managed aquifer recharge.
- To implement appropriate legal, regulatory and institutional frameworks for groundwater that establishes public guardianship and collective responsibility and beneficial integration with other uses of groundwater resources.
- To introduce legislative mechanisms for permanent engagement of diverse stakeholders, including local groundwater user communities who should have a voice in monitoring and management of groundwater.
- To implement investment programs and incentive frameworks for water users and to foster sustainable, beneficial and efficient groundwater use, coupled with adequate groundwater resource protection.

However, to fulfil its functions a major transformation will be required which will involve significant resources and capacity building and a 10 to15 year transition plan to develop the capacity and human resources.

Managing decline in water tables will require the new WRD to work closely with WASA's to introduce improved monitoring, assessment and management of the resource, Managed Aquifer Recharge (MAR) within cities to enhance groundwater storage, especially during the annual monsoon period, and water conservation measures through increased awareness of water users. Central to this will be demand management for urban water supplies.

Table 7-6: Indicative Action Plan for further studies, thematic and hot spot plans and projects

PROJECT/ACTIVITY	YEAR 0-2	YEAR 3-5	YEAR 5-10	LEAD AGENCY	INVOLVED AGENCIES
STRENGTHEN GROUNDWATER MANAGEMENT INSTITUTIONS					
Establish a strong GW management division within WRD	✓	✓	✓	WRD	
STRENGTHEN REGULATORY ARRANGEMENTS					
Develop a GW Legal/ Regulatory Framework (*GWRF*) for Punjab	✓			WRD	WASA, EPA, Consultants (Legal and Technical)
Implement GWRF on a Pilot Scale in at least two critical areas to study its effectiveness.	✓			*Monitoring Agency*	WRD, WASA
Implement the GWRF to the whole Province		✓	✓	WRD, Monitoring Agency, Undertakers	Consultants
DEVELOP AND IMPLEMENT GW MANAGEMENT PLANS					
Development of GW management plans for each sub basin that are accepted by the local community and the government.	✓	✓	✓	WRD	WASAs, EPA, Consultants, etc.
Groundwater management plan for Bari DOAB		✓		WRD	Consultants
Plan and implement conjunctive use projects for a more integrated approach which includes reducing soil salinity and drainage outflows?		✓	✓	WRD	Consultants, WUAs, Farmers, etc.
Plan and implement rainwater harvesting projects in urban areas	✓	✓	✓	WRD	WASA, Consultants
STRENGTHEN GROUNDWATER INFORMATION AND KNOWLEDGE MANAGEMENT					
Develop a detailed GW monitoring plan and improve institutional setup	✓			WRD, Monitoring Agency	Consultants, WASA, EPA
Implement the monitoring network as per plan and start data collection	✓	✓	✓	WRD, Monitoring Agency	WASA, EPA
Expand the monitoring network as required		✓	✓	WRD, Monitoring Agency	Consultants, WASA, EPA

PROJECT/ACTIVITY	YEAR 0-2	YEAR 3-5	YEAR 5-10	LEAD AGENCY	INVOLVED AGENCIES
Develop GW models for selected critical areas and study management options	✓	✓	✓	WRD	Consultants
IMPLEMENT MANAGED AQUIFER RECHARGE PROJECTS					
Plan and implement mar projects in rural catchments		✓		WRD	Consultants
Plan and implement mar in urban catchments		✓		WRD	Consultants
COMMUNITY AND STAKEHOLDER AWARENESS RAISING AND PARTICIPATION					
Community participation and raising water user awareness campaigns	✓			WRD	WASAs, EPA, Local Govts, Farmers

NOTES

1. *Raise awareness, knowledge and capacity of stakeholders, groundwater users and communities of the importance of the groundwater resource and the need for sustainable management.*
2. *Monitoring of the resource is critical for improving analysis of the groundwater system and the aquifer, and the data is critical to provide timely advice to the management of WRD and to meet the commitments under the Punjab Water Policy (PWP)*
3. *For groundwater planning and management to succeed a consensus-based forum for local water interests with diverse viewpoints regarding the exploitation of groundwater resources in Punjab is required.*
4. *Farmers will need to adapt to reducing water availability (increasing demand from other sectors and from Climate Change) by adopting improved irrigation and groundwater management practices, adopting low water use crops in part of their cropping systems, improving irrigation efficiency, better conjunctive use practices, improved soil and land management, and water conservation practices.*

8 ENVIRONMENTAL CONDITIONS OF THE BASIN'S RIVERS

8.1 INTRODUCTION:

Unsustainable development activities, combined with a number of human interventions in the last few decades have negatively impacted the health of the riverine environment in Punjab province. This is causing significant negative impact on effectiveness of valuable goods and services that have always been delivered by the Indus River and its tributaries for millennia. Ecosystem health and biodiversity of flora and fauna within the riverine system of Indus River and its tributaries are at risk and their integrity and sustainability are questionable.

The continuous inflow of contaminants into surface waters has increased surface water pollution. Punjab rivers continuously receive large volumes of raw sewage discharging from large urban areas, as well as industrial wastewater. Non-point source pollution from runoff, which includes nutrients and agrochemicals from irrigated agriculture also contaminates surface and groundwater resources, which has a significant negative impact on the riverine ecology. The water quality data, presented in Chapter 6, clearly demonstrates the effect of point and non-point source pollution. These contaminants are responsible for an increase in the occurrence of water-borne diseases within the human population, as well as a reduction in the biodiversity of flora and fauna within the Indus River Basin.

The impact of water pollution and decreased flows reduces the quality of natural ecosystems within the riverine environment and has significant negative economic and social impact due to a reduction in fish and other aquatic resources; reduces groundwater resources due to the loss of recharge from wetlands; reduces the value for recreation; affects living conditions ; and affects flooding (e.g. from sedimentation), changing river courses, bank erosion and loss of farm or urban land.

The Indus River ecosystem has been deteriorating over the last few decades and the deterioration is accelerating, making the need to assess the health of aquatic ecosystem of paramount importance[35,36]. To improve the environmental status of the Indus River basin ecosystem, development of an action plan for improving the ecosystem is strongly recommended. As a part of the action plan, it is necessary to consider the values and uses of the rivers and to enforce environmental regulations, especially with regard to water quality, discharge of effluents to surface waters and establishment of proper environmental flow to ensure improvement of the riverine ecosystem, and restore the damaged ecosystem before reaching the point of no return.

Assessments of river health and development of an index of catchment ecosystem health for the Indus River basin is strongly recommended, to assist practitioners in management of the Indus River watershed. Development of an integrated ecosystem improvement action plan should provide the proper tools to practitioners and environmental regulatory agencies

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[35] Irfan, M., Qadir, A., Habib, A., Nadia, J., & Ahmad, S. R. (2019). Vulnerability of environmental resources in Indus Basin after the development of irrigation system. In *Irrigation-water productivity and operation, sustainability and climate change*..

[36] Pappas, G. (2011). Pakistan and water: new pressures on global security and human health. *American journal of public health*, *101*(5), 786-788.

for improving the ecosystem health and ensure sustainable and long-lasting health of both aquatic and terrestrial ecosystems within the Indus River and other riverine systems within Punjab Province. Ecosystem indicators should be established based on field sampling and as well as use of modelling technologies to ensure the health of the riverine ecosystem.

Some of the environmental indicators that can be used by modelers in developing the action plan and environmental management of the ecosystem include:

- Indicators of the ecological landscape pattern based on Normalized Difference Vegetation Index (NDVI);
- Vegetative cover;
- Dominance index;
- Diversity and fragmentation indices;
- Hydrology regime;
- Physical form condition (based on substrate, habitat complexity, velocity/depth regimes, riverbank stability and channel alteration);
- Water quality (based on electrical conductivity, dissolved oxygen (DO), NH3_N, total nitrogen (TN), total phosphorus (TP), chemical oxygen demand; and
- Biological qualities, such as fish abundance and diversity.

A trend in the ecosystem health of Indus River and its tributaries should be established to determine the health of the ecosystem within upstream and downstream reaches of the riverine environment. The ecosystem health assessment can then inform future water and watershed management plans for the rivers and river sub-basins of the province.

8.2 TEMPORAL AND SPATIAL CHARACTERISTICS OF THE POLLUTANT CONCENTRATION IN THE PUNJAB INDUS RIVER BASIN

The water quality of the upstream Indus River and its tributaries (Ravi, Chenab, Jhelum, etc.) is classified as good (see chapter 6), but water quality rapidly deteriorates downstream due to non-point source pollution from agricultural fields and point source pollution from untreated urban wastewater and industrial effluent which discharges into rivers, canals and drains. The low flow in the river does not allow for adequate dilution of discharged pollutants. The contamination status of the Indus River and its tributaries is briefly discussed here.

8.2.1 RAVI RIVER

Using the U.S. EPA standards the water quality of Ravi River was found to be unsuitable for aquatic life during dry the season, especially during canal closure periods. The levels of DO, BOD and heavy metals are significantly above safe limits. The increase in flow of almost 600 m3/s through the Balloki-Qadirabad link canal assists in improving the water quality of the Balloki Barrage reservoir. However, during the canal closure period (December-January), the water quality significantly deteriorates, causing significant negative impact on the ecosystem health of the water body. Available data confirms that river water quality downstream of Lahore is unsafe for aquatic life. During the rainy season, additional river flow assists in flushing out some of the pollutants and dilution slightly improves water quality during July and August. Storm water brings a heavy pollutant load from the city to the surface waters. Disposal of untreated drainage effluent to the river

remains the most significant threat to water quality, causing deterioration of ecosystem health for aquatic and terrestrial flora and fauna[37].

Lahore municipality and industrial effluents appear to be the most significant sources of contamination of Ravi River. Without significant efforts to prevent discharge of untreated waste to the river, canals and drains, a considerable portion of the downstream river will most likely become uninhabitable for fish and other aquatic life, especially during low-flow periods. Furthermore, the current level of toxic heavy metals in fish within the river is well above the permissible levels, making them unsuitable for human consumption. This can potentially have a significant negative impact on the health of local communities, living along the river. Lead (Pb) bioaccumulation in muscles was found to be between 0.18 and 3.28 mg/kg, which is well above the permissible 2 mg/kg limit for human consumption as defined by WHO (1985). Chromium (Cr) concentrations ranged from 0.96 to 5.70 mg/kg, well above permissible levels for human consumption of 0.05 mg/kg (WHO, 1985.

The high concentrations of heavy metal pollution are attributed to the industries along the river such as tanning and corrosion control plating pigment manufacturers situated along the Hudiara drain.[38]

8.2.2 SUTLEJ RIVER

Flow in the Sutlej River has almost stopped due to upstream storage and use in India. The river channel has been converted into a sandy dry bed with little to no flow. The depleted flow has caused a decline in agricultural activity and has significantly impacted the ecosystem and flora and fauna biodiversity, causing significant disturbance of the regional ecology. Drying of the river has also significantly impacted the livelihood of local people, forcing them to move away from the area, leaving developed infrastructure in ruins. Much of the culture of this valley has already been lost, and if the ecosystem is not managed, the local civilization will be completely lost.[39]

Chenab's water has been found to be unfit for livestock consumption due to high concentration of cadmium (Cd), which exceeds permissible limits in 38% of the area. The worst contamination is found in the lower reaches, after the Tarimmu barrage. The concentration of Cd increases in areas where agriculture activities and traffic density are highest. Pb contamination was found to be higher at the entry point of the river from India, indicating that the origin of the Pb

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[37] Akhtar, S., & Nawaz, M. (2012). Impact of water quality on aquatic life in River Ravi, Pakistan. *Nature, Environment and Pollution Technology*, *11*(2), 219-224.

[38] Shakir, A., Chaudhry, A. S., & Qazi, J. I. (2013). Impact of anthropogenic activities on physio-chemical parameters of water and mineral uptake in Catla from river Ravi, Pakistan. *Environmental monitoring and assessment*, *185*(3), 2833-2842.

[39] Ricart, S., Rico, A. M., & Olcina, J. (Eds.). (2019). Irrigation: Water Productivity and Operation, Sustainability and Climate Change. BoD–Books on Demand.

contamination is not the local industry. Since heavy metals bioaccumulate in the food chain, it is strongly recommended that water from the Chenab River should not be used for livestock consumption.[40]

8.2.3 JHELUM RIVER

A study was conducted to investigate the water quality and fish diversity in Rasul Barrage on the Jhelum River.[41] Results of the study showed that the concentration of pollutants and non-stop commercial fishing are the main causes for the reduction of fish diversity and population. Two exotic fish species, *Oreochromis mossambicus* and *Ctenopharyngodon idella*, were found to become the abundant fish species in the barrage, while the population of native fish fauna has been significantly reduced. It was concluded that the reason for this phenomena was the poor quality of surface water, as is evident from the higher concentrations of BOD, COD, and heavy metals. Urgent measures are required to reduce contamination.

8.2.4 IMPACTS ON THE FISHERIES

Large amounts of potentially toxic elements (PTEs) have and are still continuing to be released into the freshwater ecosystems of Pakistan. However, there is limited information available on the ecological risk of PTEs in sediments and consumption of contaminated fish by both the general population and fishermen in Pakistan. A study by Navab et. al. (2018) collected water, sediments, and fish samples from major rivers (Chenab, Upper Indus, Lower Indus and Kabul) across Pakistan. Ecological risk analysis of sediments revealed that Cd posed a high ecological risk in the Upper Indus and Chenab, a considerable risk in the Lower Indus, and moderate risk in Kabul. The target hazard quotient of arsenic (As) in fish tissue exceeded safety levels in all the rivers, whereas Cd levels exceeded safety levels in the Upper Indus and Chenab, and Pb levels exceeded safety limits only in the Chenab. For the general population, ingestion of PTEs through fish tissues was found to be within the safety limits in all rivers. However, the total target hazard quotient in all three rivers exceeded the safety limit, representing a high risk for the fishermen of Pakistan.[42]

8.3 ENVIRONMENTAL FLOW

Water demand for irrigation, industry and human/livestock consumption has put heavy pressure on surface and groundwater supplies in the Indus River Basin, reducing river flow in Indus River and its tributaries, which is significantly impacting health of the riverine ecosystem. Although hydrologists and environmental scientists recognize the need for releasing base “environmental flows” to sustain riverine habitats and maintain ecological functions, no systematic plan is

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[40] Kausar, F., Qadir, A., Ahmad, S. R., Baqar, M., & Sardar, F. (2020). Evaluation of River Chenab water quality with respect to its users, using different classification schemes. *Water Supply*, *20*(8), 2971-2987.

[41] Iqbal, H. H., Shahid, N., Qadir, A., Ahmad, S. R., Sarwar, S., Ashraf, M. R., ... & Masood, N. (2017). Hydrological and Ichthyological Impact Assessment of Rasul Barrage, River Jhelum, Pakistan. *Polish Journal of Environmental Studies*, *26*(1).

[42] Nawab, J., Khan, S., & Xiaoping, W. (2018). Ecological and health risk assessment of potentially toxic elements in the major rivers of Pakistan: General population vs. Fishermen. *Chemosphere*, *202*, 154-164.

in place to calculate environmental flow for the Indus River and its tributaries. The lack of environmental flows can have a detrimental impact on the river's ecological functions such as dilution of pollutant and nutrient concentrations, sediment flushing, salinity intrusion control and replenishing wetlands and estuaries as well as the river uses related to ecological condition such as recreation, amenity, flooding, riverbank erosion and loss of farmland. Currently, a system to determine appropriate environmental flows is not established in Pakistan and environmental flow estimation method varies between different rivers and tributaries. A preliminary assessment by Nawab et. al. suggested that environmental flow requirements for the Indus River should equal to 25 percent of mean annual runoff, or about 46.75 km^3 per year, based on the reported long-term average annual river flow of 187 km^3 [43]. Currently, the environmental flow in the Indus River and its tributaries does not meet the proposed target. The 1991 Water Apportionment Accord between the provinces in Pakistan committed to ensuring that the annual environmental flow to the Indus Delta below the Kotri barrage should not fall below 12.3 km^3. This flow is believed to be needed to control seawater intrusion, maintain the river channel, ensure sediment transport, and support fisheries. However, the river flow has not reached these flows since the 1990s, indicating that the terms of the Accord have not been met by upstream water users and regulatory authorities.

Currently, the Project Management Office (PMO) for barrages (PMO-barrages) is responsible for releasing the volume of water requested by the PMO for canals. The estimated release volume is based on the estimated irrigation water demand within the command area. The assumption is that the base flow will then be released downstream to the riverbed through discharge from the drains, without considering the environmental and river flow needs in the water release planning. It is assumed that the drainage discharge will be adequate for sustaining the riverine ecosystem.

The current base flow is dependent on irrigation demand rather than the environmental needs of the downstream ecosystem and river water users. Establishment of a province-wide methodology to estimate environmental flows and enforcing environmental releases is of great importance, not only to ensure the health of the riverine ecosystem and population and diversity of flora and fauna, but to also ensure adequate water of acceptable quality is available for downstream users. To ensure sustainable development and to provide an environment for a healthy riverine ecosystem, it is essential to promote the concept of environmental flow and to ensure its implementation in Punjab province. To meet specific environmental and ecological functions of rivers, environmental flow releases should be planned to ensure adequate flow is available in different seasons. Thus meeting the needs of different biologic life stages of riverine flora and fauna.

Although there is no universally accepted method for estimation of environmental flow (E-Flow), the IUCN report 'Flow. The Essentials of Environmental Flows'[44], details the approaches used in several experienced countries and provides practical guidance on technical issues, such as assessment methods and infrastructural adaptation, and the economic, legal and political dimensions of establishing environmental flows. The report describes approaches from simple desktop approaches where data is limited to a holistic approach that explicitly includes assessment of the whole ecosystem, such

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[43] Indus Basin Working Group, & Arshad 'Abbāsī. (2013). Connecting the drops: An indus basin roadmap for cross-border water research, data sharing, and policy coordination. Observer Research Foundation.

[44] Dyson, M., Bergkamp, G., Scanlon, J. (eds). Flow. The Essentials of Environmental Flows. IUCN, Gland, Switzerland and Cambridge, UK. xiv + 118 pp

as associated wetlands, groundwater and estuaries, to methods which account for all species that are sensitive to flow, such as invertebrates, plants and animals, and address all aspects of the hydrological regime including e.g. floods, droughts, and water quality.

There have been a number of studies of E-Flow assessment in Pakistan. One of the methodologies used in Pakistan is described in the Hagler Bailly Pakistan study (2018). They conducted an E-Flow assessment as part of an EIA report for the ADB funded, Balakot Hydropower Project. They used flow estimates to determine suitable E-Flows during project operation resulting impact on the ecosystem[45]. PID should consider the use of E-Flow estimation for determining flow releases to the river system. It is recommended PID establish a panel to assess different methodologies for estimation of E-Flow to select the most suitable methodology for the Punjab river system. PID should develop and build the capacity of their staff in E-Flow assessment for inclusion in water allocation plans.

8.4 HABITAT FRAGMENTATION

Construction of irrigation structures such as dams and barrages has led to the fragmentation of the Indus River into 17 separate sections, resulting in the ablation of dolphins from 10 sections.[46] Dolphins used to inhabit the whole length of the Indus River, however, due to river fragmentation and barriers to their migration, the habitat for dolphins has reduced to only 20% of the total length of the river. Chemical pollution as well as accidental death by fishing equipment are also potential factors responsible for the decline in the dolphin population. In addition, sometimes dolphins are trapped in the canals and fail to return to the river which increases the morbidity of dolphins.

The Chenab River is highly fragmented due to construction of dams and barrages and which significantly influences the integrity of its ecosystem and causes a decline in species diversity and population. Kausar et.al. (2018) undertook a study on the Chenab River to provide information on fish diversity, distribution patterns and conservation issues at five artificial reservoirs (barrages) during the pre-monsoon and post-monsoon season[47]. The study found the highest population of fish species at Qadirabad barrage and the lowest at Khanki barrage. Barrages act as a barrier to the movement of fish, with connectivity established between the two sides only during the flood season. There is no fish ladder for fish migration. Point and non-point pollution sources were found to have a highly significant negative impact on the fish diversity of the Chenab River. The small size of fish captured by fishermen from most of the sites is an indication of high fishing pressure on the assemblage.

The fish population the Chenab River system is facing multiple threats including, (i) water diversion, (ii) water shortage, (iii) habitat degradation, (iv) destructive methods of fishing, and (v) fishing during the fishing closure season. The study states that the presence of near threatened species in the Chenab River strengthens the need for further study into the

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[45] https://www.adb.org/sites/default/files/project-documents/49055/49055-003-eia-en_6.pdf

[46] Ricart, S., Rico, A. M., & Olcina, J. (Eds.). (2019). Irrigation: Water Productivity and Operation, Sustainability and Climate Change. BoD–Books on Demand.

[47] Kausar, F., Aiman, U., Qadir, A., & Ahmad, S. R. (2018). Assessment of Fish Assemblage in Highly Human Managed Reservoirs Located on River Chenab. *Pakistan. J Biodivers Endanger Species*, *6*(216), 2.

causes of habitat loss, factors contributing to habitat degradation, and their rehabilitation requirements. It is recommended that a comprehensive fish conservational management of the river system be implemented by involving stakeholders, fishermen and local inhabitants.

In summary, habitat degradation is a major concern for a number of Indus River tributaries, especially in downstream sections of the river, where pollutant concentrations reach dangerous levels, causing concern for survival of threatened flora and fauna species. These concerns strengthen the notion that further study of causes of habitat losses, factors contributing to habitat degradation and their rehabilitation requirements are warranted.

8.5 RIVERBANK EROSION

Khan et. al. (2017) undertook a study to assess a 70 km stretch of the Indus River in the Layyah and Muzaffargarh districts, which was believed to be highly vulnerable to erosion.[48] The study indicated that the Indus River is continuously engulfing land on the left bank of the study area. The study estimated that an area of some 101 km^2 was eroded between 2002 to 2009 and another 72 km^2 during 2009 to 2016, giving a rate of erosion in this reach of some 11.5 km^2 per year. The study found that the river is shifting more towards its left bank in this section of the river. Erosion of the left bank caused damage to agricultural land and people's livelihoods, settlements and infrastructure. It is recommended that a study be undertaken to understand the erosion mechanism in this reach and other similarly affected river reaches in the province and to develop measures to mitigate the impacts. Recognising that migration of rivers is a natural process and it may not always be practical to prevent river migration.

8.6 WATER QUALITY MONITORING

The five key water quality indices that should be selected for assessing non-point pollution sources are:

- Biochemical Oxygen Demand (BOD5);
- Chemical Oxygen demand (COD);
- Dissolved Oxygen (DO);
- Ammonium nitrogen (NH3-N); and
- Total phosphorus (TP).

Samples should be collected and analysed for the above water quality parameters from all rivers, drains and canals in the Indus River Basin providing suitable temporal and spatial coverage to characterise water quality across the basin and provide a scientific basis for water pollution control, water environment protection, and ecological restoration . Sampling points should be selected upstream and downstream of the large, irrigated agriculture blocks. Since currently there is no

[48] Khan, H. U. A., Khalil, S. F. A., Kazmi, S. J. H., Umar, M., Shahzad, A., & Farhan, S. B. (2017). Identification of River Bank erosion and inundation hazard zones using geospatial techniques—a case study of Indus River Near Layyah District, Punjab, Pakistan. *Geoplan J Geomat Plan*, *4*, 121-130.

systematic water quality analysis network, it is necessary to establish the network as early as possible. Other pollutants like pesticides and other agrochemicals might need to be included in the analysis, depending on the cropping pattern within irrigation block and agricultural practices and agrochemicals used in the area. However, the five elements listed above are the minimum parameters that should be assessed at each sampling site. Temporal sampling requires a minimum of four samples during the year: (i) before start of irrigation during the dry season, (ii) after completion of irrigation and crop harvest during the dry season, (iii) before start of inception of agricultural development during the wet season, and (iv) after harvest of crops during the wet season.

The same process should be considered for point source pollution locations. Point source pollution usually derives from discharge of untreated effluents from industries to canals, drains or directly into the river as well as discharge of untreated sewage from cities and large and small urban areas. Sampling points should be located for monitoring of pollutants from such sources. More detail and action plans for establishment of water quality monitoring is provided in Chapter 6. The industry and urban governments should be made responsible for sampling and analysis of effluents upstream and downstream of discharge points and they should report the results to the regulatory agency (EPD). EPD should also make spot checks and unannounced visit to the identified pollution sources and analyse the water quality to ensure compliance of Industry and urban governments to ensure they adhere to the water sampling requirements and enforce regulations with regard to treatment of effluents before discharge of effluents into waterbodies. Temporal and spatial sampling procedure should follow the same process as provided above for non-point source sampling. However, elements to be analysed should also include specific heavy metals and organo-chemicals that might be specific to each different industry.

8.7 RIVER HABITAT SURVEY AND EVALUATION METHODS

A study of river habitat is required to determine ecosystem condition, underpin ecological restoration of the river and inform environmental management. Before starting the study, the classification system, survey methods (survey scale, sampling density, sampling season, and data recording) and data analysis method should be agreed upon by stakeholder and line agencies considering the characteristics of the Indus River Basin environment.

8.8 RIVER HEALTH ASSESSMENTS AND INDICES OF STREAM CONDITION (ISC)

River health assessments are required to assess the river, floodplain and ecological condition in order to identify the most critical issues to protect and enhance. This will firstly require development of a suitable methodology and index system based on international experience[49]. The assessment metrics might include:

- River hydrology and the amount of water that is within the river channel at a particular point in time at a particular location. A minimum of 15 years of monthly flow data is used and high flow, low flow, no flow, seasonality and variability can be analysed.
- Water quality in the river based on an understanding of significant pollutants and their effect on aquatic life and other water uses.

[49] For example, https://www.water.vic.gov.au/water-reporting/third-index-of-stream-condition-report

- Aquatic life based on the number and type of aquatic macroinvertebrates, fish, birds, wildlife in and around the river.
- River form, bed and bank condition considers the riverbank condition as well as instream sedimentation, habitat (logs or 'snags'), sand and gravel mining, and major barriers to fish migration, such as dams and barrages.
- Streamside zone conditions considers wetlands, vegetation characteristics, land use.

Rapid assessment methodologies based around remote sensing with strategic field assessments can be used where there are limited field and technical staff and where there is a large river length for assessment.

8.9 INDICATIVE ACTION PLAN FOR IMPROVING ECOLOGICAL CONDITIONS AND USES IN THE RIVER BASIN PLAN

Table 8-1 provides a summary of action plans and studies required for implementation of a comprehensive plan to ensure sustainability of riverine ecosystem in the Indus River Basin.

Table 8-1: Indicative Action Plan for future studies

Project/activity	*Year 1-2*	*Year 3-4*	*Year 5-10*	*Lead agency*	*Involved agencies*
Develop methodology and undertake pilot study to determine flow requirements for Punjab rivers to improve ecological condition and river other uses[50]	√	√	√	*WRD*	*FWFD, PID, EPD, stakeholders who use or are impacted by the river, local governments*
Incorporate river flow requirements into water allocation plans			√	*WRC*	*WRD, PID*
Develop river health assessment, index of stream condition (ISC) indicators, standards and methodologies	√			*FWFD/WRD*	*EPD, WWF-Pakistan, PID, EPD*
Conduct and report river health survey and ISC for a complete year (Chenab River)	√	√		*FWFD/WRD*	*WWF-Pakistan,*
River health survey and ISC reports for Indus, Jhelum, Ravi and Sutlej rivers		√	√	*FWFD/WRD*	*PID, WWF-Pakistan, PID*
Preparation of river health assessment and ISC reports			√	*FWFD/WRD*	*WWF-Pakistan, PID, EPD*
Assessment of rivers for riverbank erosion, develop prioritized plan of protection and implement to restore them,		√	√	*WRD*	*PID*

[50] Dyson, M., Bergkamp, G., Scanlon, J. (eds). Flow. The Essentials of Environmental Flows. IUCN, Gland, Switzerland and Cambridge, UK. xiv + 118 pp

Project/activity	*Year 1-2*	*Year 3-4*	*Year 5-10*	*Lead agency*	*Involved agencies*
Training and capacity building for WRD, PID, FWFD and EPD staff on river health		√		*FWFD/WRD*	*PID, EPD*

WRD = Water Resources Department, PID = Punjab Irrigation Department, EPD= Punjab Environmental Protection Department;

9 FLOOD CONDITIONS IN THE BASIN

9.1 INTRODUCTION

This chapter builds on the Flood Risk Management (FRM) report contained in the ITPID Interim Report issued and approved earlier this year 2021.

9.2 THE NEED FOR INTEGRATED FLOOD MANAGEMENT

The term flood control implies a reliance on structural flood management measures. In practice, large structural measures on their own are rarely the best or most economically feasible solution due to the high natural variability of floods, which will eventually cause failure with high community costs. Human occupation and use of floodplains is at the core of integrated flood management which incorporates a flood risk management approach. This entails an analysis of the exposure to flood risks and implementation of a mix of structural and non-structural measures.

Structural measures involve civil works that aim to keep floodwaters away from people or property, whilst non-structural measures aim to limit exposure to risk.

Integrated flood management involves taking the most appropriate blend of structural and non-structural measures and it requires comprehensive assessment of flood management risks and measures at river basin scale. A narrower focus on local flood control and benefits leads to adverse impacts elsewhere such as downstream, or on the opposite riverbank. IFM also means considering the full economic, social, and environmental objectives for the greatest good and best outcomes for society.

9.3 DEFINITION OF FLOOD RISK

Figure 9-1 shows the Flood Risk Management Flowchart to understand how flood risk can be determined based on flood probability/frequency of occurrence and flood consequences/ damage.

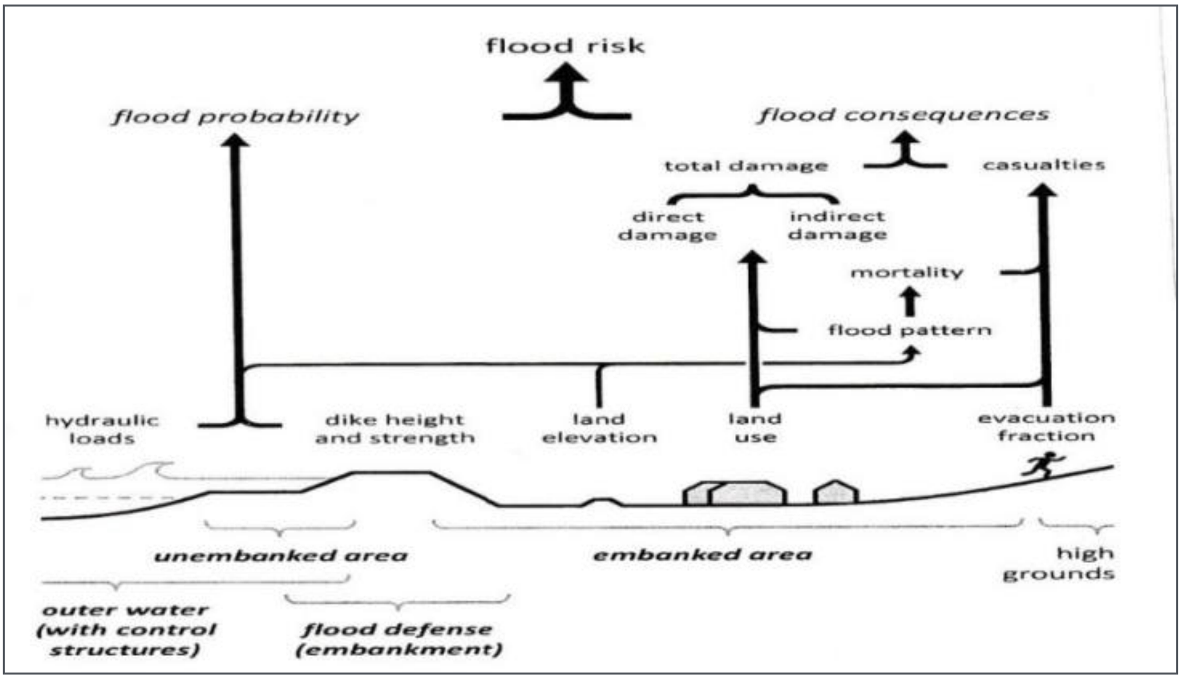


Figure 9-1: Flood Risk Management Flowchart

Flood risk is computed as the event frequency multiplied by economic/monetary damage to the various categories of FRM-related structural measures (refer to the Interim Report).

Flood Risk = Flood Event Probability X Flood Consequences (Damage)

9.4 CURRENT FLOOD SITUATION

Other than the Indus River, the major Punjab rivers are the 5-rivers: Jhelum, Chenab, Ravi and Sutlej-Beas. The Jhelum river discharges onto the Chenab river at the Trimmu barrage. After that, the Chenab river continues its trajectory toward the Panjnad barrage located about 100 km downstream. There the Chenab converges with the Sutlej river at the Panjnad barrage. From there, the Punjnad (Chenab) river acts as the collector for the other three upstream rivers and ultimately discharges into the Indus river about 40 km downstream from the Panjnad barrage.

The five rivers are individually all capable of causing severe flooding. Inundation usually occurs on the floodplains and low-lying areas round the rivers, potentially causing damage to irrigation schemes, road infrastructure, bridges and communication networks.

9.4.1 FLOOD EVENTS

Floods in Pakistan/Punjab usually occur in the summer season from July through October. The frequency of occurrence of floods in Pakistan has considerably increased in recent years. For instance, Pakistan experienced 5 consecutive large floods, in 2010, 2011, 2012, 2013 and 2014. These floods were caused by torrential rains during the monsoon season, exacerbated by snowmelt runoff. It is not clear whether these floods were caused by the impacts of climate change, but it is likely.

The flood of 2010 (**Figure 9-2**) was the worst of all recorded flood events. The rains/floods of 2014 (**Figure 9-3**) were devastating to private and public infrastructure in the Punjab. Torrential rains during first week of September 2014 in the north-eastern parts of the country, exacerbated by flood flows from India, resulted in exceptionally high flood discharges at various control points (barrages) on the river Chenab, Jhelum and Ravi. The unprecedented rains in northern Punjab (Lahore & Gujranwala Divisions) have caused severe urban flooding/flash flooding. The exceptionally high flood flows in the Jhelum and Chenab rivers and their tributaries (local Nullahs) have inflicted severe riverine/flash flooding in northern and central parts of the Punjab Province (Lahore, Gujranwala, Rawalpindi, Faisalabad, Sargodha and Multan Divisions). However, the rains/floods of 2010 were the worst on record.

Figure 9-2:Extent of 2010 flood event

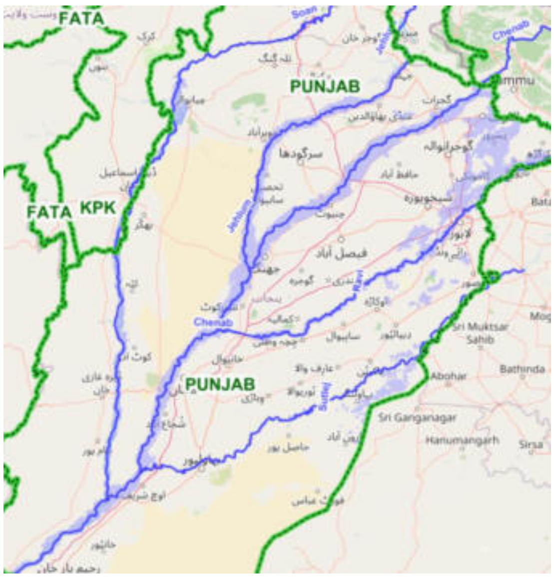


Figure 9-3: Extent of 2014 flood event

The evolution of flood events depends on the geographical extent and duration of regional rainfall and the evolution of related weather depressions. Typically flooding in the 5 rivers area would involve high flows discharging from the Trimmu barrage, continuing downstream over 100 km to the Panjnad Barrage, merging with flows from the Ravi river. However flood flows in the Ravi river are usually relatively small and do not pose extra flood risk to the Panjnad barrage. If the flood waves from Jhelum and Chenab arrive simultaneously at the Trimmu barrage, this is likely to cause an extreme flood downstream from the Trimmu barrage.

Sometimes exceptionally high flood flows in major rivers are generated due to the formation of temporary natural dams by landslide or glacier movement and their subsequent collapse.

9.4.2 FLOOD RISK

Figure 9-4, (WRMIS) shows the high risk (50 RPF) and low risk (5 RPF) zones of flooding and in Punjab this is along the Indus River and downstream of Panjnad barrage.

Significantly, the flood risk map (Figure 4) only identifies high and low risk along the Indus River and downstream of the Panjnad barrage. A map of the built-up areas in Punjab (Figure **9-4**) shows the distribution of population centres and where flood costs would be greatest. Urban centres are larger and more concentrated in the eastern half of the five river areas, with only low concentration of towns along the Indus river itself.

The PID FRAU has mapped the most vulnerable/flood-prone districts (Figure 6) from which it can be concluded that the flooding is mostly river-related (fluvial flooding). It is not clear what the partial contribution is from direct rainfall events (pluvial flooding as opposed to fluvial flooding).

Again, while this map assigns district flood risk, with cross reference to **Figure 9-4** it can be seen that there are areas of low settlement density, such as the lower left and right bank areas of the Indus river below the confluence with the Panjnad /Chenab river. This suggests that the maps are of flooding probability rather than of flood risk. This distinction is important in planning flood management investments.

It is noted that classified flood extents for all rivers, hill torrents and major 'nullahs' have been established, which implies that the Punjab Indus River basin has been adequately delineated into smaller sub-basins to the scale of rivers, effluents, hill torrents and 'nullahs'.

9.4.3 FLOOD DAMAGES

There is frequent occurrence of severe flooding in Indus Basin with loss of life, a very large number of affected villages and high flood costs (**Table 9-1**).

Table 9-1: Flood Damage in the Indus Basin, 1950–2011

YEAR	DIRECT LOSSES ($ MILLION)	LOST LIVES	AFFECTED VILLAGES	FLOODED AREA (KM^2)
1950	227	2,910	10,000	10,000
1955	176	679	6,945	6,945
1956	148	160	11,609	11,609
1957	140	83	4,498	4,498
1959	109	88	3,902	3,902
1973	2,388	474	9,719	9,719
1975	318	126	8,628	8,628
1976	1,621	425	18,390	18,390

YEAR	DIRECT LOSSES ($ MILLION)	LOST LIVES	AFFECTED VILLAGES	FLOODED AREA (KM²)
1977	157	848	2,185	2,185
1978	1,036	393	9,199	9,199
1981	139	82	2,071	2,071
1983	63	39	643	643
1984	35	42	251	251
1988	399	508	100	100
1992	1,400	1,008	13,208	13,208
1994	392	431	1,622	1,622
1995	175	591	6,852	6,852
1998	N/A	47	161	161
2001	N/A	201	N/A	N/A
2003	N/A	230	N/A	N/A
2010	10,056	1,600	N/A	N/A
2011	66	516	38,700	38,700

Sources: Government of Pakistan, Ministry of Water and Power, Federal Flood Commission. 2006. Flood Protection Plan, 2006. Islamabad.

9.5 THE FLOOD MANAGEMENT APPROACH

The traditional management response to severe floods in Pakistan was an ad-hoc reaction i.e. a quick implementation of a civil engineering/hydraulic structure projects that considered both the problem and its solution to be self-evident, and that gave no thought to the consequences of flood risks for upstream and downstream areas of the river basin. Thus, flood management practices have largely focused on mitigating flood intensities and reducing their localized damages to private and public property. Traditional flood management has employed both structural and non-structural interventions, besides physical and institutional interventions. These interventions were employed prior, during and after flooding and have often overlapped.

The traditional flood management interventions in Pakistan may be interpreted as follows:

- Source control to reduce runoff through reforestation and groundwater recharge (potential FRM risk reduction);
- Separation of rivers and populations through floodplain mapping and zoning, removal of illegal encroachments (potential FRM risk reduction);
- Emergency management during floods through flood forecasting and early warning (potential FRM risk reduction);
- Post-flood recovery through monetary compensation of flood-affected people and restoration of damaged public infrastructure (potential FRM risk reduction).

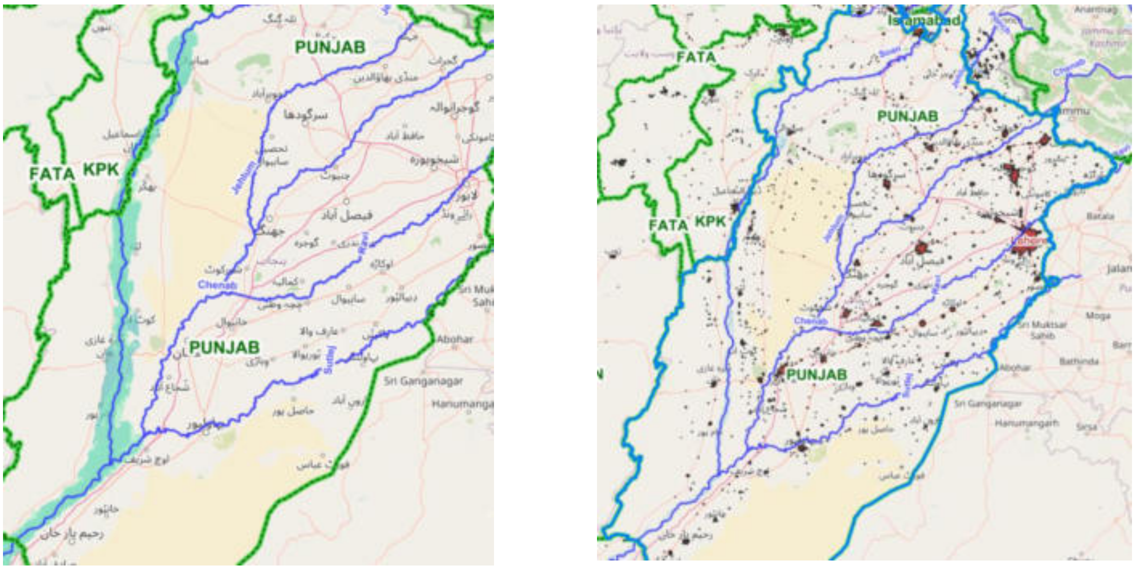


Figure 9-4: Flood risk map (high and Low Risk and Build up areas within Punjab Province

District	Risk	District	Risk	District	Risk	District	Risk
Bhakkar	A	Muzaffargarh	A	Kasur	B	Khushab	C
DGKhan	A	Narowal	A	Khanewal	B	Lodhran	C
Gujranwala	A	Rajanpur	A	Gujrat	B	Nankana	C
Hafizabad	A	RYKhan	A	Lahore	B	Faisalabac	C
Jhang	A	Sialkot	A	MBDin	B	Rawalpindi	C
Jhelum	A	Sheikhupura	A	Okara	B	Sargodha	C
Layyah	A	Bahawalpur	B	Pakpattar	B	Attock	C
Mianwali	A	Bahawalnagai	B	Sahiwal	B	TT Singh	C
Multan	A	Chiniot	B	Vehari	B	Chakwal	C

Figure 9-5: Punjab Districts Flood vulnerability

In principle, this listing of potential interventions is adequate, but the FRM-oriented approach is missing as it entails more than the above interventions alone, e.g. the ranking of floodable areas in accordance with their respective assigned flood risks (risk = frequency x damage cost). Moreover, Pakistan is currently building new dams which will impact river flood flows and the FRM approach in general.

9.5.1 FLOOD FORECASTING AND WARNING

The Flood Forecasting Division, Lahore, the specialized unit of Pakistan Meteorological Department, plays a pivotal role in flood forecasting and warning. They obtain hydro-meteorological data from various national and international sources, which is then analysed to produce weather and flood forecasts and warnings which are disseminated to the various Federal/Provincial organizations and electronic/print media. They are also uploaded on Pakistan Meteorological Department website.

9.5.2 FLOOD PROTECTION AND DAMAGES

The predominately fluvial mechanism for flooding means that riverbank erosion occurs quite often. In the upper part of the Indus Basin (Punjab & Khyber Pakhtunkhwa) floodwater may spill over both riverbanks, but generally the spill-over waters flow back to the main river as the flood wave passes. This differs from the lower Indus basin in Sindh province (outside

the study area), where the river is at a higher elevation than adjoining lands, hence, spilled flood waters do not return to the main river channel. This flooding usually inundates a large geographical area causing significant damage to standing crops and private and public infrastructure.

Usually, flood damage is repaired, and infrastructure reconstructed after flooding, either by federal and/or provincial agencies. The most frequently applied flood protection measure consists of levees or earthen embankments. These generally include provisions for deliberate breaching, with explosives or excavators, to prevent uncontrolled overtopping of embankments which can result in severe damage to vulnerable infrastructure and extensive damage to embankments. Embankments are breached where the damage will be lowest. This system is well known and is successfully applied. The existing barrages are also equipped with an embankment breaching section. That is why, no barrage has been overtopped/damaged by extreme floods.

The barrages are all equipped with electrically powered offtake structures at both riverbanks to feed main canals and these are operated to cap the maximum discharges into the irrigation main canals. As a result, irrigation canals usually do not overtop and inundate farmlands. On the other hand, high rainfalls in the irrigated areas may cause local flooding and related damage for which there is no protective provision other than surface drains. This local pluvial flooding may cause damage to the canal system and farmer's livelihood. In hill torrent areas, addressed in another chapter, irrigation schemes are located in the flat valley area surrounded by hilly areas from where pluvial runoff may cause flash flooding.

River training works designed to train the thalweg channel of a river and/or to stem the development of so-called 'BELA'/shoaling, has been applied upstream of barrage sites.

Legal and illegal encroachments on flood plains are intensively being used for agriculture, fishery, industrial estates, commercial and residential development and also cheap housing. This development hinders flood flows resulting in worse local flooding and prolonging inundation. The land use situation addressed under a legalized spatial land use plans (maps). There do not appear to be such spatial plans.

Floods might be caused or worsened by the deliberate release of additional flood waters from the upper catchment reservoirs/barrages in Pakistan or in India as is the case for the Ravi and Sutlej-Beas rivers. There are mechanisms to improve the operations of reservoirs in Pakistan, however this is not the case for those rivers where an upstream country is active in water storage and management, as there are no effective international flood data sharing and warning systems, including for breaching ice dams.

9.5.3 FLOOD MANAGEMENT DATA AND INFORMATION

Water level and streamflow gauging data is important as it can be used to inform flood forecasting and to calibrate flood routing models. Flood routing models can be used to assist with flood forecasting, map flood liable areas, assess the existing flood risk and assess flood management/mitigation measures. Accurate digital elevation models (DEM) are required to establish reliable flood routing models, especially where landscapes are flat.

River discharges are measured at the rim stations and river barrages (**Figure 9-6**). The flood monitoring network and flood estimation procedures should be reviewed according the WMO guidelines and improved where necessary.

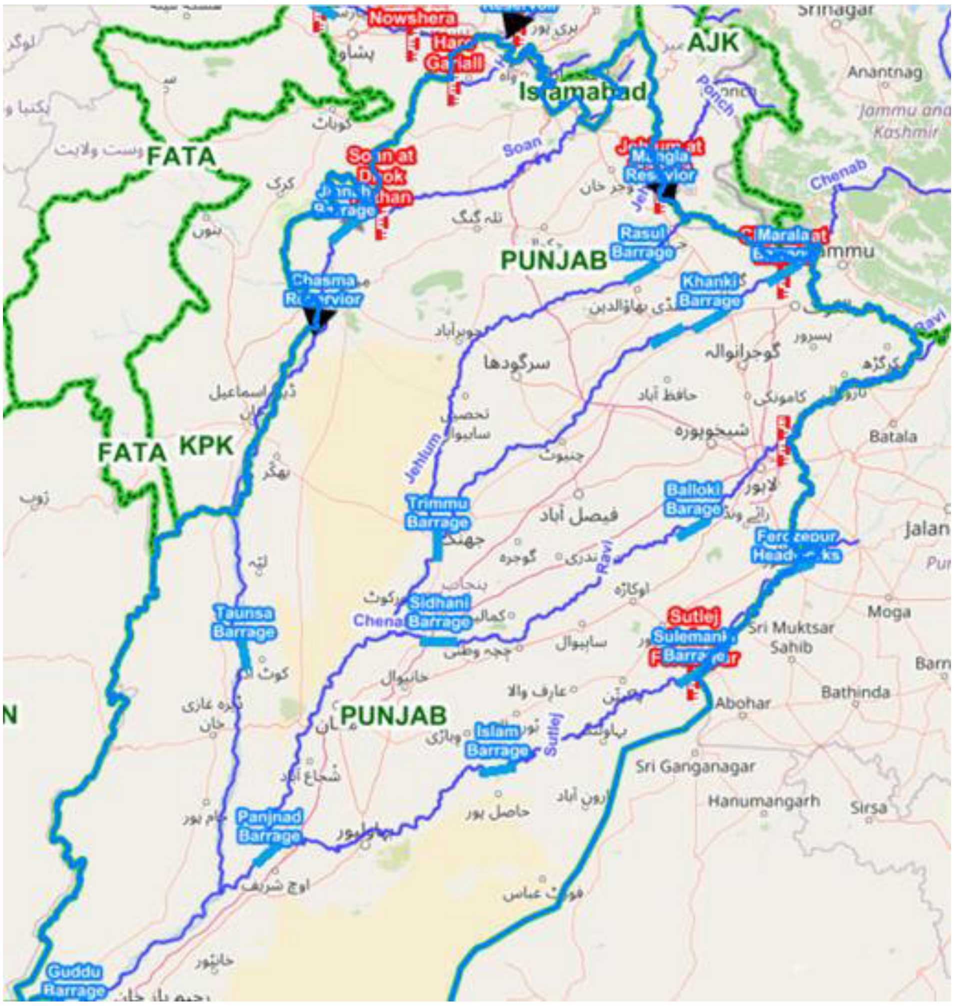


Figure 9-6: River discharge gauging stations, Rim Stations (red), Barrages (blue)

9.5.4 FLOOD REPORTING

Two Punjab flood reports published by the Federal Flood Commission. have been reviewed as part of this study, namely the flood report for 2010 and flood report for 2014. It was found that the information provided in these flood reports is generic and not sufficient to enable assessment of the current policy of structural measures in line with the Punjab Water Policy 2018. Moreover, damage cost data is aggregated and does not permit calculation of flood risk per sub-basin.

It is recommended that future flood reports be improved to provide more useful information. The flood reports produced by European Union countries , should be used as templates for future flood reports. They are especially useful where they provide detailed data on rainfall and runoff and related detailed mapping products and statistical frequency analysis, the mechanism/ genesis of floods and their management.

Punjab should produce its own flood reports addressing local problems and solutions. The local flood reports could be improved by including: reference to relevant organisations and their activities; weather drivers and conditions; flood genesis, analysis, status and impacts; the adequacy of flood forecasts; all control measures (structural and non-structural) and their performance; land use and the status of spatial planning; the future actions to be implemented to address specific problems and responsibilities for implementing these; post flood recovery; the impact of climate change on the frequency and magnitude of the extreme floods; ample use of maps including detailed maps of hotspot areas; update of hazard and risk maps; and, reports should be produced annually.

9.6 STRUCTURAL MEASURES FOR IMPLEMENTING THE FRM APPROACH

A range of structural measures can be implemented to reduce flood risk, which are shown in **Figure 9-7**. On the left side of the sketch is the flood-protected area, whilst on the right is the river with potential flood protection works including river widening, river deepening and construction of dikes/embankments.

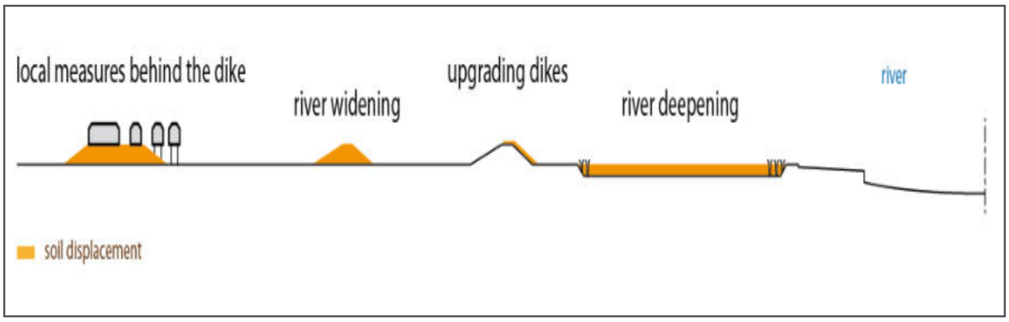


Figure 9-7: Structural measures to reduce flood risk

These three structural measures have been widely applied with success across Europe and could potentially be applied to the Punjab rivers. These measures will have an impact on the hydraulic and morphological conditions of a river (refer to the Interim Report).

9.6.1 FIVE PHYSICAL ELEMENTS IN LINE WITH THE PUNJAB WATER POLICY 2018

Areas is the floodplain can be grouped into the following categories:

A. **Embanked areas**: Areas which are protected from flooding by embankments, termed flood protection levees.

B. **Embankments or flood structures**: The flood structures/embankments that protect selected areas from flooding.

C. **Unprotected areas**: Areas which are not protected by flood structures. This includes areas on the floodplain that are inundated and areas that have elevations above the maximum flood height that are not exposed to flooding.

D. **Natural Waterways**: Rivers, lakes and wetlands which hold permanent water, or are regularly inundated. These often include important eco-systems.

E. **Control structures**: Structures across the rivers and lakes which are used to control floods including barrages, dams, water intake structures, canals, embankments, river training works.

Flood maps can be generated to assist in identifying flood risks and developing flood management responses. Maps can be generated that show:

- The depth, flood level, flow velocity and extent of inundation for floods of various recurrence intervals (frequency of occurrence).
- Location and type of development – agriculture, housing, industry.
- Areas defined by hydraulic category such that:
    - Areas that convey flows are categorised as floodways
    - Areas that have contain deep water (say more than 0.5 m) but low velocity are categorised as flood storage.
    - Areas with shallow water and low velocity are categorised as flood fringe.

The hydraulic category plays an important role in floodplain zoning. Generally, development should not be permitted in floodway zones. New development in floodways should not be approved, whilst attempts should be made to relocate development that already exists in floodways.

Development in flood storage zones may be permitted provided adequate provisions are made to protect the development from floods AND provided it can be demonstrated that the development does not impact flooding elsewhere, as a result of removal of flood storage. It needs to be understood that when flood water spills out into a floodplain the floodwaters are temporarily stored and this reduces the flood discharges further downstream. If the floodplain is filled by development, then this can reduce the flood storage and cause downstream flood flows to increase, which increases downstream flooding. Flood planning should avoid this.

Generally, development in flood fringe areas will be permitted because the flood risk is low and the potential impact on flooding elsewhere is low.

Mathematical models are used to produce the above flood maps. They may be composed of multiple sub-models provided by multiple stakeholders/organisations and then knitted together by policymakers (PID Management).

9.6.2 STRUCTURAL MEASURES ADOPTED IN PUNJAB

The Flood Report 2014 provided aggregated data on structural measures implemented for flood protection but did not provide a detailed breakdown by sub-basin or river stretch. Useful information would include a description of the infrastructure including the location (maps), asset condition, dimensions and costs (construction and maintenance). This information is indispensable to compute flood risk values for water infrastructures in the Punjab River basin and future studies should seek to develop this information.

The extent of flood management infrastructure in the Indus Basin of Pakistan is shown in **Table 9-2.**

Table 9-2: Flood Management Infrastructure in the Indus Basin, Pakistan

Name of Province	Embankments (km)	Spurs (No)
Punjab	3,334	496
Sindh	2,424	46
Khyber Pakhtunkhwa	352	186
Baluchistan	697	682
TOTAL	**6,807 km**	**1,410**

Source: Government of Pakistan, Ministry of Water and Power, Federal Flood Commission. 2011. Annual Report 2010. Islamabad.

Figure 9-8 shows the flood control levees and built-up areas in Punjab. Embankments are a standard application at/around barrages and large dams, around irrigation schemes, towns, villages and adjoining agricultural lands. In general, embankments are very much appropriate to be constructed in areas with high flood risks situation (flood risk mitigation). There are numerous types of spurs or groynes for application along riverbanks and their effect, benefit and detailed design of such structures are well known. These measures are not meant to reduce flooding as the structures themselves can be flooded and submerged by passing flood flows in the river.

As stated here above, five types of physical interventions can be devised to reduce the flood risk in rivers. Hence, embankments or levees or low-height earthen bunds are just one of the many potential options. It is assumed that the other options have not been applied in the Punjab River basin.

It is evident from **Figure 9-8** however that there are extensive levees along the lower Indus and Panjnad/Chenab rivers in Punjab. These areas however are not densely populated, and it can be speculated whether such systems are the most appropriate flood management infrastructure for these locations.

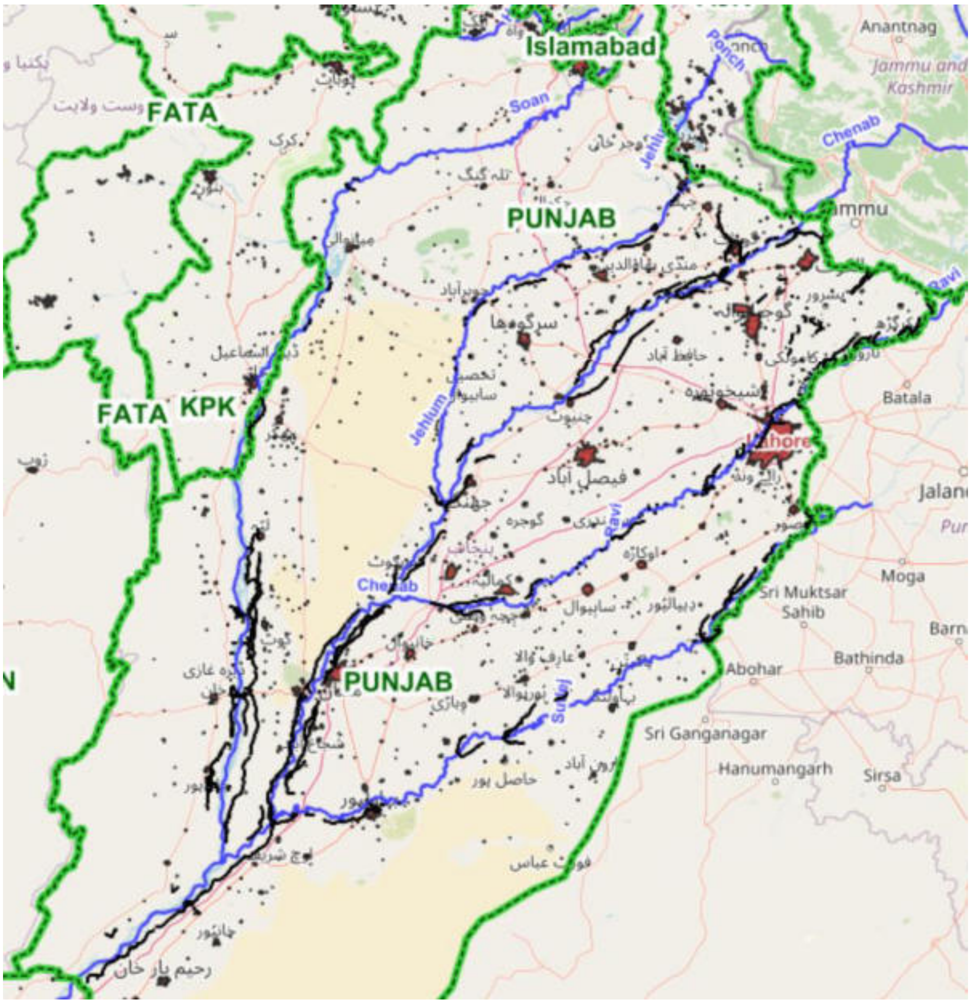


Figure 9-8: Flood infrastructure and build up areas

There appears to be no asset inventory or asset management plan with information on flood management infrastructure such as their effectiveness, age, condition, damage/failure, repairs and proposals for new structures.

The operation and management of the three large reservoirs Tarbela, Chashma and Mangla is undertaken by the federal agency WAPDA under the direction of the Indus River System Authority. It is assumed that WAPDA manages this task adequately, avoiding sudden releases that might create downstream flooding. The risk of human-induced flood disaster is therefore not addressed by the ITPID TA.

9.7 INSTITUTIONAL ARRANGEMENTS AND WATER RELATED LEGISLATION

Institutional arrangements for flood management are reported in detail in the ITPID Interim Report and will be addressed in detail in the ITPID report on institutional arrangements and strengthening. There is a large library of related legislation in Pakistan which is described in **Table 9-3**.

Table 9-3: Major Water-Related Legislation in Pakistan

ORGANIZATION	ORGANIZATION
• Water and Power Development Authority Act, 1958	• North-West Frontier Province (NWFP) Canal and Drainage Act, 1873
• Territorial Waters and Maritime Zones Act, 1976	• NWFP Irrigation and Drainage Authority Act, 1997

ORGANIZATION	ORGANIZATION
• Indus River System Authority Act, 1992	• Punjab Minor Canals Act, 1905
• Environmental Protection Act, 1997	• Punjab Minor Canal (North-West Frontier Province Amendment) Act, 1948
• Provincial Water Accord, 1991	• Punjab Soil Reclamation Act, 1952
• Balochistan Ordinance 1980	• Punjab Canal and Drainage Act, 1873
• Balochistan Water Supply Regulation 1941	• Punjab Water Users Association Ordinance, 1981
• Balochistan Pat Feeder Canal Regulation ,1972	• Punjab Irrigation and Drainage Authority Act, 1997
• Balochistan Canal and Drainage Ordinance, 1980	• Sindh Water Users Association Ordinance, 1982
• Balochistan Coastal Development Authority Act, 1998	• Sindh Irrigation and Drainage Authority Act, 1997
• Balochistan Irrigation and Drainage Authority Act, 1997	• Sindh Irrigation Act, 1879
• Balochistan Groundwater Rights Administration, Ordinance, 1978	

Source: Indus River Floods, Mechanism, Impacts and Management 2015 ABD

9.7.1 INVOLVED AGENCIES

Flood management tasks and activities in the Punjab are being handled by a large number of national and provincial agencies which are listed in (**Table 9-4**).

Table 9-4: Organisations involved in flood management in Punjab Province

ORGANIZATION	RESPONSIBILITY	STATUS
Pakistan Commissioner for Indus Waters	Coordinates with India on floods in the transboundary rivers	National
Water and Power Development Authority (WAPDA), Ministry of Water and Power	Operates and manages the Mangla and Tarbela reservoirs and manages hydrometeorological data	National
Federal Flood Commission (FFC) Ministry of Water and Power	Prepares and coordinates implementation of national flood protection plans, and conducts oversight of flood forecasting and warning	National
Pakistan Meteorological Department (PMD)	Forecasts rainfall and flood, and issues warnings	National
Flood Forecasting Division	Conducts model simulations, forecasts flood, and issues warnings	National
Emergency Relief Cell, Cabinet Division	Coordinates relief operations at the national level	National
National Disaster Management Authority (NDMA)	Conducts oversight and coordination of disaster management including rescue and relief operations, at the national level	National

ORGANIZATION	RESPONSIBILITY	STATUS
Provincial Irrigation Departments	Constructs, manages, operates, and maintains barrages and flood protection works, and implements protective measures	Provincial
Provincial disaster management authorities	Coordinates with other provincial departments, including for rescue and relief operations	Provincial
District Administrations	Conducts relief and rescue operations at the district level	Provincial
Other relief organizations, NGOs	Manages post-flood relief operations at the provincial level	Provincial
Pakistan Army	Assists the civil authorities in real-time flood fighting and rescue and relief operations	National

Source: Indus River Floods, Mechanism, Impacts and Management 2015 ABD

The role of pivotal agencies PID, WAPDA, PMD and FFC in flood management is described below:

(a) The Punjab Irrigation Department (PID)

The PID plays a frontline role in flood management, flood fighting and flood mitigation. Major flood-related functions include: the operation and maintenance of barrages; the measurement of discharges at specific sites (barrages/headworks) in rivers, irrigation & drainage networks, and the flood management facilities; planning, design, construction and maintenance of irrigation, drainage, flood protection and river training works; collection and dissemination of river flow data to the FFD Lahore, FFC and other concerned organisations for flood management activities; establishment and operation of the flood warning centre during the monsoon season each year for sharing flood flow data and other information, besides timely processing and dissemination of the flood forecasts/early warnings to concerned quarters; preparation and implementation of the annual flood fighting plans during every monsoon season. The PID has a leading role in flood management practice across the Punjab.

Flood Risk Assessment Unit (FRAU}

FRAU was established in 2016 as a part of PID aiming to improve flood management in Punjab. Its term of employment for staff ends on 30 June 2022 unless there is an extension. The current staffing strength of FRAU consists of 31; 16 Officers and 15 Officials. The terms of reference for the FRAU are to:

i. Develop a province-based run-time flood monitoring and management system.
ii. Forecast time and volume of a specific flood peak likely to pass at a specific location.
iii. Issue and disseminate of Flood Forecasting Report on daily basis during the flood season (15 June to 15 October).
iv. Identify villages likely to be inundated for a specific range of floods.
v. Map and disseminate inundation maps for better decision making and flood fighting.
vi. Extract flood paths and identify areas/villages under risk of breach of canal or flood bund.
vii. Collect all relevant data for assessment of the flood risk.
viii. Monitor storms and extract Rainfall hazard zones in river catchments.

While FRAU is making progress with these tasks, the terms of reference do not fully reflect a comprehensive approach to flood risk management. In particular an FRM-oriented approach should be embedded in the FRAU cell organisation, under

the PID umbrella. This will require good data sharing and data exchange for mathematical modelling and flood scenario studies with WAPDA and PMD.

(b) Water and Power Development Authority (WAPDA)

WAPDA is a national agency actively involved in the flood forecasting process as it provides hydrometric flood data, water levels and discharges for major reservoirs (Tarbela, Chashma, Mangla) to the FFD Lahore, the FFC and other concerned organisations. It collects river flow and rainfall data through its own Flood Telemetric System/gauging stations in the catchment areas of the major rivers . WAPDA supports another hydrometric data measurement and transmission system through its Surface Water Hydrology Project. WAPDA's Flood Telemetric Network is directly linked with the FFD cell in Lahore. FRAU is one of the many end-users of WAPDA data and maps for its own work on flood forecasting and early warning in the Punjab.

(c) Pakistan Meteorological Department (PMD)

The PMD as a national agency has its specialised Flood Forecasting Division (FFD) in Lahore. It works together with WAPDA for the flood forecasting and early warning system activities, whilst FRAU takes care of flood forecasting and early warning within the Punjab only. The FFD Lahore acquires the necessary hydro-meteorological data from the various national and international sources, which are then analysed to produce the weather forecasts, flood forecasts and early warnings. These products are then disseminated to various Federal/Provincial organisations and electronic/print media and also uploaded in the PMD/FFD Website. It employs a range of technical facilities to assist with its forecasts including the Indus River system mathematical model which computes stream hydraulics, including stage and discharge hydrographs, to estimate the areas vulnerable to inundation for early flood warning targets.

(d) The Federal Flood Commission (FFC)

The FFC is a national/federal agency currently in charge of the Flood Plain Mapping & Zoning Studies for the identification/inventory of flood hazard/ flood risk in flood plains/waterways and to make a comprehensive plan for the removal of river encroachments and formulate restrictions on future settlements in flood-prone areas. These hazard maps are useful/indispensable for the FRM activities.

9.8 IMPROVING THE FRM APPROACH

Much can be learned from the European approach to FRM.

9.8.1 A COMPREHENSIVE APPROACH TO FLOOD MANAGEMENT

Unfortunately, due to the covid19 pandemic situation it was not possible to visit Punjab and review the detailed flood management plans. Nevertheless, the key elements of the FRM approach and the situation in Punjab are as follows:

(a) **Institutions**: There are many institutions and levels of government involved in flood management in Punjab which confuses responsibilities and interferes with swift and clear communication. The preferred approach is to have one line-of-command with one coordinator/director/manager endowed with a full mandate to act on behalf of the national government. This institutional deficit was also observed in the recent floods in Germany, Belgium and the Netherlands. The lack of coordination has exacerbated the risk to human lives including drownings due to delayed rescue.

(b) **Data and information management**: There appears to be inadequate meteorological, radar, water level and discharge data across Punjab province. This includes inadequate density of gauging stations and poor or missing rating curves. Moreover, a combined national database such as prescribed by WRMIS does not exist. There is also a lack of flood plain mapping products to underpin a flood risk management approach. In many European countries such database and mapping products including detailed spatial planning maps are publicly available.

(c) **Flood planning**: Flood planning is an important component in European countries. Planning usually involves extensive consultation with the stakeholders and the wider public. This ensure the flood maps are reviewed for accuracy and the Plans are developed in a manner that suits the needs of stakeholders. It needs to be acknowledged that this approach takes many years and there is a need to deal with floods as they occur.

(d) **Flood preparedness**: In most European countries, flood preparedness activities are devolved to the sub-basin authority/waterboards by national/federal laws on water management and implemented according to the sub-basin spatial planning and flood plain planning maps. These local authorities act together with the city mayors and disaster management activities rest also in the hands of the same low-level government/technical entities.

(e) **Flood forecasting and warning**: Flood forecasting and early warning activities in European countries are the responsibility of the national/federal agencies who then inform the public and issue further orders to the same low-level agencies, including the city mayors. Provinces and cities have their own TV and radio broadcasting system for news dissemination 24/7. Most of the national rivers are transboundary rivers and international cooperation among riverine states was well established decades ago and are well managed, e.g. under the one unified comprehensive European Union directives and guidelines system. Some shortcomings still exist e.g. differences between digital and analogue systems and the risk that power might get cut during floods resulting in gsm/mobile and telephone antenna breakdown.

(f) **Flood protection**: Flood protection measures are continuously being implemented in Europe, a non-stop government policy. Billions of Euro funds are made available every year. O&M costs, repair costs, engineering adaptation costs are provided by the federal government. All possible non-structural measures are being considered to complement structural measures. Non-structural measures include land use planning and zoning, building controls, flood forecasting, flood warning, evacuation, flood awareness campaigns.

(g) **Flood disaster management**: Flood disaster management in European countries is usually entrusted to lower-level institutions such as city mayors and waterboards. These services are well equipped in terms of human and material resources and can draw assistance from NGOs, citizen volunteers, Red Cross, Fire Brigades, Police, Military and private sector stakeholders. The national government usually declares an emergency Situation which allows the government to swiftly allocate funding. The causes of flooding are usually well researched, and the unfolding flood disaster is well monitored through mathematical modelling and remote sensing and mapping. In doing so, the local authorities are enabled to disseminate warnings to the flood-affected people and implement evacuation measures. At the conclusion of floods the repair of the damaged roads is a top priority for the local authorities. Currently there is not a single organisation responsible for coordinating the multi-sector group of first responders, which is a deficiency. Recovery from large floods may take many years.

(h) **Flood recovery**: Flood recovery is the last stage in disaster management. Recovery deals with returning evacuees to their homes, cleaning of affected homes etc, removing of debris to a site outside the floodplains, repair of gas, water, electricity and other public amenities. The recovery of the damage costs/subsidies is done through the national government in cooperation with insurance companies. The recovery phase may take a very long time, e.g. five years, which is too long, due to the cumbersome process and procedures to settle the submissions and to settle and honour their payment claims.

9.8.2 A WHOLE OF LANDSCAPE APPROACH:

Using elements of FRM some important and relevant lessons are from European experience:

(a) **Water shedding areas** will cause flash flooding as they come progressively ‘harder’ such as by deforestation of small catchments, flow path straightening, increasing impervious areas such as from housing and sealed areas (e.g. roads). Strict control of deforestation of watersheds is important to reduce flash floods, erosion, and

downstream sedimentation. The effect of new developments on catchment hardening should also be considered and measures put in place to slow runoff and increase local storage.

(b) **Floodplains** have been reduced to less than half of their original extent (which reduces flood storage and increases downstream flooding. Measures need to be taken to reactivate the encroached parts of the floodplains through relocation/removal of buildings and hydraulic structures/embankment.

(c) **Flood retention basins and dams** attenuate flood peaks in many flood-affected river catchments and are an effective structural flood management option.

(d) **Localised management** is more effective than a centralised/federal approach. Local governments are able to be to act swiftly when a flood occurs and therefore, they must be endowed with wider mandates. This local approach is also true for the post-flood disaster management phase of rescue, recovery and reconstruction. Moreover, such decentralised approach is very effective in small catchments in case of frequent flash floods, aiming at the management of wetlands, erosion control and restoration of nature processes.

The current flood management approach involves breaching embankment adjacent to barrages to protect the barrages when the flood peak is about to exceed design barrage capacity. However, there is generally no planned, safe route for the released water and as a result the emergency release causes significant local damage. Construction of a safe escape channel, using natural flow paths for this water, should be a part of any new barrage construction plan and safe escape channels should be constructed at existing barrages.

9.8.3 IMPROVING THE WORKS APPROACH.

Flood works such as dikes (flood embankments) aim to reduce flood damage, mainly to irrigation infrastructure and crops, but also urban areas. Construction of dikes constrains the flood flow and can cause upstream flood levels to increase which can exacerbate flooding in other areas. The dykes also diminishes the drainage capacity of the floodplain. Construction of spurs to protect lands/villages from stream erosion from meandering stream can result in erosion elsewhere, essentially transferring the problem. It is therefore important when design flood protection and erosion control works to understand the broader impacts and adopt designs that avoid transferring the flooding and or erosion problem. This requires an understanding of river morphology and flood behaviour.

9.8.4 OPERATION AND MAINTENANCE OF FLOOD INFRASTRUCTURE

Embankments or levees have been a long tradition in flood management, especially along large rivers. However, these are effective only if they are well maintained and design levels are not exceeded by fresh extreme floods. Overtopping and/or breaching (failure) of embankments can create destructive damage. Annual monitoring, repair, maintenance and reassessment of the structural strength/FRM is absolutely critical. It is inevitable that a flood will eventually occur that is larger than the embankment design flood and it is therefore strongly advised to design over topping locations. In these locations the embankment crest will be locally depressed to allow overtopping to occur at this selected location. The embankment should include erosion protection to prevent failure of the embankment. The spill location will be selected to allow safe passage of overflows.

9.8.5 COMMUNICATIONS

Communication during flood emergencies between the authorities and flood-affected people shows many shortcomings. Residents are often not aware of the flood risks including how frequently the area may flood, the depth of flooding, potential flow velocities or flood warning times. They are not informed about suitable flood responses, such as evacuations or when certain responses should be triggered.

Residents mostly acknowledge that embankments do not provide 100% flood protection, nevertheless, potential embankment overtopping and failure scenarios must be presented more transparently and consistently to local residents.

To overcome common communications problems, a wide information campaign can be envisaged, which should include the setup of flood marks, compilation and dissemination of hazard maps, creative educating ideas, as well as the communication of precautionary and coping strategies. Flood hazard and risk maps should be provided/ disseminated by local governments and also made publicly available and accessible on the internet and social media.

It is often not sufficiently clear to flood-prone people whether they live in a flood-prone area or how to protect themselves against flood risks. To further improve flood risk information and communication, the setup of a joint and nationwide natural hazard portal and related information campaigns of the federal government, the federal states, local governments, municipalities and NGOs/other relief organisations are recommended. In other words, information on flood hazards and coping measures should be readily available.

9.8.6 HYDROMETEOROLOGICAL MONITORING AND FLOOD FORECASTING

It was observed in Punjab that small/hilly river basins including hill torrents are not equipped with hydro-meteorological and hydrometric gauging stations, making the forecast of floods impossible. There is little interest to study smaller river basins. Generally, the density of gauging stations across Punjab is insufficient. Therefore, more gauges should be installed across the Punjab river basin, namely rain gauges, water level gauges, radar weather data/maps, flow and sediment transport gauges, along with the remote sensing products for quantifying the geographical extent of floods/submerged flood plains.

9.8.7 SPATIAL PLANNING AND LAND USE

It is widely understood that to reduce flood damage the prevention of urban development and infrastructure in flood-prone areas should be a top priority, with emphasis on own-house-and-backyard-flood prevention measures. Legal rules for governing the development in flood-prone areas should be formulated clearly and unambiguously.

Currently, there is no control of the use of the floodplain and economic developments have continued including housing, commercial, industrial developments. This serves to increase the number of people and properties at risk during flood events, resulting in increasing flood damages and loss of life. In the event of floods, losses have increased many fold. An important control over the floodplain can be banning of the amenities like the municipal water supply, electricity and the pipes gas supply to the development works residential or commercial.

9.8.8 EMERGENCY RESPONSE

In regard to emergency response, it is observed in Punjab that:

- Early warning systems may fail due to damage to telephone and internet antenna systems and/or power cuts;
- Confusion occurs between federal, provincial and municipal levels on who is doing what;
- Transport routes (road and rail) may be flooded or damages rendering access to the devastated areas for the first responders impossible;
- NGOs and volunteers are impeded to help the flood victims;
- Public health services are unable to set up a rescue action at short notice (complicated logistics and terrain conditions) or know when and where to intervene;
- Food and medicine are not immediately available to isolated flood victims;
- Red Cross and representatives of different relief and aid organisations face difficulties to participate in the rescue and recovery activities (lack of one umbrella coordinator);
- Military and police assistance are often triggered at a late phase;

- Access to the flood victims through rivers may be difficult due to dangerous flow conditions which impeded evacuation to safer places;
- There was no coordinator to control cross-sectoral field actions with full mandate to act on behalf of the national government; and
- Due to the above factors, emergency response, rescue and recovery responses often underperform.

9.9 FUTURE DIRECTIONS

9.9.1 PUNJAB WATER POLICY

For flood management, the following policy should be adopted:

- An Integrated Flood Management approach embedded within IWRM is to be adopted
- Flood protection facilities (embankments, spurs) should be regularly maintained annually and new structures constructed where required on the basis of model studies
- Design, maintenance standards and operation rules for barrages should be reviewed and updated
- Flood Plain Maps and Flood Protection Plans should be updated regularly
- Coordination be enhanced with WAPDA for reservoir operation of Mangla Dam
- Hill Torrents Flood Management Plans be developed and implemented. Watershed Management Plans be prepared and integrated with flood management
- Drainage plans of urban and rural areas be developed
- A 'River Act' to be enacted to address flood zoning and development controls along all rivers
- Coordination with PMD be carried out for early flood forecasting and warning
- Community participation be encouraged for flood zoning, disaster management and relief
- Adequate revenue be provided for maintenance and management of flood infrastructure

9.9.2 INDICATIVE ACTION PLAN FOR FLOOD RISK MANAGEMENT.

An initial action plan, consistent with the Punjab Water Policy, for strengthening flood management in the Punjab Indus Basin is presented in the following table. Recommendations for structural works have not been included as it was not possible to obtain details to review projects being considered by PID.

Table 9-5: Indicative Action Plan

PROJECT/ACTIVITY	YEAR 0-1	YEAR 2-5	YEAR 6-15	LEAD AGENCY	INVOLVED STAKEHOLDERS
STRENGTHENING OF FRAU					
Review and update a compressive mandate for flood management within IWRM for frau	√			PID	WAPDA
Recruitment of staff with required technical skills	√	√		PID	WAPDA

PROJECT/ACTIVITY	YEAR 0-1	YEAR 2-5	YEAR 6-15	LEAD AGENCY	INVOLVED STAKEHOLDERS
Provision of resources to enable FRAU to execute its duties including training of the FRAU staff at international level	√	√	√	PID	WAPDA
FRAU prepare a business plan for its strengthening and priority projects to strengthen flood management in Punjab				PID/FRAU	WAPDA, PMD, local governments, universities and institutes, civil society
Develop innovative flood management approaches based on international best practice and by conducting research				PID/FRAU	WAPDA, universities and institutes
Prepare best practice notes and guidelines, and standards for operational agencies				FRAU	WAPDA, PID, district governments
International and national flood management specialists to assist PID and frau implement a comprehensive and effective approach to flood management	√	√	√	PID/FRAU	Consultants
DATA AND INFORMATION					
Strengthen the hydrometeorological and river discharge monitoring network		√	√	PID/FRAU	PMD, WAPDA
Undertake flood mapping studies			√	FRAU	WAPDA, consultants
Develop and apply flood models for flood planning and flood warning		√	√	FRAU	WAPDA, consultants
INTEGRATED FLOOD PLANNING					
Prepare a proper risk based provincial flood management plan	√	√		FRAU	WAPDA, district governments, civil society, consultants
Develop and implement a spatial (zoning) system with community participation		√	√	PID/FRAU	WAPDA, district governments, civil society, consultants
Develop and implement rural and urban drainage plans with input from local government and communities			√	PID/FRAU	PID, district governments, civil society, consultants/contractors
Incorporate climate change into flood planning	√	√	√	PID/FRAU	WAPDA, district governments, civil society
FLOOD PREPAREDNESS					
Develop and implement an efficient emergency communications approach with other flood management agencies		√	√	PID/FRAU	WAPDA, Disaster Management Authority, District governments, civil society

PROJECT/ACTIVITY	YEAR 0-1	YEAR 2-5	YEAR 6-15	LEAD AGENCY	INVOLVED STAKEHOLDERS
Develop and implement an awareness raising program for the community and civil society		√	√	PID/FRAU	WAPDA, district governments
Involve community in different elements of flood planning and management		√	√	PID/FRAU	WAPDA, district governments
Strengthen flood forecasting and warning					
Update flood forecasting and early warning system and coordinate with WAPDA and PMD		√	√	PID/FRAU	PMD, consultants
FLOOD PROTECTION					
Prepare operational rules for reservoirs and barrages		√	√	PID/FRAU	WAPDA
Prepare and implement a climate adaptive asset management database and plan and ensure effective O&M		√	√	PID/FRAU	District governments
Undertake rehabilitation and strengthening of priority flood infrastructure		√	√	PID	WAPDA and district governments
Implement flood plans			√	PID	WAPDA and district governments
FLOOD RECOVERY AND WARNING					
Provide detailed flood management reports annually		√	√	FRAU	WAPDA and district governments
Provide recovery reports after each flood event, including a programme for rehabilitation of damaged infrastructure and related budget needs and timelines for civil works execution		√	√	PID	WAPDA, District governments, national government
Arrange financing for repair of damaged infrastructure, for homeowners, and public infrastructure.				Punjab government, PID	WAPDA, District governments, national government

10 WATERSHED AND HILL TORRENT CONDITIONS

10.1 GENERAL

The Punjab province can be divided into four hydrogeological zones. These Zones (**Figure 10-1**) depict different types of climatic and geologic conditions that ultimately control the occurrence and movement of surface and groundwater. These are

- Alluvial plains of Central Punjab (Doab areas)
- Pothohar Plateau and Salt Range,
- Piedmont deposits of Suleiman Range (DG Khan area), and
- Cholistan Desert.

This Section reviews the present status findings and recommendations of the previous reports and identifies possible improvements in the management scenarios.

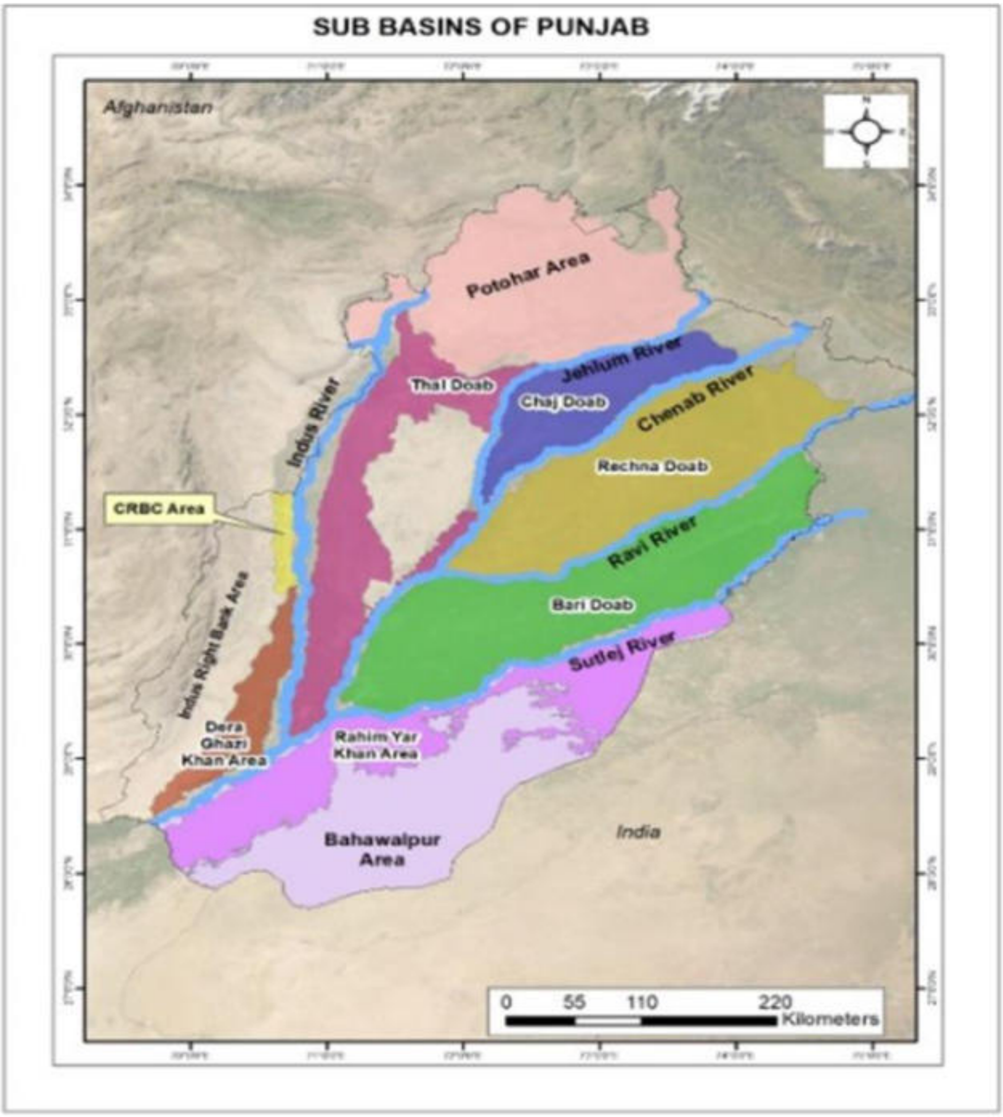


Figure 10-1: Indus River Basin, sub-catchments within Punjab Province

10.2 POTHOHAR PLATEAU AND THE SALT RANGE

The Pothohar region lies between the Indus River and the Jhelum River and stretches from the salt range northwards to the foothills of the Himalayas. Pothohar plateau has an area of 22,275 km^2 and a population of 17.6 million. The region thus includes the Attock, Jhelum, Rawalpindi and Chakwal districts and is typified by undulating topography and erratic rainfall. The climate of the area is semi-arid to humid and the annual precipitation ranges from 380-510 mm.

Ground elevations vary from 305-610 masl. The area is drained by the Haro and Soan rivers, which are tributaries of the Indus. The streams are deep and are not suited to canal irrigation. The area is best suited to food crop production under rainfed conditions (Chaudhry et al., 2004). The lands adjacent to the Indus are very fertile.

The Pothohar region has over 100 sites that are suitable for construction of small dam (such as Rawal Dam and Khanpur Dam), which could be constructed to eliminate water shortages in the region.

About 80% of the annual rainfall occurs in the period from July to October (Sarwar et al., 2014). Unconsolidated sand and gravel and semi-consolidated conglomerates and sandstone constitute the aquifer material. Yields of wells vary greatly in accordance with local geological conditions. Well water is in generally suitable for drinking and agricultural purposes.

10.2.1 CLIMATE

The summer temperature ranges between 15oC and 40oC while the range of winter temperature is generally between 4o to 25oC. Around 1.0 Mha of Pothohar plateau are cultivated (GoP, 2016) with approximately 4% of the cultivated land being irrigated and 96% is dependent is rain fed (Majeed et al., 2010). The crops grown in Pothohar include wheat, maize, barley, sorghum, onion, legumes, tobacco, bajra, and groundnut.

10.2.2 MAJOR ISSUES

Productivity of the Pothohar region is reported to have decreased by a factor of 2.5 to 7 due to over grazing and removal of vegetation for fuel wood. The major constraints for limited agricultural production are:

- Unreliable rainfall
- Subsistence-oriented farming system
- Age old cultural practices
- Small size and fragmented farms
- Low soil fertility
- Unsuitable cropping pattern
- Soil erosion
- Limited role of farm input services

Out of 3.5 MAF annual runoff, only 0.10 MAF is controlled by existing small and mini dams. The remaining 3.4 MAF goes to the Indus and Jhelum rivers. It has been suggested that the region requires construction of more dams to control the runoff and to reduce large-scale soil erosion. These dams can also help to mitigate floods.

The small dam organization at Islamabad is responsible for management of irrigation through construction of small dams. The Barani Area Development Authority works under the Planning and Development Department and performs soil conservation works. The drinking water supply is mainly through small dams. The dams are also a major source of recharge of groundwater.

Recently, the Punjab Government under 'Kissan Package' constructed 101 mini-dams in the Pothohar Region. In addition the last two years has seen construction of 201 water ponds, 39 water storage tanks, 148 gabion spurs and 28 earthen

bunds. The construction of water reservoirs and soil erosion control structures has added 32,190 acres cultivable land to the region. Beneficial impacts include: the water table is rising; fish and cattle farms are flourishing and employment has increased.

10.2.3 RECOMMENDED INTERVENTIONS

The potential for agriculture can be further improved by adopting rainwater harvesting techniques and employing scientific soil and water conservation. The water accumulated in mini dams can be utilized for vegetable and fruit cultivation.

- The Sloping Agriculture Land Technology (SALT) can be adopted with the collaboration of PARC and International Centre for Integrated Mountain Development (ICIMOD). Construction of reservoirs at higher levels to irrigate lands at lower levels through pipes and lined channels can be beneficial.
- Growing of forests, fruit trees, natural shrubs and cultivation of grass can be priority projects. Solar pumps are suitable for Barani areas.
- To address the drought problem, desertification and global warming; help can be sought from the international union of natural resources (IUCN), Agha Khan Rural Support Program (AKRSP) as well as NGOs and CBOs.
- After conversion to WRD, the Soil Conservation Department working under P&D department may be transferred to PID. The area will continue to be developed under Chief Engineer, Pothohar at Islamabad.

Pothohar region is highly susceptible to soil erosion therefore continuous monitoring of erosion is necessary for sustainable land management. Geospatial techniques offer potential for fast, accurate and cost-effective erosion assessment (Iqbal M., 2018).

10.2.4 WAY FORWARD

Future actions include:

- Identification of interventions for capturing rainwater runoff
- Prioritization of watersheds and sub watersheds
- Identification of rainwater storage sites
- Assessment of site specific conservation approaches
- Suitability assessment of perennial crops/trees
- Interventions in agriculture practices
- Public awareness and community mobilization

10.3 CHOLISTAN DESERT AREA

The Cholistan covers an area of 25800 km2 (10,000 sq. miles) in Bahawalpur, Bahawalnagar and Rahimyar Khan. It extends 480 km in length and 32, km to 192 km in width at an elevation of 112 masl. It joins Thar Desert in Sindh and India. The mean temperature is 28.33 C^0 (82.99 F^0). The hottest month is July, with a mean temperature of 38.5 C^0(101.3 F^0). The average annual rainfall is 180 mm, with July and August the wettest months. Droughts are common, with an annual rainfalls as low as 10 mm. Subsoil water is found at depth of 30-40 m and is mostly brackish and unsuitable for plant growth. The backbone of the economy in the area is animal rearing.

The area is subjected to strong winds and erosion with shifting sand dunes. It has a livestock population of 1,318,000 heads (2018). Tobas (ponds) serve as watering points for animals and are maintained by the Cholistan Development

Authority. People in the area have a nomadic lifestyle moving from one place to another in search of water and fodder for their animals.

Dead River Hakra runs through the Cholistan desert, and the area is also known as Hakra Civilization. The area provides carpet wool of superior quality. The camel has been an important part of Cholistan economy. Local vegetation like koreer, jund, kikar and mallah is the best fodder for camels.

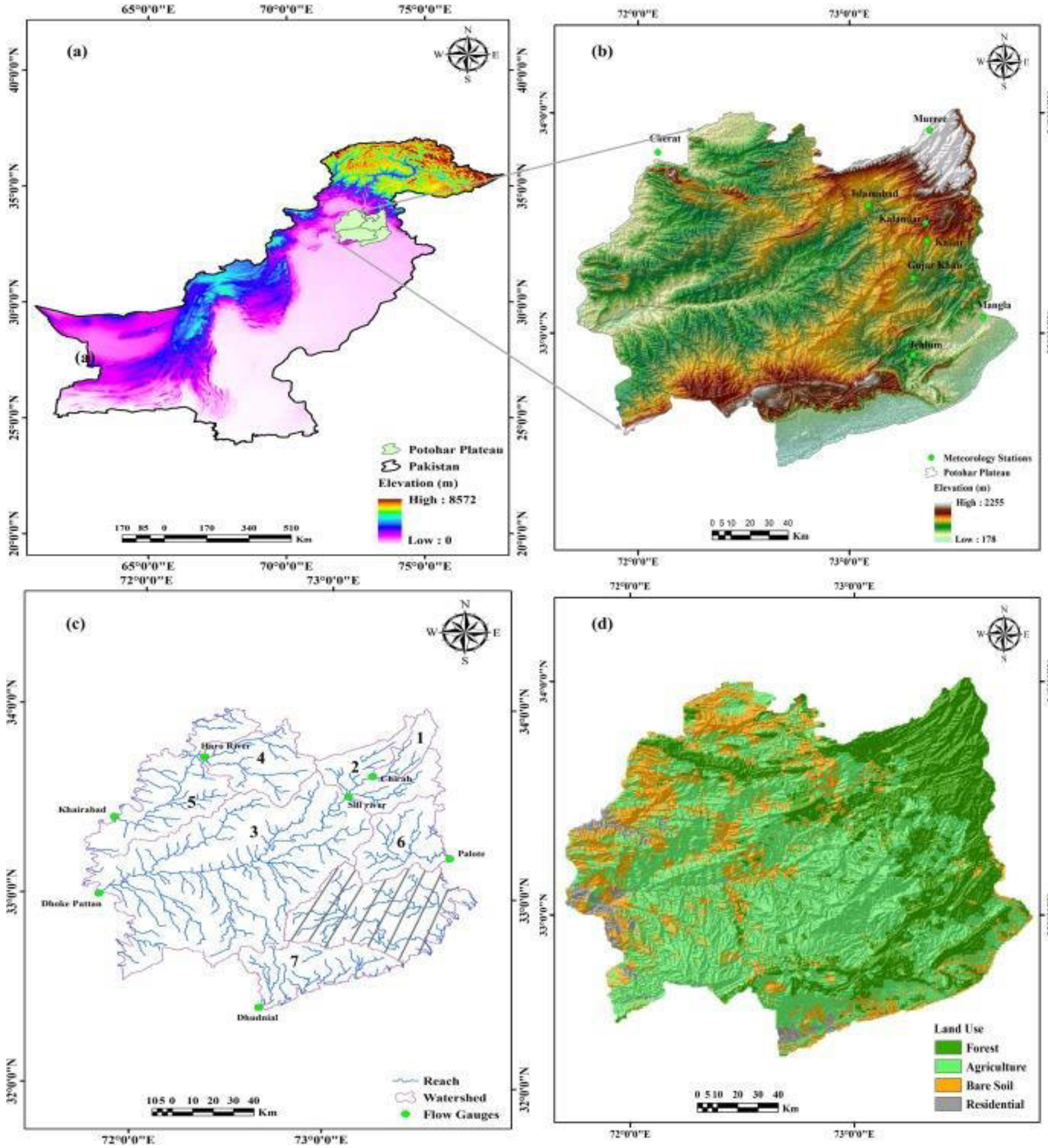


Figure 10-2: Hydrogeological Zones of Climatic and Geologic Conditions in Pothohar [Iqbal, 2019]

10.3.1 PROPOSED INTERVENTIONS TO IMPROVE OVERALL CONDITIONS

The challenge for this region is to improve resilience to drought and climate change, rather than development. Potential interventions include:

- Construction of additional Tobas for watering animals is the best and most cost-effective option for agriculture.
- The entire area can be developed as organically grown agriculture.
- Emergency feed banks for animals need to be created. During drought leaves from nearby forest areas (such as Lalsohara Park) can be brought to Cholistan for feeding animals.
- Plantations established along the canal system neighbouring the desert can be used to supply fodder during drought.
- Transfer of flood waters from Suleimanki Barrage to the Hakra River may be used to supply additional water resources for the area.
- Aquifer recharge areas can be developed by breaching the Bahawalpur Canal and the Desert Branch at suitable locations during the low demand period (March to April and September to October).
- The Cholistan Development Authority should be transferred to the PID as water is essential to the economy of the area.

10.4 WATERSHED AND HILL TORRENT CONDITIONS

This Basin is located on the right bank of the Indus River and includes two parts:

- Canal commanded area; CRBC, DG Khan canal commands
- Hill Torrents area

The toe of the mountain range of Kohe Suleman follows the right bank of the Indus having some flat lands. These areas are commanded by two main canals CRBC and DGC mainly along their left banks. These canals originate from Chashma Barrage and Taunsa Barrage, respectively. CRBC is a 272km long canal and commands 250,000ha, out of which 61% lies in D.I. Khan District of KPK province and remaining 39% in Punjab (WAPDA, 2002). Kachhi canal also originates from Taunsa Barrage and flows parallel to DG Khan Canal, however, it commands areas mainly in Baluchistan province.

The basin has a population of 4.192 million and a total area of 21,575 km^2 (**Table 10-1**, GW Management Report, 2021). There are two districts in this sub-basin i.e. DG Khan and Rajanpur.

Most of the groundwater in the basin is marginal to saline. DG Khan Canal is used to supply water for drinking purposes and irrigation water. Groundwater quality has improved in the vicinity of canal over the period due to seepage losses. The ground levels on the right side of the canal are higher, therefore the command (irrigated) area is planned along its left bank.

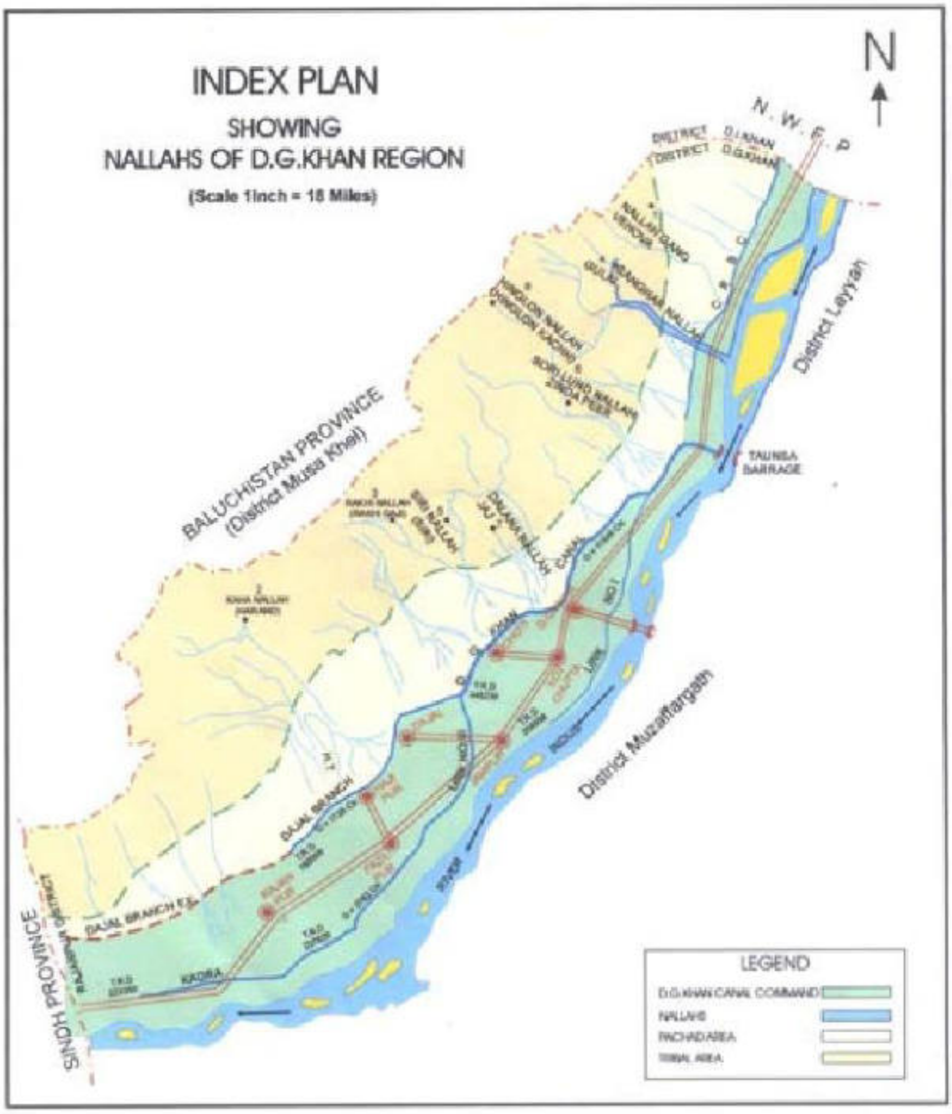


Figure 10-3: Hill Torrens of DG Khan Area

Table 10-1: Salient Features of DG Khan Sub-basin (Population census, 2017)

DISTRICT	DIVISION	POPULATION (2017)	TOTAL AREA (KM2)	POPULATION DENSITY/KM2	ANNUAL GROWTH RATE (1998-2017)
Rajanpur	Dera Ghazi Khan	1,995,958	12,318	162.04	3.16%
Dera Ghazi Khan	Dera Ghazi Khan	2,196,445	9,257	237.3	2.98%
Total		**4,192,403**		**21,575**	

The districts of DG Khan and Rajanpur in Punjab mainly have spate/Rod Kohi irrigation systems, where the main channel is dry for most of the year, but seasonal floods are diverted to provide irrigation water. These districts cover an area of 2.39 Mha, out of which, 17 percent is canal commanded, 35 percent is Pachad area (Rod Kohi/spate Irrigated), and 48

percent mountainous and sub mountainous area. The Pachad area lies within the arid climatic zone, having thirteen major and 192 minor hill torrents originating from the Sulaiman range.

Torrents means fast flowing water; the term is primarily used for a steep mountainous stream that generates quick runoff. A large number of hill torrents join the River Indus on its right bank, causing major disruption to infrastructure such as roads and canals. The catchment areas of these torrents vary from small to medium and they can generate peak flows ranging from a few hundred to a few thousand cubic meters per second. Hill torrents display large variations in peak flows, high sediment loads and the channel beds constantly migrate (move) depositing sediment in a fan shaped area. Hence the channels are not stable due to moving channel beds. These characteristics make the management of Hill Torrents more challenging. Different structural and non-structural measures are proposed in the previous studies to control and improve the use of water from these torrents and their economic viability.

The main objectives of the Hill Torrents Management Project was to reduce the flood damages to the CRBC, DG Khan and recently constructed Kachhi canal and improve water availability for irrigated agriculture.

The major hill torrents are located in the D.G.Khan and Rajanpur districts of southern Punjab province. The Kaura, Vehowa, Sanghar, Sori Lund, Vidore, Sakhi Sarwar, Mithawan hill torrents are located in district D.G.Khan, whilst Kaha, Chachar, Pitok, Sori Shulali, Zangi and Sori Janubi torrents are located in Rajanpur district. Total catchment area of hill torrents is 19,279 Km^2. Part of these catchment areas is in Baluchistan province. The top elevations range from 1500 to 2500 masl whilst the elevation at the Indus River outfall is 200masl. Flow in these torrents is highly seasonal.

The torrents exit the Darrah debouch and discharge into the River Indus after partly irrigating the fan areas. The fan areas become flatter with the passage of time due to soil deposits made by the torrents through each flood. The locals use the land for cultivation relying on the flood flows in the torrents.

10.4.1 THE SUB-BASIN AREA

The area covered by hill torrents in southern Punjab is about 0.5 million hectares (1.4 million acres). The flow generated by the torrents is of the order of 3.34 BCM (2.7 MAF). The cropping intensity is around 10 percent. The hill torrents are ephemeral streams. The rainfall period is mostly from July to September each year, but some flows also occur in the winter season.

The irrigation system for hill torrents is called Rod Kohi (spate irrigation). The agricultural command area 'Pachad' is divided into smaller patches by the owners, constructing 0.5-1.0 m high earthen bunds. Water is diverted from the local stream, flooding the area between the bunds. All the hill torrents have traditional cultivation systems based on spate irrigation. Offtakes and wahs originating from the main channel serve the secondary channels as inundation canals for farmers' fields.

Water rights in the area are already defined. The upstream user has a priority over the downstream user. The system of water rights is known as 'Saropa Piana'. It was agreed by all parties in nineteenth century and vetted by the civil administration.

The main issue restricting increased cropping is storing the water and utilizing it according to crop water requirements. If this could be addressed a cropping intensity of 50 to 60% could be achieved in the Pachad area.

10.4.2 CLIMATE AND AGRICULTURE

The area is located in semi-arid subtropical continental monsoon regions characterized by two distinct seasons i.e. summer and winter. Mean annual precipitation in the area is around 350 mm (13.8 inches). Most of the rainfall takes place during the months of June to September under the influence of the monsoon rains.

The mean annual summer day temperature in the project area is 34 C. The hottest month is June and the mean of maximum day temperature is 41.5 C, whereas the minimum temperature which is observed in January is 4.2 C.

10.4.3 DATA AVAILABILITY

A list of 15 rainfall gauging stations and 4 stream flow gauging stations are provided in the report by Nespak. Most of the stations are maintained by the IPD Punjab. Barkhan station which is being maintained by Pakistan Met Department has a record for 100 years. Most of the remaining stations have less than 15 years of record and most are now abandoned.

One important features that can be discerned from the data is that nearly all the streams respond to the same rainfall events, which shows that nearly all the hill torrents of the project area are influenced by the same weather system, but intensities vary.

10.4.4 SOIL COVER DATA

Based on the surveys conducted by Soil Survey of Pakistan, the catchment areas are steep mountainous slopes ranging from nearly vertical to 1:1 to bed slopes of 1% to 10%. The soils in the catchment areas are mainly composed of the following soil formations:

- Shale and sandstone with some limestone (49.2%)
- Shale and sandstone with some conglomerate (35.7%)
- Homogenized loams with sandy loams (6.2%)
- Dominantly shale with little limestone and gypsum (8.9%)

It is apparent from the data that the catchment area is composed of steep slopes and with thin soil cover and high potential of runoff. The agricultural potential of the area is low, as the soils lack organic material. Thus the land is suitable for grazing or pasture and matches the SCS soil classification of Group C.

The alluvial fan areas (about 30 km wide) are predominantly sandy, with intermittent layers of sand and clay. Silt and gravels are also present in thin layers. Tertiary deposits are consolidated sedimentary rocks, like the shale interbedded with sandstone and gypsum. Grain size distribution of a typical soil sample is as follows:

- Coarse Sand 19.1 %
- Coarse to Medium Sand 13.3 %
- Medium Sand 27.4%
- Medium to Fine Sand 14.2%
- Fine Silt and Clay 26.0%

10.4.5 LAND USE

The upper catchment area is mainly rangeland with agriculture comprising less than 3%. Agricultural development has a low potential and indicated by the poor results in response to the projects such as the Kaha Torrent Management Project.

In the Pachad area, 12% of the total cultivable area is irrigated. Most of the water discharges as runoff through hill torrent streams causing damage to the infrastructure. Land potential is highly underutilized. The soils are laminated and weakly structured, farming methods are traditional and water diversion methods are generally vulnerable and unreliable. The economy of the area depends on agriculture and livestock. The cropping pattern largely depends on the availability of water and the mode of irrigation. Wheat, millets and oilseeds are the main crops. Livestock is the major source of income, includes cattle, buffalo, goat and sheep.

Soils of the Pachad area vary from coarse silt to fine sand. The area has a medium runoff potential below Darra. The bed slopes in the Pachad area range from 1:100 to 1:250. Initial abstraction through the area is high, due to the presence of edge bunds that were constructed to irrigate the land.

10.4.6 AGRICULTURE

The area of hill torrents is divided between Haqooq and Non Haqooq. The Haqooq area has water rights and Non Haqooq area utilizes flood flows if available in, excess of those taken by the Haqooq area. The irrigation is through wahs (distributaries) and construction of bunds around fields. The irrigation supply to Wahs is through intake structures and distributors constructed by PID under public sector development funds. Irrigation is done through a community-based system of “Saropa and Piana” head to tail, those at head of wahs get first turn and the tail enders have secondary established right. The major crops grown are sorgham, bajra, oil seeds and wheat. In addition to flood water, some of the hill torrents like, Kaura, Sanghar and Kaha have perennial flow locally called “Kala Pani”, where cotton crop and seasonal vegetables are also grown successfully. The average yield is 400-500 Kg/ha (JICA-1992).

Natural vegetation is used for livestock grazing and collection of firewood. The main tree species are babool (Acacia arabica), Jand (Prosopis spicigera) and Frash (Tamarix articulate). There is general shortage of water in the Pachad area and the catchment areas of the hill torrents. There are also problems with salinity and alkalinity in soil and water. Particularly the Pitok and Sori Shumali torrent water which is moderately to highly saline and unfit for irrigation. The Vehowa, Sanghar and Vidore have good agricultural lands. There are sandy soils in Zangi and Sori Janubi. The perennial flows (locally known as kala pani) on Kaha, Sanghar, and Vehova are 0.85, 1.28, 1.42 m3/s, respectively.

The excess water from pachad area is drained to the Indus River through cross-drainage works of insufficient capacity. With the result that every year the main canal is breached, with interruptions to canal supply to the command as well as damage to crops (NesPak 1998).

As an example, the flood damages of 2012 are reproduced from PID records:

- Damage to cropped area = 75,056 hectares
- Damage to houses = 45,809 Nos
- Damage to schools = 103 (totally collapsed)
- Damage to schools = 106 (partly damaged)
- Damage to Bridges = 12 Nos
- Canal offices inundated = 06 Nos

The farmers of these areas face a number of problems, such as high cost of diversion structures, poor financial resources, damage from floods, heavy sediment load, low crop yields, less attention by the researchers and government. The crop yield of spate irrigated areas is less than its potential, mainly due to poor irrigation management. Spate irrigation is applied once before the sowing of crops and subsequently, the crops are dependent on direct rainfall which typically satisfies less than 15% of the requirement (Qureshi et al., 2004b). If subsequent irrigation is applied by the spate water, then already germinated crop gets buried by heavy sediment loads. Furthermore, the spate irrigation system needs to repair the bunds and construct heavy duty structures across the flow of water to divert it into the field, which are costly.

10.4.7 SITUATION ANALYSIS FOR MANAGEMENT OF HILL TORRENTS

The Pachad Area is the most underdeveloped part of Punjab. The constitutional heads of Punjab like the Chief Minister (except current CM) and Governor generally omit the area during their visits as they are remote areas. The annual rainfall is low, uncertain and patchy. There is scarcity of water in the area. Livestock rearing and agriculture production based on flood flows are the main sources of income. During wet years only a small part of runoff is utilized in Pachad Area for agriculture, while the flood flows cause serious damage to earthen bunds, standing crops and infrastructure. The water rights are registered and work on local system of "Saropa-Paina", first land first and second afterwards. This system is working very well.

The available flood water from hill torrents on average is 100,000 MCM to 170,000 MCM. The main problem is the diversion of flows during peak floods. The surface and ground waters are linked and should be managed together. Climate change is real and adaptation measures should incorporate 0governance, infrastructure development and water management.

The flood water being utilized in the area is highly variable and cannot be accounted for as a continuous supply under the WAA. Nevertheless, the irrigation requirements in the area would not reduce the flood runoff to the Indus significantly and additionally, a part of the applied water will gradually drain to the Indus as subsurface flow.

10.4.8 PREVIOUS STUDIES

The following technical reports were reviewed:

- NesPak (1984). Flood Management of Hill Torrents in D.G.Khan District.
- JICA (1992). Feasibility Study on Development of Irrigation Based Upon Flood Flows of D.G. Khan Hill Torrents.
- NesPak (1998). Master Feasibility Study for Management of Hill Torrents in Pakistan
- NesPak (2005). Feasibility Study for Management of Hill Torrents along CRBC.
- T.A. Report (ADB-2007) Additional Study for Review of Feasibility Study and Design Report Prepared by NesPak for Management of Hill Torrents along CRBC
- PID Annual Flood Damages Report on Hill Torrents (last 05 years)
- Technical Reports of Individual Experts of PID
- Watershed Management by Forest Department of Punjab in Catchments of Torrents.

The Master feasibility report of 1998 on the management of Hill torrents produced by M/s Nespak described all the hill torrents in Pakistan and their basic characteristics. The report gives a comprehensive account of possible interventions to tame the torrential behaviour of the streams. As stream flow measurement data on most of these torrents is missing, a synthetic method of unit hydrograph was used to convert rainfall data to peak runoffs and a subsequent frequency analysis was carried out on the peak runoff data to estimate design discharges for a range of return periods.

Nespak (2005) carried out a feasibility study to establish the water potential of streams crossing the CRBC alignment in the DG Khan area and to identify possible structural interventions to divert the flows to agricultural lands for irrigation purposes, thus reducing the magnitude of flow reaching the crossings on CRBC. These interventions are planned to reduce the flood magnitude and resulting losses along the CRBC alignment and to improve agricultural production. The feasibility report contains detailed analyses to establish the economic viability of the management schemes.

The following different management options were considered:

- construction of storage dams
- construction of delay action dams

- diversion of excess flows to adjacent smaller hill torrents
- diversion of excess flows to Non Haqooq channels
- diversion of excess flows to evaporation ponds
- dispersion of flows through diversion/distribution structures

The last option 'dispersion of flows through diversion/distribution structures' was considered as the most suitable due to its flexibility in supporting the old system of water rights of Saropa Paina and also its reliability, which has been established through a pilot study, the Kaha Hill Torrent Management Project.

A number of experts/reviewers have suggested improvements to the approach and methodology of the feasibility report. Two types of structures were recommended for the managements of hill torrents. The main distributor structures are proposed for distributing water immediately downstream of Darra, according to historic water rights. Smaller offtake structures at the mouth of the major channels are then used for diverting flow from the mainstream into channels to supply water to the agricultural lands. Other structures include bed fixers, spurs, stone pitching and aprons where strengthening and safety of the banks is required.

The following is a summary of recommendations from the above studies and reviews:

- Effective flood management of hill torrents requires balanced use of structural and non-structural measures. The works can be executed in a phased manner.
- Research studies relating to the hydrology and meteorology of hill torrents should be given priority. This data is of utmost importance for proper planning of flood management measures.
- Dispersion structures may be constructed at suitable locations on hill torrents in order to reduce flood peaks and to use flood water for irrigation purposes. The location of these structures should be decided on technical considerations.
- There is need to plan and implement effective measures for watershed management in order to prevent excessive soil erosion, which is causing sedimentation and management problems in the downstream areas.
- The design of cross drainage works needs to have due regard to the hydrological and meteorological characteristics of catchments. Adequate capacity should be provided for safe passage of floods.
- The use/ development of computer models for the prediction of flood heights, location of structures and identification of areas expected to be affected by floods of various hill torrents should be encouraged to help the authorities to plan for flood management.
- There is an urgent need for the installation of flood warning and forecasting systems in areas liable to flood damages by the Hill Torrents.
- Properly qualified and competent engineers should be posted for execution/ maintenance of flood management schemes in Hill Torrents areas, because of complex nature of job.
- Integrated watershed management is be adopted for catchments of all hill torrents.
- Participatory watershed management is must for success. Watershed management should be based on the findings of the Mithawan Hill Torrent pilot project.

10.4.9 RECENT PROJECTS IN THE AREA

Storage dams have previously been proposed at Darrah sites, but these have not constructed due to concerns regarding weak rocks in the foundations and potentially a very short lifespan due to high sediment loads.

Following is a list of projects that have been implemented in the area during the last 20 years:

- 2000: Mithawan hill torrent project was launched by PID, which included distributor at Darrah.
- 2003: Vidore hill torrent project was launched with assistance from ADB, including dispersion and distribution structures.
- 2007: ADB provided assistance for preparation of a hill torrents management plan along CRBC on the hill torrents of Kaura, Vehowa and Sanghar.
- 2020: WAPDA is entrusted with construction of Murul Dam at Darrah of Kaha hill torrent (mega project).
- 2021: NesPak awarded Feasibility for construction of medium and small dams over 13 hill torrents at a cost of Rs. 1,250 million. Dam at Surra site of Sanghar hill torrent has been proposed for construction during 2021-23.

10.4.10 MANAGEMENT OF HILL TORRENTS

The hill torrents are managed by Project Circle D.G. Khan under the administrative control of Chief Engineer of the Zone of PID. The main responsibility of the circle is control of hill torrents, construction and maintenance of river training works of River Indus (flood embankments, spurs) and also control of the agricultural drainage system of D.G. Khan Canal. The Chief Engineer of the Zone of PID is assisted by Executive Engineer D.G.Khan and Jampur Construction Divisions. The former manages hill torrents falling in D.G.Khan district and the latter is responsible for hill torrents of Rajanpur district.

The administrative operational unit is DGK Zone of PID. Under this unit, a Project Circle was created in 1995 under a Superintending Engineer with the mandate of Flood Management of Hill Torrents, River Training Works on Indus River and Surface Drainage in the command of Dera Ghazi Khan Canal. The Superintending Engineer is supported by two Executive Engineers, each responsible for DG Khan and Rajanpur districts.

10.4.11 PROBLEM OF CAPACITY BUILDING

The main pillars of Punjab Water Policy (2018) are equitable access to water, sustainable supply of water for all uses with effective allocation and distribution of water. Technical and institutional support is needed for Integrated Water Resources Management (both for the control of floods of hill torrents and watershed management). This is also required for transformation to a WRD.

The current working setup is a weak institution, with poor linkages, lack of support for enforcement of legislation and very little financial stability. There is political interference in all matters including transfers and recruitment of staff. Competent and qualified staff are not allowed to complete their normal tenure of posting, unless they protect the interests of the elite class of the area. Major gaps in capacity building are:

- Insufficient trained manpower
- Limited knowledge of decision makers and policy makers
- Lack of innovative technologies for utilization of flood flows.

Only well-trained staff with a clear mandate and operational autonomy can contribute towards a change in effectiveness. Training for capacity building needs to be continuous.

10.4.12 SUGGESTED TRAINING PROGRAM.

Training in the following fields is recommended:

- Soil, water and hill torrent conservation methods
- Hydrological Modelling of hill torrent flows

- Use of GIS and Remote Sensing (RS)
- Training of WUAs in participatory management and soil and water conservation of hill torrents
- Foreign training for selected staff to PhD and MSc level.

The above trainings can be a part of the investment component.

10.4.13 INTEGRATED WATERSHED MANAGEMENT

Effective integrated watershed management practices address both soil and water conservation. The objective is to improve farmer livelihoods using participatory approach with incentives. Watershed management serves the purpose of controlling damaging runoff, manages and utilizes runoff for useful purposes, enhances ground water storage, increases cropping intensity in watershed areas with appropriate use of land resources for growing forest and fodder. The types of works proposed include:

- Sediment retention structures (check dams, silt trap dams, debris basins, etc.)
- Afforestation and vegetative cover
- Village infrastructure for water supply facilities
- Terracing of slope lands, horticulture and growing of fruit trees
- Create flood bypass channels for transferring supply from one to another hill torrent
- Create temporary retention areas for storage of water
- Build technical capacity for sustainable management practices
- Digitization of command area
- Delineation of potential catchments areas
- Construction of ponds/small reservoirs for continuous supply during no rainfall period

The main steps for Integrated Watershed Management (IWM) are:

- Community engagement and awareness creation
- Area selection assessment
- Participatory planning (project implementation agency, watershed development team, village development committee)
- Implementation of watershed management plan
- Monitoring, learning and adopting.

The major benefit from watershed conservation works would be to stop soil erosion from the watershed and sedimentation in the downstream reaches which subsequently shortens life of dispersion structures and increases maintenance costs of distribution structures. The suggested measures for watershed conservation are:

- Planting of contour hedges of vetiver grass and or Saccharum Munj in the grazing area.
- Construction of earthen bunds around grazing and cultivable area.
- Structural measures to construct small check dams and masonry structures at suitable locations.
- Assistance to farmers for agriculture in watershed areas.

The local population living in hill torrent areas is vulnerable to climate change and require increased investment in a range of measures to ensure their economic resilience. It is essential to educate and secure their cooperation for hedge planting, rotational grazing and introduction of sowing seeds of fodder crops. Public awareness, consultation and participation must be an integral part of watershed management projects. The development strategy for management of hill torrents is recommended as below:

- Give priority for flood damage reduction for canal crossings and pachad areas.
- Utilize maximum flood flows for agriculture in pachad areas.
- Introduce measures for watershed conservation so as to develop agriculture on a sustainable basis in the pachad area and the watershed of hill torrents.

10.4.14 ACTION PLAN FOR DEVELOPMENT

It is suggested that management of hill torrents in Districts of D.G. Khan and Rajanpur areas shall be carried out as per the following action plan in a phased manner (**Table 2-2**).

Table 10-2: Indicative Action Plan for Further studies, thematic and projects

PROJECT/ACTIVITY	YEAR 0-2	YEAR 3-5	YEAR 5-10	LEAD AGENCY	INVOLVED AGENCIES
Community participation and awareness raising water users' campaigns.	✓			WRD	EPA, Local Govts, Farmers
Development of a management plans for each hill torrent accepted by the local community and the government.	✓	✓	✓	WRD	EPA, Consultants, etc.
Trainings for capacity building of staff and farmers of the Pachad area.	✓			WRD	EPA, Consultants (Legal and Technical)
Rehabilitation of existing dispersion structures, WAHS and restoration of flood damages in Pachads.	✓			Monitoring Agency	WRD,
Construct new dispersion structures in the remaining torrents.	✓			WRD Monitoring Agency	Consultants EPA
Install flood forecasting and warning system	✓			WRD	
Design and implement integrated watershed management projects.	✓	✓	✓	WRD	EPA,
Design and construct storage dams.		✓	✓	WRD	Consultants, Funding Agency
Utilizing new developments in technology to improve irrigation efficiency in Pachad areas		✓		WRD	PAD,
Design and implement GW recharge projects		✓		WRD	EPA
Conjunctive use projects for a more integrated approach which includes reducing soil salinity and drainage outflows.		✓	✓	WRD	PAD, EPA
Introduce rainwater harvesting techniques to rural community.	✓	✓		WRD	EPA, Social, Local Gov.

11 IRRIGATION AREAS/ZONES& COMMAND AREA CONDITIONS

11.1 INTRODUCTION

11.1.1 OVERVIEW OF THE IRRIGATION SYSTEM

The Punjab Irrigation Department (PID) is responsible for operation & maintenance of the canal irrigation systems in Punjab with WAPDA responsible for higher level infrastructure (reservoirs, dams, some barrages and some link canals).

Most of the Punjab Indus River Basin is mildly sloped towards the south and the east. All the rivers flow in south, east directions and merge before entering into Sindh province. The area between the rivers is called a Doab, which means area between two water bodies. The canal commands are therefore within a Doab. The Doabs in the Punjab are:

- Indus and Jhelum (Upper Sindh Sagar Doab or Thal Doab)
- Indus and Chenab (Lower Sind Sagar Doab/ Thal Doab)
- Western bank of Indus between Suleman range and west bank of Indus (Pachad or Suleman piedmont)
- Pothohar area draining into Indus and Jhelum (Pothohar and Pabbi)
- Jhelum and Chenab (Chaj Doab)
- Chenab and Ravi (Rachna Doab)
- Sutlej and Ravi (Bari Doab)
- Left bank of Indus between River Sutlej and Panjnad (Bahawalpur/Cholistan/Indus corridor)

There is an old course of the river Beas which runs through the middle of Bari Doab. The area between river Beas and Sutlej is also called Nilibar Doab, which now get supplies from Bari Doab.

11.1.2 MAJOR CHALLENGES

The major challenges for the irrigation sector in Punjab include:

- Increasing demands from urban and industrial sectors;
- Climate change;
- Expansion of agriculture
- Growing water shortages;
- Progressive deterioration of irrigation infrastructure;
- Low water productivity;
- Soil salinity and sodicity
- Lack of transparency and inequities in water distribution;
- Gaps in governance and trust;
- Progressive deterioration of water quality of canals, drains, and rivers due to disposal of untreated industrial and municipal effluents; and
- Over exploitation of groundwater.

11.1.3 AGRICULTURE AND IRRIGATION SYSTEM MANAGEMENT

An important element of river basin plans is the sharing of water between sectors. Management of command areas and irrigated agriculture is a sectoral responsibility similar to other sectors such as urban, hydropower, industry etc.

Irrigation is important for river basin planning in Punjab, however, most of the available water is already used for irrigation. At the same time current water use is not sustainable due large demands in some locations to supply water for cities and industry; groundwater diminishing in many areas, sedimentation of reservoirs and climate change. At the same time, there is pressure to increase the area of irrigation.

Water for any new purposes can only come from raising the water productivity and efficiency of the irrigation sector so that any saving can be utilised elsewhere to realise the full economic value of the province's water.

11.1.4 AGRICULTURE

Agriculture is the mainstay of Pakistan's economy and Punjab provides the largest share in national agricultural production. It accounts for 19% of the GDP and together with agro-based products fetches 80% of the country's total export earnings. More than 42.3% of the labour force is engaged in this sector.

Punjab is the second largest province with an area of 20.63 million hectares. Approximately 72% of the total land is available for cropping. 10.81 million hectares (53%) is a net sown area; an area that is cultivated at least once and year. 9% of the land is categorized as current fallow; an area that is not used for cultivation during a year. 8% land is marked as culturable waste which means an area that is not cultivated for more than three years and is a part of cultivated area.

In 2018-19, Punjab's total cropped area was 16.68 million hectares – of which 5.87 million hectares was sown more than once during the year. Three main crops were wheat (40%), cotton (11.5 %) and rice 12.8 %. To fulfil the needs of the livestock population of the province, fodder was cropped in 11% of the, following Maize and Sugarcane occupying 4.2 % and 4.8% area respectively. Oilseeds, pulses and vegetables were cropped only in 12 % of the area.

Table 11-3: Major Crops in Punjab Province

Crop type	Cropped Area (%)
Wheat	40%
Rice	12.8%
Cotton	11.5%
Fodder	11%
Maize	4.2%
Sugarcane	4.8%
Oilseeds, pulses and vegetables	12%

Census of agriculture 2016-17 shows that there were 5,249,800 agriculture farms in Punjab, these farms consist majorly of very small farms. A break down farmland ownership is provided below:

Table 11-4: Farm Sizes

Farm Area	No of Farms	By Area
< 1 ha	42%	8.9%
1-10 ha	50%	68.9%
>10 ha	8%	22.2%

11.2 IRRIGATION SYSTEM DEVELOPMENT.

Irrigation in the Indus River Basin has a long history dating back to the Indus Civilization. The remains of Mohenjo-Daro and Harappa remind us that the inhabitants of this fertile valley were acquainted with the practice of irrigating the lands by using dug wells and river spills during the flood season. The ancient civilizations that flourished along the riverbanks were mainly dependent on irrigated agriculture.

Established Irrigation Practices can be traced back to the 8th century when Arab conquerors of the Sindh Province differentiated between irrigated and non-irrigated lands to levy land taxes. The Moghul emperors also constructed a number of canals including the Western Jumna, Hasli, Shah Nehr, Shalimar and a series of other inundation canals.

11.2.1 PRE-INDEPENDENCE DEVELOPMENT (1850-1947)

The current irrigation development started in the British Raj era. Soon after annexation of the territories of Punjab in 1849, the British rulers started an integrated gravity-run canal construction program. Inundation canals were first improved, and then gradually converted to a regulated canal command system based on diversion of river flows by construction of weirs and headworks. Command Areas were demarcated to supply canal water equitably. Inter-river water transfers were also developed to mitigate regional water shortages. This system became the world's largest contiguous canal command irrigation network supplying irrigated agriculture for 33 million acres of land in the Indus Basin of which 21.71 million acre is in Punjab. The chronological sequence of canal construction in the Punjab Province during this period is given in Table 11-5.

The pre independence development of irrigation changed the socio-economic fabric of the province. New irrigation development led to development of roads, industry, cities and markets that generated enormous economic activity and supported a huge population.

Table 11-5: Chronological sequence of canal construction in Punjab

YEAR	MAJOR EVENT / CANAL CONSTUCTION
1854	• Directorate of Canals was established.
1859 1872	• Construction of Upper Bari Doab Canal - from river Ravi at Madhopur (now in India), • Sirhand Canal - from river Sutlej at Rupar (now in India).
1872 1892 1901	• Sidhnai Canal - from River Ravi at Sidhnai Headworks • Lower Chenab Canal - from River Chenab at Khanki headworks • Lower Jhelum Canal - from Rasul headworks (1901)
1905-1917	• Triple Canal Project • Upper Jhelum Canal - from river Jhelum at Mangla Headworks • Upper Chenab Canal - from river Chenab at Marala Headworks • Upper Bari Doab Canal - from River Ravi at Balloki Headworks
1922-33	• The Sutlej Valley Project, comprising: ○ Depalpur, Bikaner and Eastern Canals - from Ferozepur H/Works ○ Eastern Sadiqia, Fordwah and Pakpattan canals - from Sulemanki H/Works Bahawal, ○ Qaim and Mailsi canals - from Islam headworks. ○ Punjnad, and Abbasia Canals - from Punjnad headworks
1939	• Haveli and Rangpur Canals - from River Chenab at Trimmu Barrage
1947-48	• Thal Canal - from the river Indus at Jinnah Barrage

On independence, the international border between Pakistan and India divided the Irrigation System. The irrigated agriculture on the Ravi and Sutlej rivers in Punjab was truncated, without consideration to any geographical or environmental issues. The majority of flow upstream of Pakistan was diverted for use in India by the Madhupur headworks on river Ravi and the Ferozepur & Sulemanki headworks on river Sutlej. The Lower Riparian areas of command in Pakistan Punjab were deprived of irrigation supplies.

The immediate challenge was to restore irrigation supplies to this region. The dispute with India on water rights was eventually resolved under the auspices of the World Bank by the signing of the Indus Water Treaty in 1960 between the two countries. During this period, efforts were made to bring some new areas under cultivation through water transfers from other rivers. The measures taken from 1947 to 1960 are explained in the table below.

Table 11-6: Irrigation Canal Development 1947-60

YEAR	CANAL CONSTRUCTION
1948	Continued work on development of Thal Canal System from Kalabagh Barrage (now Jinnah Barrage)
1952	Construction of Shahpur branch - from Lower Jhelum Canal to irrigate 15,000 acres of new area)
1953	Construction of Balloki -Sulemanki Link Canal - from river Ravi
1956	Construction of Marala Ravi Link Construction of BRBD Link Canal
1954-58	Construction of Taunsa Barrage Project with two off-taking canals; Muzaffargarh Canal from its left and Dera Ghazi Khan Canal from its right (new area)

11.3 INDUS WATER TREATY 1960

The dispute between Pakistan and India regarding the sharing of the water of the Indus Basin was resolved through international mediation under the auspices of the World Bank in 1960 after protracted negotiations. Under the Treaty India was entitled to the exclusive use of the three eastern rivers (Ravi, Beas and Sutlej), while the western rivers (Chenab, Jhelum and Indus) were allocated to Pakistan. However, India retained the right for power generation on tributaries of western rivers, with the consensus and approval of Pakistan. Indus water commissions were established both in India and Pakistan to administer and regulate the Indus Water Treaty.

11.3.1 INDUS BASIN PROJECT

Indus Basin Project was launched with financial aid from the World Bank and International consortium to undertake the replacement works for restoring the supplies of the eastern river irrigation system by transferring water from western rivers. WAPDA was created under the federal ministry of water and power to undertake the replacement and development works, to enhance the water and power requirement of the country.

Two large storage dams, 8 inter-river link canals, one sub link, one syphon, one canal crossing complex and 5 barrages were constructed under the Indus Basin replacement works. The construction of storages and link canals allowed the operation of the Indus irrigation system in an integrated manner, with greater control and improved river water utilization. As a result, the average annual withdrawals increased from 67 MAF in 1949-52 to 85 MAF by 1959-60, and 95 MAF just after the construction of the Mangla Dam in 1967-68. The withdrawals further increased to 101 MAF just after the Tarbela Dam was completed and reached a peak of 108 MAF in 1979. The canal withdrawals remained at this level up to 1989-90 but have now declined to around 105 MAF due to a reduction in reservoir capacities caused by progressive

sedimentation. This withdrawal is likely to be restored and further enhanced on completion of Mohmand Dam on river Swat and Basha-Diamer dam on river Indus.

The works constructed under the Indus Basin Project are listed **Table 11-7**.

Table 11-7: Irrigation Canal Development Post 1960

Works	Description
Storage Dams	• 1967 - Mangla Dam on river Jhelum (1967) • 1974 - Tarbela dam on river Indus (1974)
Barrages	• 1968 - Marala barrage was constructed at new site on river Chenab along with head regulators of MR Link and UCC. • 1967 - Qadirabad barrage was constructed on river Chenab to off-take Qadirabad Balloki Link in order to transfer water received from Rasul Qadirabad Link . • 1968 - Rasul barrage was constructed on river Jhelum. • 1971 - Chashma barrage was constructed with a live storage of 0.87 MAF. • 1965 - Sidhnai Barrage was constructed. • 1965 - Mailsi Syphon under river Sutlej was constructed to accommodate crossing of Mailsi Bahawal Link canal
LINK CANALS	• 1965 - Trimmu -Sidhnai Link from river Chenab to Ravi, Sidhnai-Mailsi Link from river Ravi to Sutlej and Mailsi –Bahawal Link through Mailsi Syphon were constructed • 1967 - Rasul-Qadirabad Link from river Jhelum to Chenab, Qadirabad Balloki Link from river Chenab to Ravi and Taunsa Panjnad Link from river Indus to Chenab was constructed • 1968 - Balloki Sulemanki Link from river Ravi to Sutlej was remodelled and a new BS Link II was constructed parallel to BS Link I. • 1970 - Chashma Jhelum Link from river Indus to river Jhelum

In addition to the above listed works, the following works were also constructed:

- LCC Complex for crossing of LCC and QB Link canal with LCC feeder channel.
- A sub-Link to feed BRBD from MR Link.
- BRBD and MR Link canals were modified/reconfigured along with some other distribution canals.
- Chashma Right Bank Canal
- Greater Thal Canal
- Jalalpur Canal

11.3.2 WATER APPORTIONMENT ACCORD 1991

Prior to 1991 there was no inter-provincial agreement for the sharing of excess water resulting from new storages and consequently flood waters were running unutilized into the Arabian Sea. Further development of irrigated command areas, therefore, remained frozen from 1976. The signing of the Water Apportionment Accord between the four provinces and the Federal Government in 1991 was a major step towards removing the hurdle to undertake new projects for command area development. The accord defined the shares for each province, including shares from future development projects and untapped/unutilized river flood flows to the ocean. Indus River System Authority (IRSA) was created with equal representation of all the provinces to administer the accord. IRSA makes policy decisions for regulation and distribution of river water to the provinces, as per the formula agreed and acts to redress grievances of provinces in the case of disputes and water shortages. The need to construct new storage reservoirs and future projects for irrigated agriculture command area development was recognized under this accord.

11.3.3 WATER ENTITLEMENTS

The Water Accord allowed for a minimum environmental water flow of 10 MAF into the sea below Kotri barrage and shared the remaining flow between the provinces. The distribution of water agreed for different provinces was based on historic withdrawals.

(f) Punjab 69.03 BCM (55.94 MAF)
(g) Sindh 60.17 BCM (48.76 MAF)
(h) KPK 7.13 BCM (5.78 MAF) (+3.00 MAF from un-gauged canals above the rim stations)
(i) Baluchistan 4.78 BCM (3.87 MAF).

The balance river supplies (including run of the river flood flows and future storage) are agreed to be distributed as per the following formulae:

(j) Punjab and Sindh 37% each
(k) KPK 14%;
(l) Baluchistan 12%.

The total water allocations made to the provinces are 141.11 BCM (114.35 MAF) (+ 3.00 MAF above the RIM stations). The actual median diversion is 105 MAF. In reality the probability of occurrence is so diverse that there is no 100% surety to divert 105 MAF to the canals each year as per provisions of the accord. Every year the available flow will differ and the probability of shortages can be as high as 50%. The distribution of shortages and internal arrangement of adjustment of inter-provincial shares on need basis is the responsibility of the IRSA. The effect of climate change could be more of a concern in future. Therefore, there is a dire need to construct large, medium and small dams wherever possible. Public awareness and strong political will is required for intricate shortage distribution mechanism for the benefit of all provinces.

11.4 OVERVIEW OF THE IRRIGATION SYSTEM AND CANAL COMMANDS

11.4.1 THE IRRIGATION INFRASTRUCTURE

The current Punjab irrigation system supplies on average 55.94 MAF of water annually to 21.71 million acres (8.79 million hectare) of Culturable Command area. There are 15 Diversion structures with 45 main canals which have a discharge range from 15 to 42.5 m3/s. The current cropping intensity is 125%–150%, with groundwater contributing half of the water supply.

The Punjab Irrigation Department (PID) is responsible for operation & maintenance of the majority of the canal irrigation systems in Punjab, whilst WAPDA is responsible for large water storages and power production. However, the Chashma barrage and Chashma Jhelum Link canal are controlled by WAPDA, a federal agency, to ensure equitable allocation of water shares to the provinces.

The irrigation infrastructure comprises

- 13 barrages / headworks,
- 6425 km long main canals (25 canals with total off-take capacity of 120,000 cusec);
- 850 km of inter river link canals (with total off-take capacity of 110,000 cusec);
- 2,794 number of distributaries and minors (with a total length of 31,503 km);
- 57 small dams;
- 10,177 km long surface drains;
- 3379 km flood embankments; and
- 58,000 farm outlets.

11.4.2 DISTRIBUTION CANAL SYSTEM

There are Distribution canals, Distribution cum Link canals and Link canals. Almost all the canals are gravity fed, but there are a few lift channels. Typically, each canal command canal has a Main Line Upper (MLU) and Main Line Lower (MLL). Main line upper is the reach of canal from its head to the first distributor from where gravity flow is possible in either direction. Thereafter, the main line has a distribution system for divided into Branch canals, distributaries, minor canals and sub-minor canals. Each main canal constitutes a canal command and is administered by a canal circle, headed by a superintending engineer.

The canals are further categorized into perineal canals, non-perennial canals and seasonal flood flow canals. This categorization and water allowance (cusecs per thousand acres) was based on soil type, hydrology, intended cropping pattern and availability of water. The categorisation, however, needs to be revised and rationalized based on cropping pattern and crop water requirement. The allocations should be dynamic.

11.4.3 THE LINK CANAL SYSTEMS

The link canals are used principally for transferring water from one river to the other, but some are also used to supply water to areas which are deprived of water due to partition. Some distribution canals like UJC, UCC and BRBD are primarily distribution canals but have provision for inter- river transferring of water at their tail end.

11.4.4 MAJOR CANAL COMMANDS

There are 25 major canal commands within Punjab and these are shown in Figure 11-1. These canal commands are grouped into two groups:

a) Jhelum Chenab Zone or Mangla Command Canals (13 canals).

b) Indus Zone or Tarbela Command Canals (12 Canals).

The salient features of Tarbela and Mangala commands are provided in **Table 11-8** and **Table 11-9**.

Table 11-8: Salient Feature of Tarbela command

INDUS ZONE (Channel Name)	Rabi WINTER Share (MAF)	Kharif Season share (MAF)	GCA (acre)	CCA (acre)	Design Discharge (cusec)
Abbasia Canal	0.207	0.34	117,663	111,333	1,394
CRBC-III	0.357	0.545	275,666	267,666	1,800
D.G Khan Canal	0.951	2.116	947,874	901,981	8,993
Thal Canal	1.605	2.367	2,460,681	2,115,931	9,000
Haveli Main Line	0.231	0.351	13,741	13,315	5170
Lower Bahawal Canal	0.692	1.224	1,229,174	1,048,805	6,730
Mailsi Canal	0.564	1.342	824,000	707,000	3705
Muzaffargarh Canal	0.643	0.472	906,490	838,380	8,901
Pakpattan Canal Lower	0.402	3.069	345,000	309,000	6594

INDUS ZONE (Channel Name)	Rabi WINTER Share (MAF)	Kharif Season share (MAF)	GCA (acre)	CCA (acre)	Design Discharge (cusec)
Panjnad Main Line	1.439	3.069	1,293,941	1,186,537	10,884
Rangpur canal	0.131	0.434	3,200	3,052	2710
Sidhnai Canal	0.904	1.339	0	0	4,005

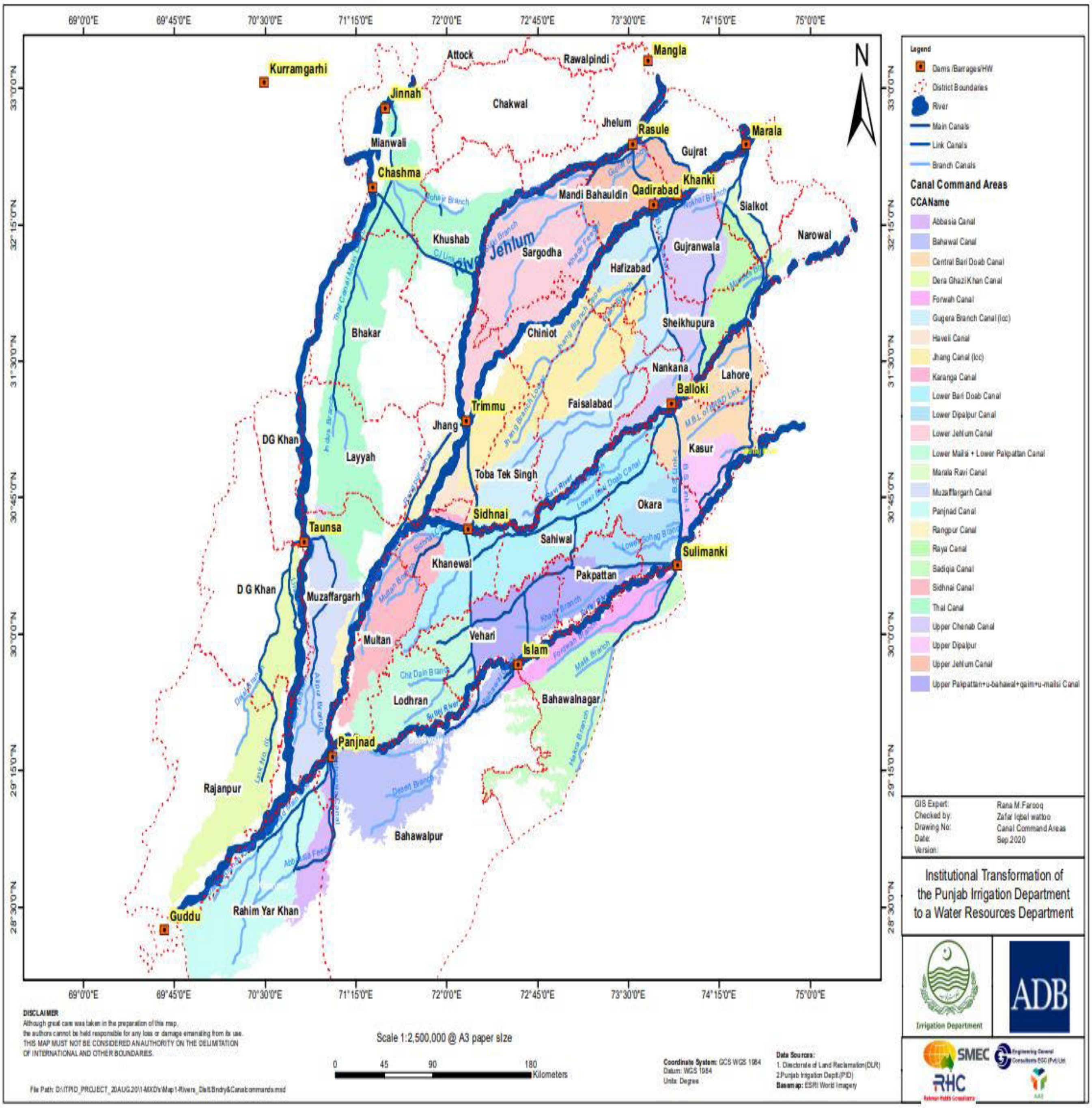


Figure 11-1: Major Canal Commands of Punjab

Table 11-9: Salient Feature of Mangla command

JHELUM CHENAB ZONE (MANGLA COMMAND)	Rabi WINTER Share (MAF)	Kharif Season share (MAF)	GCA (acre)	CCA (acre)	Design Discharge (cusec)
Central Bari Doab Canal (part of Upper Bari Doab)	0.563	0.738	1,407,210	1,219,190	3,505
Eastern Sadqia Canal	1.438	1.693	6,16,035	5,47,472	6,820
Fordwah Canal	0.147	0.761	465,024	430,112	3,448
Lower Bari Doab Canal	2.134	2.776	2,130,937	1,845,974	9,842
Lower Chenab Canal	3.097	3.768	3,762,000	3,031,000	15,528
Lower Depalpur Canal	0.292	1.071	528,500	450,500	2,360
Main Line Upper (UCC)	0.604	1.166	19,600	12,449	16,850
Main Line, Lower Jhelum Canal.	1.229	1.721	1,639,000	1,453,000	6,600
MR Link Canal	0.098	1.238	0	0	22,000
Pakpattan Canal Upper	1.115	1.741	10,46,326	9,61,158	6,594
Upper Bahawal (internal) & Qaim Canal	0.251	0.424	450,00	42,000	892
Upper Depalpur Canal	0.161	0.579	3,67,499	3,36,782	2,380
Upper Jhelum Canal	0.703	1.035	6,42,447	6,03,749	9030

(Source; Punjab Irrigation Department)Punjab Irrigation Administrative and Operational Set-up

The Punjab Irrigation Department is operated under the Ministry of Irrigation, Punjab.

The primary responsibilities of PID are:

- Provision of Irrigation supplies.
- Planning, development, construction, maintenance and operation of irrigation and drainage system.
- Planning, development, maintenance and protection of flood management infrastructure.
- Construction of Small Dams and water conveyance development works.
- Applied research in hydraulics, soil physics, groundwater, land reclamation, river training and design of hydraulic structures.
- Management of vertical and surface drainage.
- Management of workshops and machinery pool
- Participatory Irrigation management and conflict resolutions through Khal Panchayat committees.
- Water Revenue assessment and assistance in collection

11.5 SALINITY

Salts are contained in natural river flows. In arid climates ground water is not refreshed frequently due to the low rainfall and high evaporation rate, thereby increasing salinity in the soil. Each Irrigation brings a certain amount of salt into the root zone. Water is lost by evapotranspiration and the salts are left behind in the root zone causing salinity and sodicity.

The average annual salt inflow by the Indus River and its tributaries is estimated at 29 million ton and only 10 million ton is carried to sea with the remaining retained in the catchment. 49 million ton is added by Groundwater which has an average concentration of 1200 ppm. In Punjab 15 million ton is added by Indus system and 28 million ton is added groundwater abstraction. About 93% of this is retained by the soil. It is estimated that about 3 ton per hector is added annually into the Punjab soils. The groundwater quality gets deteriorated when about 5.6 million ton of fertilizer and 70 ton of pesticide is added annually into the soil which is washed down to root zone and beyond. In Punjab, the sediment concentration is alarming. About 1.84 million hector has ppm between 1000 t0 3000 and about 4.8 million hectors has ppm more than 3000. About 12,6% of the irrigated area by groundwater has total dissolved salts more than 3000 ppm.

The large-scale exploitation of poor-quality groundwater without any regulation is another substantial source of salt inflow in the Indus basin, thereby aggravating the problems of salinity. An estimated 24.7 Mg of salt are annually brought to the irrigated lands by the extensive tube well pumping taking place in the Punjab Basin.

The drainage system in Punjab is inadequate and is not properly developed and maintained, which results in waterlogging, salinity and crop damage issues. The irrigated lands are uneven and drainage is impeded by barriers. Farmers and operators have poor knowledge of the requirements for effective field drainage requirements.

11.6 DRAINAGE SYSTEM

Surface Drainage is supplementary and complementary to any irrigation system. The irrigation canals intersects drainage lines which impede/obstruct natural drainage and therefore man-made drains are required to capture drainage from trapped areas. Drains are also required to take seepage flow and irrigation excess from the agriculture fields prevent waterlogging and to attain acceptable yields. Drains also play an important role in managing salinity.

Drainage networks were not constructed when the irrigation networks were originally established, as water tables were low and the need for drainage was not appreciated. Cross drainage structures like culverts, syphons and causeways were provided for handling storm flows and flood water spills. As a result many areas were poorly drained and waterlogged. Over the time the cross drainage structures were connected with drainage channels and dedicated outfall structures were provided to improve drainage. This haphazard development of the drainage system has resulted in a suboptimal layout and suboptimal results. The Punjab drainage network was constructed under SCARP projects by WAPDA from 1959 to 1994 and covers the major area of Punjab Indus Basin.

About 95% of the drainage projects have their outfalls into the Chenab, Ravi, Sutlej and Jhelum Rivers. The drainage system constructed on the left side of River Sutlej, near Bahawalnagar and close to the Indian Border, outfalls to saline ponds. In addition to surface drains, about 12,000 fresh and saline tube wells were also constructed by WAPDA. **Figure 11-2** shows the various drainage systems along with Indus Basin and their outfall locations.

11.6.1 DETERIORATION OF PID DRAINAGE NETWORK

PID treats drainage as a support function to its primary function of irrigation water delivery. It is not given an adequate priority, as an important sub-sector within PID. Development, operation & maintenance of drainage infrastructure remained deferred for years due to inadequate budget allocation and drainage management. With the passage of time, the amount of untreated sewerage and industrial effluent being discharged into poorly performing drains has progressively increased, resulting in environmental and health issues. A major issue for surface drains is the growth of vegetation / weeds and available wastewater budgets are not sufficient for effective treatment.

Following are the factors affecting the effectiveness of the drainage system:

- Drainage within PID is being treated as support function to its primary function of irrigation water delivery. It is not assigned adequate priority as an important sub-sector within PID.
- There is no leadership for the drainage sub-sector at PID level. The Chief Engineer Drainage and Flood has only a ceremonial role in drainage requirements. The Drainage circles and divisions do not interact with the Chief Drainage Engineer in planning and development.
- Drainage administration properly exists in only three irrigation zones at circle level and other zones have low representation. Even these three circles are not linked for exchange of know-how, data, information system or experiences sharing. They have no external linkages with other drainage related departments.
- Inadequate share of resources required to maintain surface drains.
- Lack of asset management and planning.
- Ineffective operation and maintenance. A major issue for surface drains is the growth of vegetation and weeds. Chemical sprays and mechanical equipment are used periodically to control weeds, which requires timely provision of adequate materials, equipment and funds.
- Poor or no control over contaminated domestic and industrial effluent and its proper treatment before discharge to the drainage system. No collaboration, coordination and liaison with sister Government Departments such as:
  (a) Public Health Engineering Department and Water and Sanitation Agencies.
  (b) Environment Protection Department
  (c) Forestry, Wildlife and Fisheries Department
  (d) Agriculture Department
- The polluted sewerage and industrial effluent is disposed into rivers through drainage systems without any treatment. It enters into canal system and groundwater recharge. This water is not fit for agriculture, human consumption, livestock, or many other uses. The following components must be addressed in forward planning and development:
  (a) Agriculture drainage
  (b) Flood drainage and rain fall excess disposal
  (c) Disposal of industrial and municipal effluent
  (d) Wastewater treatment before disposal in drains
  (e) Water quality control and monitoring
  (f) Water quality policing

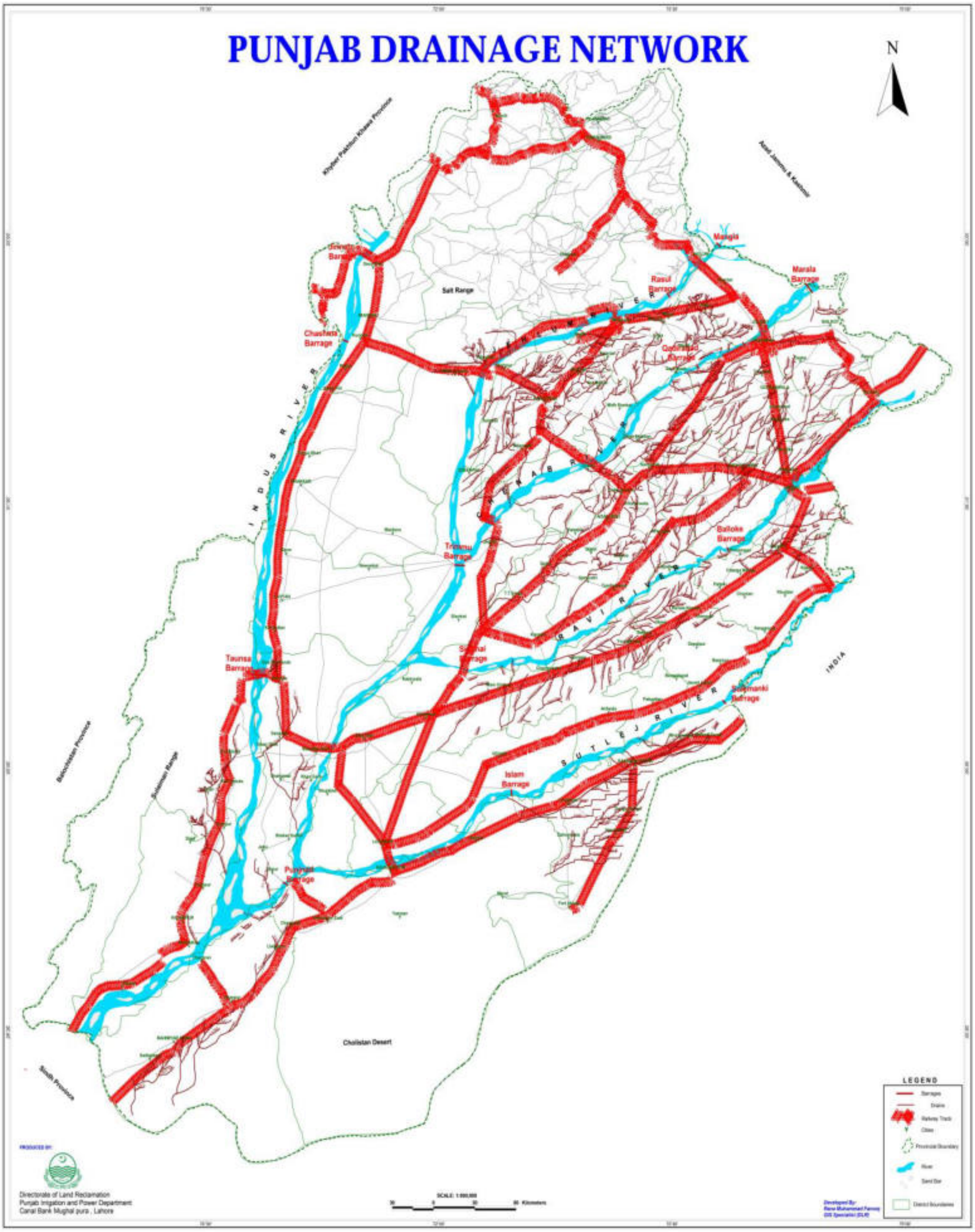


Figure 11-2: Drainage Network of Punjab

11.7 PUNJAB IRRIGATION SYSTEM ADMINISTRATION

The irrigation system is administrated in zones and project units as described below.

11.7.1 OPERATIONAL ZONES

There are seven operational zones. Each zone is headed by a Chief Engineer and is further divided into Circles headed by Superintending Engineers, who are responsible for managing a full or part of canal command. Each Circle has Divisions and Subdivisions which are headed by Executive Engineers and Sub-Divisional officers respectively.

Table 11-10 and **Table 11-11** summarises all irrigation zones, circles and divisions within Punjab and their salient feature.

Table 11-10: Punjab Irrigation Operational zones, Circles and Divisions

Operational zones	canal circles	CANAL DIVISIONS
Lahore Zone	• Upper Chenab Canal Circle	• Shahdara Canal Division • Gujranwala Canal Division • Marala Barrage Division • Shiekhupura Canal Division
	• Depalpur Canal Circle	• Kasur Canal Division Kasur • Lahore Canal Division lahore • Pandoki Canal Division Pambha
	• Link Canal Circle	• Pasrur Link Division Sialkot • Chakbandi Division Lahore • Flood Bund Division Lahore
	• Lahore Drainage Circle	• Rachna Drainage Division Sheikhupura • Gujranwala Drainage Division Gujranwala • Lahore Drainage Division Lahore
Faisalabad Zone	• Lower Chenab Canal Circle East	• Khanki H/W Division • Upper Gougera Canal Division Sheikhpura • Lower Gougera Canal Division Faisalabad • Burala Canal Division Faisalabad
	• Lower Chenab canal Circle West	• Hafizabad Canal Division • Faisalabad Canal Division • Jhang Canal Division
	• Drainage Circle Faisalabad	• FSD Drainage Division • Samunderi Drainage Division • Khairwala Drainage Division
	• Qadirabad Balloki Link Canal Circle	• Qadirabad Barrage Division • QB Link Division
	• Development Circle	
Sargodha Zone	• Upper Jhelum Canal Circle	
	• Lower Jhelum Canal Circle	• Kirana Canal Division Sargodha • Bhalwal Canal Division • Sargodha Canal Division • Sargodha • Shahpur Canal Division • Sargodha
	• Bhakkar Canal Circle	• Bhakkar Canal Division Bhakhar • Khansar Canal Division Kallur Kot • Layyah Canal Division, Layyah
	• Thal Canal Circle	•
	• Sargodh Drainage Circle	• Sargodha Drainage Division Sargodha • Mandi Bahauddin Drainage Division • Bhalwal Drainage Division
	• Greater Thal Canal Circle	• Mankera Canal Division

Operational zones	canal circles	CANAL DIVISIONS
		• GTC-II Adhi Kot Khusab • Chubara Canal Division
Multan irrigation zone	• Haveli Canal Circle	• Shujabad Canal Division Multan • Multan Canal Division Multan
	• Trimmu Canal Circle	• Trimmu H/W Division • Sidhnai H/W Division • NTD Canal Division
	• Development Circle	
	• Mailsi Canal Circle	• Lodhran Canal Division Lodhran • Mailsi Syphon Canal Division • Lower Western Bar Canal Division
Sahiwal Zone (newly created in 2021)	• Nilibar Circle	• Upper Western Division Thingi • Eastern Bar Division Pakpattan • Suleimanki H/W Division Sulemanki
	• Sukrawa Canal Circle	• Khanwah Canal Division • BS Link Canal Division • Sukrawa Drainge Division
	• Lower Bari Doab canal circle	• Khanewal Canal Division Sahiwal • Sahiwal Canal Division Sahiwal • Okara Canal Division Okara • Balloki H/W Division Balloki
Bahawalpur Zone	• Bahawalpur Canal Circle	• Bawalpur Canal Division • Islam H/W Division • Ahmadpur Canal Division
	• Bahawalnagar Canal Circle	• Fordwah Canal Division • Sadqia Canal Division • Hakra Canal Division • Drainage Division • Malik Canal Division
	• Rahimyarkhan Canal Circle	• RYK Canal Division • Dallas Canal Division • Khanpur Canal Division • Tubewells Operation Division
	• Punjnad Canal Circle	• Punjnad H/W Division • Abbasia Link Canal Division • Punjnad Canal Division
	• Development Circle	
DG. Khan Zone	• Derajat circle	• DG Khan Canal Division-I • DG Khan Canal Division-II • Rajanpur Canal Division
	• Muzaffargarh Canal Circle	• Muzafargarh Canal Division • Alipur Canal Division • Kot Adu Canal Division
	• Taunsa Canal Circle	• Taunsa Barrage Division • River Diversion Division • CRBC Canal Division
	• Project Circle	• DG Khan Construction Division • Jampur Construction Division

Operational zones	canal circles	CANAL DIVISIONS
Pothohar Zone (Newly created in 2021)	• Director Small dams Organization	*This zone has been established for development of small dams in Pothohar region of Punjab*
	• Small Dam Circle-I	• Small Dam Division • Islamabad • Small Dam Division Fateh jhang • Small Dam Division DG Khan • Small Dam Division Rajanpur
	• Small Dam Circle-II Chakwal	• Small Dam Division Jhelum • Small Dam Division Chakwal • Small Dam Division Talagang

Table 11-11: Salient feature of irrigation zones

Description	Bahawalpur Irrigation Zone	Sargodah Irrigation Zone	Lahore Irrigation Zone	Faisalabad Irrigation Zone	Sahiwal Zone	MULTAN ZONE	DG Khan Zone	Pothohar Zone
No. of Channels	549	576	350	262	331	706	423	
Length of Main, Branches and Link Canals (Miles)	725	657.75	544	454	344.65	519.60	453	
Outlets (No.)	12,499	9,046	8,380	6,709	6,100	7,812	8,197	
G.C.A (M. Acres)	4.5	4.694	3.436	3.762	1.83	3.50	2.33	
C.C.A (M. Acres)	4.0	4.11	3.22	3.03	1.66	3.25	2.11	
Design flow (CFS)	29,767	23,225	21294	15528	9,292	3593	20088	
Length of Drains (Miles)	527	1835.27	1500	1552.29	425	498.18	412	
No of Small Dams	-	-	-	-	-	-	-	57

(Source: Punjab Irrigation Department and Manual for Irrigation Practice Punjab (MIP))

11.7.2 NON-OPERATIONAL ZONES

In addition to operational zones the following zones are for planning, research and management and training purposes:

I. Drainage and Flood Zone
II. Research Zone
III. Development Zone
IV. Water Resources
V. Government Engineering Academy
VI. Khal Panchayat Committees

11.7.3 PROJECT UNITS

In addition to Zones, there are various Units established for Planning, Monitoring, Management of various projects and reforms as below:

- Strategic Planning and Reform Units (SPRU)
- Program Monitoring and Implementation Unit
- Project Management Office (Barrages)

- Project Management Office (Canals)
- Flood Risk Assessment Unit (FRAU)
- Hydraulic Safety Structure Evaluation Unit
- Program Implementation Unit

There are also some functional Units exclusively for Project Implementation

- Project Management Office Barrages
- Project Management Unit Canals

Table 11-12: Detail of Drainage projects

Sr No.	Circle Name	Length of Surface Drains (km)	Established (Year)
1.	Faisalabad Drainage Circle	2,433	1960
2.	Sargodha Drainage Circle	2,954	1976
3.	Lahore Drainage Circle	1,500	1978

(Source: Punjab Irrigation Department)

11.8 SMALL DAMS

The barani (rain fed) area development is being specifically targeted to harvest 3.6 MAF of rainfall in Pothohar and 2.71 MAF of Hill Torrents in Pachad.

The Small Dam Organization is part of the Punjab Irrigation Department headed by Chief Engineer Pothohar Zone. They have been constructing dams in the Pothohar Plateau since 1961. To date 57 small dams have been completed, while 11 are under construction. PID is considering construction of dams on Hill Torrents of the DG khan Pachad area on the right bank of river Indus. The tender for detailed design of the first project has just been released.

The completed dams have played their role in storage of water, but no irrigation networks have been implemented for efficient delivery to farms. The small dams play a role in domestic water supply, minimisation of soil erosion and enhancing aquifer recharge. The small dams have improved the quality of life in rain fed arid lands, rural and town communities. Suitable high value crops can be grown on virgin lands of low salinity and groundwater issues. Recently Olive production has been introduced very successfully in the Pothohar area.

There is a national program for enhancing Command Area of Small and Mini Dams in the Barani areas of Pakistan. The Punjab component is to promote an environment friendly, socially sustainable, resource efficient and economically viable irrigated agriculture in rain fed (Barani) areas of Punjab. In addition to construction of 57 small dams for rainwater storages across various Nullahs under various programs, the command area development is planned with the integrated participation of the Agriculture Department. The programme includes, construction of Farm Ponds, solar pumping systems, installation of high efficiency irrigation systems, development of dug wells and solar pumping systems, construction of water courses for efficient conveyance, laser land levelling, and agriculture extension services for suitable plant selection and seed development for enhanced production. Details of small dams in Punjab is provided in

Table 11-13.

Table 11-13: Small Dams in Punjab

Classification	No. of Dams	Gross Storage Capacity (AFT)	Drinking purpose	CCA (Acre)
Completed / Operational	57	219,419 (0.219 MAF)	27.5-MGD +1000-Gallon per day	66,804
Problematic / Non-Operational	12 + 10	64,087 (0.064 MAF)	15-MGD	16,824
Under Construction	11	293,793 (0.293 MAF)	35-MGD	69,800

11.9 PERFORMANCE CHALLENGES OF IRRIGATION SYSTEM OPERATION

Major challenges include:

I. System and Supply Constraints and growing water shortages.
II. Operational constraints.
III. Progressive deterioration of irrigation infrastructure; Unsatisfactory Operation and Maintenance.
IV. Low water productivity.
V. Lack of transparency and inequities in water distribution.
VI. Lack of effective Monitoring and Evaluation.
VII. Inefficient Water Resource Information Management System.
VIII. Gaps in water governance and trust.
IX. Deterioration of water quality in canals, drains, rivers and groundwater due to disposal of untreated industrial and municipal effluents.
X. Over exploitation of groundwater creating ground water mining conditions resulting in deteriorating ground water quality and overstressing of resource.
XI. Issues relating to Ground Water Management and Surface Drainage.
XII. Flood Management and Flood Risk Management.
XIII. Awareness of Environmental challenges and climate change.
XIV. Financial constraints.
XV. Institutional constraints.
XVI. General Public awareness and participation

The century-old PID require institutional transformation for managing diversified and complex water issues and has limited capacity to operationalize emerging approaches such as integrated water resources management (IWRM) and Disaster Risk Management (DRM). Thus, a comprehensive policy and institutional review and a transformation of the PID into a responsive Water Resources Department (WRD) is required. The Punjab Government has come up with Punjab Water

Policy 2018 and Punjab Water Act 2019 which provide a fundamental framework to improve institutional and technical issues

Punjab's midterm development framework, 2015–2018 prioritizes reliable irrigation supplies, enhanced agricultural productivity, improved rural economy and broad-based institutional reforms.

11.10 IRRIGATION SYSTEM EFFICIENCIES

The current irrigation system is highly inefficient with over 40 percent of canal water is lost in conveyance and delivery. In addition, a significant (25 to 40%) amount of irrigation water is lost on-farm due to inefficient on-farm irrigation practices, uneven fields and poor farm layouts. This leads to excessive application to low patches and under irrigation of higher lands. Over-irrigation leaches soluble nutrients from the crop root zone, makes the soil less productive, and degrades groundwater quality.

Crop water requirements are usually not met at the correct time because of supply based irrigation water delivery mechanism, which negatively affects the overall agricultural and water productivity.

11.11 WATER AVAILABILITY, CROPPING PATTERNS AND WATER PRODUCTIVITY

Punjab irrigation Department is responsible for delivering water to the tertiary canal level, the respective Khal Panchayat are then responsible for supplying water to the farm outlet and from there the farmers take control of water and irrigation. A Khal Panchayat Authority has been enacted for administering the water distribution. The Punjab Department of Agriculture is responsible for supporting farmers with irrigation, agriculture extension and other agronomic and farm management methods and advice. Ultimately, the farmers manage application of water to the fields. This enables:

- Improved crop productivity and ease of management at farm gate level.
- Transparency of farmer's allocation.
- Sustainable availability of water as per agreed schedule and delivery rate and time.

11.11.1 WATER AVAILABILITY AND USE

Currently water is supplied to farmers as per the pre-set water allowance to land holdings and the water availability does not necessarily match actual crop water requirements. The water balance carried out at irrigation sub-basin (Doab) level found that there were large differences in actual crop water demand and water availability. The water balance also found that the available water is not sufficient to meet the future 2050 water demand projections. **Figure 11-3** provides a snapshot of water balance for current and future (2050) scenarios. Section 5 provides complete water balance for current and future 2050 water demand scenarios.

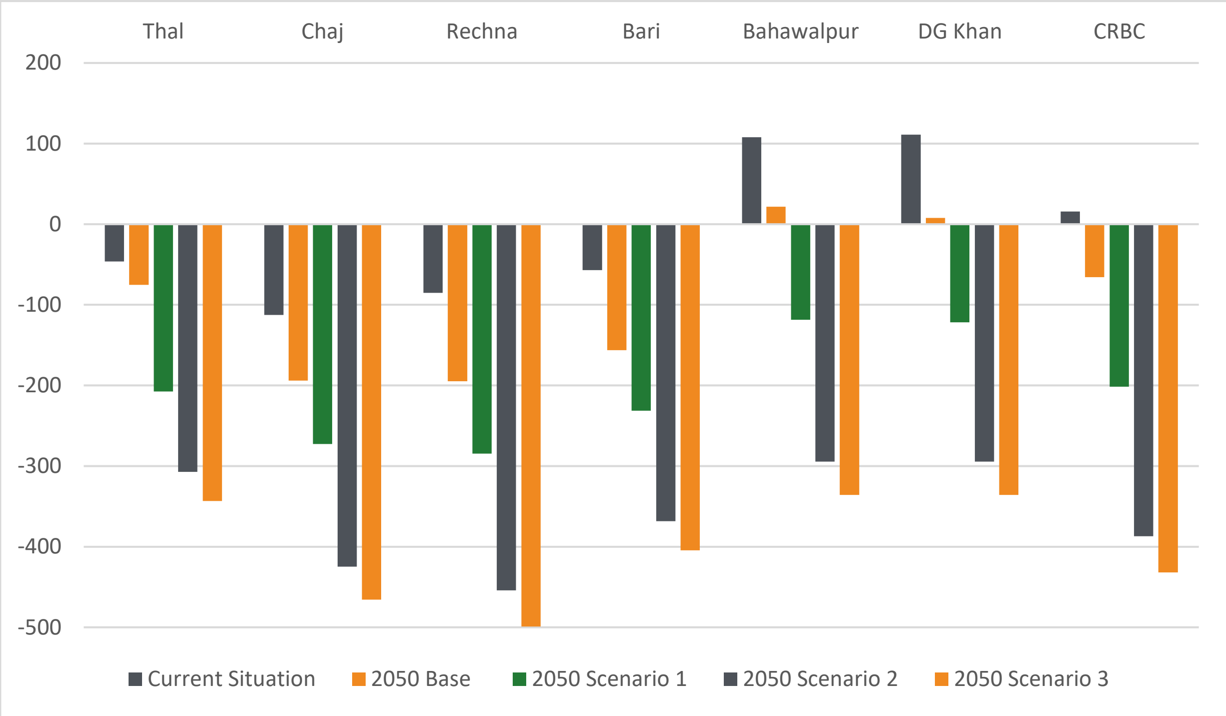


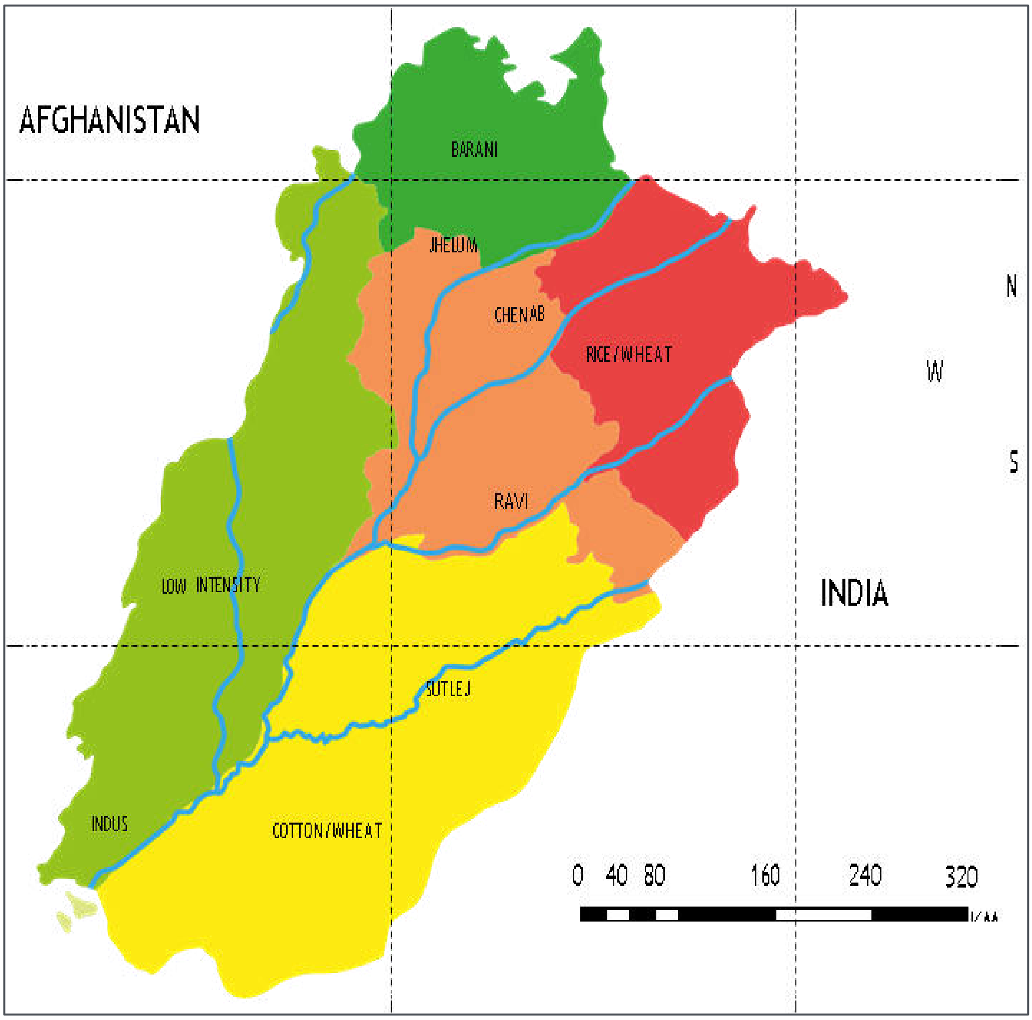
Figure 11-3: Doab/hill torrent CA water balance scenarios (mm)

11.11.2 CROPPING PATTERNS AND PRODUCTIVITY IN PUNJAB

The typical regional distribution of crops in Punjab are shown in **Figure 11-4**.

The crops grown in Punjab mostly have low economic value and there are several reasons why a farmer chooses to grow low value crops which are:

- farmer's family consumption;
- these crops are tolerant to the uncertainties in water availability and growing conditions;
- historical familiarity with such crops;
- risk averseness (not confident in trying alternatives);
- skilled farm labour requirements;
- lack of education and knowledge sharing; inadequate financial services; and
- government subsidies and/or direction to grow certain crops.



COTTON/WHEAT	RICE/WHEAT	MIXED Sargodha	LOW INTENSITY	BARANI
Vehari	Gujranwala	Khushab	Bhakkar	Attock, Rawalpindi, Jehlum, Chakwal
Multan	Gujrat	Faisalabad	Mianwali	
Khanewal	Sialkot	Jhang	DG Khan	
Lodhran	Hafizabad	Toba Tak Sing	Lyyah	
Bahawalpur	Mandi bhaudden	Chinot	Rjanpur	
Bahawalnagar	Narowal	Okara	Muzafargarh	
Rahim Yar Khan	Lahore			
Sahiwal	Kasur			
Pakpatan	Sheikpua			

Figure 11-4: Regional distribution of crops in Punjab

Increasing productivity in Punjab would require refining the following services:

1) Agriculture extension services need to provide knowledge-based guidance to farmers for adopting suitable cropping patterns each year including the benefits of crop rotation.
2) Water allowances need to be prioritised in canal commands based on high value crops with low water consumption. This will require regulatory control on growing and mixing of some crops keeping in view the dollar value of water consumed.

3) Undertaking agriculture economic analysis for each crop season.
4) Understanding the water footprint of every use and consumption.
5) Cropping patterns need to be changed regularly, with crop rotation keeping in view the overall food and fibre requirement of the country. High value crop production can be traded with low value crop production internationally where possible.
6) Reforming the current water distribution (The Warabandi) system gradually to a crop area sown and crop water requirements as per approved cropping pattern.
7) Encouraging of corporate Farming by pooling resources at Khal Panchayat level.

The productivity of crops is determined by many inputs in addition to water such as fertilizers, pest management, soil type, soil management, weather conditions, access to farm machinery, labour and capital and modern crop varieties.

Significant factors restricting crop productivity in Punjab are

- low soil fertility,
- availability of water at the right timer,
- climate change affects,
- poor control of diseases/ pests
- crop repetition,
- land levelling,
- field drainage,
- land tenure,
- Inappropriate farm sizes,
- poor education and awareness,
- aversion to change/adopt new technologies and methods,
- seeds development and old practices,
- lack of innovation, poor research and development.

Pakistan has an agriculture-based economy, with agriculture accounting for 19% of the GDP and providing livelihood to 42% of the rural population. The sector acts as a source of raw materials for the country's major industries; textile, leather, rice, edible oil, sugar and various food processing industries. Agriculture-based products account for around three fourth of the country's total export, of which about 60% is contributed by Punjab. Cereal and cash crops constitute a bigger share of the total value and enjoy an added importance due to their higher relevance in ensuring food security. Reliance of the textile industry on cotton and the export of rice has underlined continued focus on conventional crops.

Two third of the total cropped area of Punjab is devoted to the 3 largest crops; wheat, cotton and rice. Fodder is another key crop in Punjab (10.6% share of the cropped area), and it plays an important role feeding livestock. Maize and sugarcane are the two other main crops. Fruit, vegetables, condiments, flowers, pulses and oilseeds combined occupy 10% of the cropped area, in spite of their higher value and higher profitability.

Punjab's total horticultural production of 10.7 million tons accounted for 67% of the total national production. Punjab contributes 64% of the national fruit production, with citrus and mango being the two main contributors in Punjab's total fruit production, followed by guavas. olives, grapes, strawberries, peanuts and dates. Punjab's share in national vegetable production (excluding potatoes) is 63% with a wide range of vegetables grown across the province for local consumption while some are also being exported. Punjab enjoys a monopoly in potato production by producing 3.83 million tons annually.

11.11.3 GENDER AND IRRIGATION

Punjab's agriculture is labour intensive and women make significant contribution. The participation of women in agricultural activities is over 60% (**Table 11-14**) and on average they work 11 hours a day.

Female labour is predominantly used in harvesting of wheat, rice nursery transplantation and harvesting and livestock-related activities. Female labour participation significantly depends on the landholding status of farmers, household size,

family type and level of education. They, however, make limited contribution in decision making, managing irrigation supplies or participation in water user associations (WUA) due to cultural attitudes in a predominantly male dominated society.

Table 11-14: Women Participation

Activity	Percentage
Women participation in agricultural activities	61
Women participation in livestock related activities	38
Women participation in other economic activities	100

The gender gap relates to land ownership, livestock, technology, education, extension, financial services, planning of faming activities and improving farm productivity.

There is a greater trend towards mechanisation of farming activities which poses a threat to female participation, as women lack the skills to operate machinery as a result of informal state policies and cultural barriers.

The Article 23 of the Pakistan Constitution recognizes equal property rights of all citizens. However, farm ownership by women is very low. The Pakistan's parliamentary committee recently approved amendments to the constitution by a new bill 'Enforcement of Women's Property Rights Bill 2021'. It is hailed as a step forward as it puts time restrictions in resolving disputes relating to women's property.

11.12 IRRIGATION SYSTEM IMPROVEMENT OPPORTUNITIES

Irrigation system management issues are multi-faceted and all opportunities need to be identified in a comprehensive and integrated manner to address all the issues that impinge on the management and performance of the irrigation system/agency. For instance, changing the institutional framework or policies is unlikely to be effective without addressing the physical and other issues/constraints.

A holistic review identifying the real bottlenecks in the management and development of comprehensive strategies is required to improve the overall irrigation system in Punjab. Solutions need to be appropriate to the conditions in Punjab. Any preconceived ideas based on adopted practices elsewhere may not be sustainable in long term in the Punjab.

11.12.1 STRUCTURAL MEASURES

Structural measures required to address supply constraints in the backdrop of rapidly increasing water demands include remodelling and modernising the irrigation supply systems, renovation and upgrading of hydraulic structures, optimal use and of river flows, water conservation measures and improving drainage facilities. There shall be tight controls to prevent pollution of water bodies by municipalities, industries and agriculture.

11.12.1.1 Remodelling and Modernising the Irrigation Supply Systems

Most of the existing irrigation system was designed and constructed with poor control on sediment entry at intakes. The system has thus significantly deteriorated due to sediment ingress. The vast majority of the irrigation system, including main canals and branch canals, are losing their design capacities which causes significant delivery issues resulting in short supplies at tail ends. The systems need to be redesigned to restore/increase capacity. The link canals constructed under IBP were designed with compound side slopes and a mild bed slope following composite hydraulic theories and model studies. After several years in operation, some sections of the link canals have doubled in width due to the inherent

meandering nature of the canal layout. Several structural measures such as rock armouring were undertaken, however the problem still persists during high flow periods. This results in high maintenance and vigilance is required for their operation and safety. The system capacity is greatly influenced by the performance of these transferring link canals. The success of irrigated agriculture depends on meeting the demands of distribution canals and being able to equitably provide water supply to all farm gates.

Remodelling and modernising the irrigation infrastructure for transferring and distribution of canal water in an efficient manner is urgently required. The works required can be grouped into the following categories:

1. Upgrading of channel capacities due to change in water demands.
2. Remodelling to restore where required.
3. Implementing calibrated operation and preventive maintenance programme in a methodical manner.
4. Modernising to enable improved off-farm and on-farm water management
5. Canal lining in saline or marginal water quality areas.
6. Remodelling and providing surface and vertical drainage network to improvise irrigation network intervention and storm water disposal.
7. Flood Risk Protection measures and works.

11.12.1.2 Renovation of Hydraulic Structures

It is understood that the vast majority of the existing hydraulic structures are nearing their end of life or adopt outdated technology. Several of these structures have deteriorated badly and have inherent deficiencies. They typically experience siltation and/or scour and have inadequate hydraulic capacity.

Several structures have damages/deficiencies including:

- Aging.
- Damaged, stuck and irreparable gates, mechanical components and hoisting systems are a major barrier to timely operation.
- Scour damage and choking of water ways of hydraulic structures. Structures require comprehensive remodelling with modern hydraulic and structural design
- Deferred and lack of preventive maintenance.
- Inability to maintain approved full supply line for equitable distribution.
- Structural deficiencies and constraints.

A rehabilitation and remodelling program needs to be formulated which prioritizes the most urgent repairs, short-term fixes to extend asset life, asset replacement and modernisation. The structure rehabilitation program should be developed to cover current design and operational requirements and allow for future automation of the system.

11.12.1.3 Maximising the use of rainfall and river flows

Water is a finite resource and Punjab is expected to experience severe water shortages by 2050. The water demand is increasing due to population increases, climate change and economic development. It is vital to develop schemes to maximise rainfall harvesting and river/flood flows. Possible solutions include:

- Decision Support Systems to manage storage releases to enhance use of tributary inflows and rainfall runoff flows.
- Additional dams, storages (en-route and offline) including:
  - Construction of large dams at storage sites on main rivers like Kalabagh, Chiniot etc.
  - Construction of small dams on river tributaries like Akhori, Dandhocha, Soan Sora etc.
  - Construction of small dams in Pothohar and hill torrent areas (Suleman range in Mianwali, DG Khan and Rajhanpur).
- Managed aquifer storage – building low level levees , bunds, infiltration galleries, ponds or wells to enhance groundwater recharge in dried river reaches and nullahs.
- Rainwater tanks – for domestic use

    - Rainfall Harvesting in cities and towns by collecting rainwater in tanks from roof top and street run-off in ponds in low-lying areas which can enhance aquifer recharge.
- Rainwater ponds at village level to enhance rainwater harvesting
    - New ponds for stock and domestic use
    - Existing Ponds - desilting and rehabilitating
- Flood water
    - Diversion of flood excess into deserts for enhancing groundwater recharge instead of Arabian sea
- Ground water regulation and licensing
- Water conservation and optimal utilization
- Integrated Water Resource Management
- Water recycle
    - Wastewater harvesting and reuse
    - Stormwater harvesting
- Water scarcity and conservation awareness in masses
- Public awareness and policing of water body misuse, waste and pollutions

11.12.1.4 Water Conservation Measures

The water conservation plays an important role in sustaining agricultural development and meeting future demands. This can be achieved via structural as well as institutional measures including:

1. land levelling,
2. use of more efficient irrigation methods and water application system,
3. improved operation and maintenance of irrigation system
4. improved water pricing structures for canal water
5. adopting dynamic cropping patterns, crop rotation patterns, adopting crops suitable for different Agro-climatic zones and changing to high value crops having higher economic returns.
6. Improved Seed adaptation for higher yield with low water application

11.12.1.5 Improving Drainage Facilities

The surface drains in Punjab are generally constructed with flat gradients due to flat land slopes and thus have low velocities. The drainage water has heavy nutrient rich sediments which settle on the bed. This loose, moist and nutrient rich sediment is ideal for weed growth which increases channel roughness and decreases the cross-sectional area. Both of these factors decrease the drain capacity and causes flooding of the adjoining agricultural lands and properties. There is a need to identify effective and efficient methodologies for the maintenance of drains.

Outfalls - the outfall conditions of the existing main and branch drains are not favourable under all flow conditions. To avoid stagnation and spillage, provision of pumps and/or relocation of outfalls should be considered, especially in the saline and marginal water quality areas.

Maintenance – Regular desilting of the surface drainage network and control of weeds and vegetation is required to maintain drain capacity and agriculture productivity.

Operation – Flow and level monitoring along the drains and outfalls could improve drain operation and drainage flow management.

***Water Harvesting* -** Drainage water could be used for farming and should be encouraged. This would not only meet part of the agriculture demand but also would minimise nutrient exports and improve water quality in the downstream rivers.

On-farm drainage – On-farm field drains and land levelling are also very important to improve on-farm drainage, provision of tile drainage.

11.12.2 MANAGEMENT INTERVENTIONS

There is a growing awareness that management interventions need to precede the structural measures in implementing reforms and/or modernisation.

11.12.2.1 Monitoring and Improving Overall System Performance

The objectives would be to introduce key performance indicators and maximise irrigation system performance. Key indicators that could be considered are:

- ***Economic value:*** Establish the economic value of the irrigation sector to Punjab's economy.
- ***Water Use Efficiency:*** Improved water use efficiency is critical to provide the water required to allow growth in urban, industrial and agricultural sectors.
- ***Productivity***: Productivity refers crop yields (yield/ha) and water productivity (yield/m^3 water and \$/m^3 water). Improved productivity allows the agricultural sector to achieve improved economic outcomes. It is recommended that productivity be compared with benchmarks elsewhere in Pakistan and Asia as this will provide meaningful and achievable targets for improvement.
- ***Social Equity:*** This refers to providing fair and equitable opportunities to various individuals and stakeholders to have access to water for their various needs.

11.12.2.2 Improved Level of Service

A high level of service may increase water and farm productivity in multiple ways such as:

a. High yields that are uniform across the farm with no areas suffering stress due to poor supply of water.
b) Optimization of land use through multiple cropping and crop rotation.
c) Growing high value crops require reliable water supply at the right time.
d) Improved labour productivity as they can optimise time spent in irrigating.
e) Adoption of modern irrigation and agronomic technologies to grow high value crops.
f) Increase in farm yields as well as water savings.
g) Water savings could be used to bring rain fed areas under irrigation or be directed to other usages such as water for domestic/industrial/commercial demands.

11.12.2.3 Improving System Operation

Improved irrigation system operations with the use of a decision support system and information management system for routing and canal automation can improve water productivity at system and farm scales. Adoption of modern technologies has yielded significant water savings and improved productivity in overseas irrigation systems. The first step in the process is to document requirements at various levels (main, branch, tertiary etc), identify improvement opportunities and develop a step-wise program to improve canal operation.

11.12.2.4 Planned Maintenance

Routine, proactive and preventive maintenance is essential for optimal asset management and to ensure assets last their design life. The following key steps are required:

- Asset management plans
- Identifying maintenance and operation requirements
- Defining routine proactive and preventive maintenance standards
- Defining limits of proactive and preventive maintenance
- Development of annual, routine and periodic operation and maintenance works plans
- Prioritisation and scheduling of maintenance works
- Sourcing of funds and resource allocation
- adequate supervision and quality control
- Monitoring and evaluation

11.12.2.5 **Demand Management**

The Demand Management Plan may include the following alternatives:

- Smoothing Peak Demands - staggering of farming to attenuate peak water requirements
- Change of crops - growing water-efficient crops
- On-farm practices – improve agriculture practices such as irrigation methods to optimize water use
- excluding areas covered by saline, poor or marginal soils
- Water allocation - allocation of water to preferential crops during sensitive stages of growth
- Water Tariffs - rationalizing water and power tariffs and economic policies for encouraging efficient water use

11.12.2.6 **Water Resources Information Management System (WRMIS) and Decision Support Systems (DSS)**

The systematic and on-going information gathering, monitoring and evaluation are key to develop, support, guide and refine management decisions. The key steps are:

- Develop an effective WRMIS (part of current CDTA)
- Design DSSs (part of current CDTA)
- Review and enhance monitoring capabilities
- Effective and efficient data collection, analysis, interpretation and identifying improvement opportunities
- Develop reports for management
- On-going performance review of various units with reference to the agreed/identified objectives, targets and performance indicators
- Transparent access/shortage sharing due to mismatched supply and demand

11.13 PLANNED PROJECTS

The PID is rehabilitating poorly performing command areas to increase reliability of water supply for crop production. The list of under rehabilitation and new Barrages Projects for optimization of available Water has been planned, designed and constructed as provided in below list.

Table 11-15: PID –25 Year Capital Works Program

NO	PROJECT NAME	CURRENT STATUS	PROJECT DETAIL	INSTITUTION	FINANCIERS	REMARKS
A. CURRENT PROJECTS						
1	Jalalpur Irrigation Project (JIP)	Under Construction	The Project cost is about Rs 4,960 million is expected to be completed in year 2026.	PID	ADB	Package 3 Construction is expected to be completed in May 2025.
2	Remedial measures to control waterlogging due to Muzaffargarh & Taunsa Panjnad link canals Project.	Under Construction	The project revised cost is Rs 16,699 million.	WAPDA	ADB	Lining of canals and other Remedial measures to control canal water seepage.
3	The Greater Thal Irrigation Canal (Choubara Canal)	Under Tender	The Project with an estimated total cost of Rs. 25,000 million is expected to start by first quarter of 2022.	PID	ADB	Procurement of design and construction supervision is in progress.

NO	PROJECT NAME	CURRENT STATUS	PROJECT DETAIL	INSTITUTION	FINANCIERS	REMARKS
4	Lower Bari Doab Canal (LBDC) Improvement Project	Under Construction	The Project cost is about Rs. 29,833 million.	PID	ADB	The Project commenced in 2007 and expected to be completed in 2023.
5	Detailed Design of Irrigation Canals and Link Canals	Under Tender		PID	ADB	Under process
6	Remodelling of Ravi Syphon of BRBD	Under Tender		PID	ADP	Local funding
7	Construction of Small Dams in Pothohar	Under Tender		PID	ADB	
B. PLANNED PROJECTS						
A)	Rehabilitation and Upgrading of Upper Jhelum Canal System Project.		Project cost would be US $ 174 million and Culturable command area of 2,44,328 ha			
B)	Remodeling and Upgrading of Dera Ghazi Khan Canal System Project		Project cost would be US $ 68 million and Culturable command area of 3,840,82 ha			
C)	I. Greater Thal Canal (Phase-III) Project Dhingana Branch System II. Noorpur Branch System III. Mehmood Subbranch System		Project cost would be US $ 600 million and Culturable command area of 4,408,50 ha			
D)	Remodeling of I. R-Q Link Canal II. Q-B Link Canal III. B-S Link Canal		Project cost is US $ 50 million and Culturable command area of 1,083,159 ha			

11.14 INDICATIVE ACTION PLAN

Table 11-16 provides a summary of action plans and studies required for implementation of a comprehensive water quality monitoring program for the Punjab River basin.

Table 11-16: Indicative Action Plan

NO	PROJECT/ACTIVITY	YEAR 0-1	YEAR 1-5	YEAR 5-10	LEAD AGENCY	INVOLVED AGENCIES
1)	Strategic Irrigation System Modernisation Plan- Develop in the next 12 months and implement in years 2-5.	√	√		PID	PID
2)	Strategic Asset Management (asset replacement, renewals and maintenance)	√	√		PID	PID
3)	Demand Management (Delivery to match demands)	√	√	√	PID	PID
4)	Enhance existing WRMIS and include DSS to improve irrigation system operations		√	√	PID	PID
5)	Enhance rainfall and flood harvesting new infrastructure: village ponds, small dams and large storages Existing infrastructure: Desilt dams		√	√	PID	PID
6)	Upgrade IRI to support modernisation and support modernised assets		√	√	PID	PID

12 URBAN WATER SUPPLY AND WASTEWATER TREATMENT

12.1. INTRODUCTION

12.1.1 IMPORTANCE OF WATER SUPPLY AND SANITATION

Punjab has the largest provincial population in Pakistan with 110 million, based on the 2017 census. Around 37% live in urban areas, while 63% live in rural areas. The population has increased by 36 million in the last 19 years. The rate of urbanization of Punjab is expected to reach 50 % by 2030. This poses a very serious challenges in terms of providing sufficient drinking water and sanitation facilities.

Safe drinking water is a basic necessity for every individual and is also vital for a sustainable environment. With urbanization, households increasingly have to rely on large-scale public infrastructure and tap connections, as compared to private hand pumps and wells in rural areas. Urban water supply is the most critical challenge facing Punjab and Pakistan.

12.1.2 FACTORS AFFECTING PROVISION OF CLEAN DRINKING WATER

Urban areas in Punjab are overwhelmingly dependent on groundwater for fresh water supply with only a small portion of the population serviced by surface water. About 55% of the population in urban areas have access to piped water, whereas in rural areas 85% of the population rely on self-managed groundwater extraction through motorized and hand pumps. 92% of the population has access to piped water supply for less than 6 hours a day.

Key issues which affect the provision of clean drinking water supplies in urban areas are described below:

- Discharge of untreated industrial, commercial and domestic effluent contaminates ground and surface water supplies.
- A significant increase the levels of arsenic and other heavy metals has been observed in the groundwater over the last few decades.
- Leakages due to the old water and sewerage pipelines contributes to contamination of urban drinking water.
- Uncontrolled urbanization reduces groundwater recharge compared to the previous irrigated agriculture regime.
- In rural areas about, 88% water is unfit for drinking at the point of use, due to brackish groundwater

12.2 CURRENT STATUS OF WSS

12.2.1 WATER SUPPLY

Rapid urbanization causes serious issues of unsustainability in large urban centers of the province. Among many issues, one of the biggest challenges is to provide sufficient quantity of safe water supply to the inhabitants of these urban areas.

Presently, there are no major urban water storage reservoirs, rainwater harvesting systems, or aquifer recharge systems to increase water availability. As a result, the urban and peri-urban regions are almost completely dependent on the current groundwater supply, which is rapidly depleting due to increasing urbanization. Outside of major urban centres, provision of freshwater is not a major issue.

The Government of Punjab has concluded that low water supply and sanitation coverage is one of the major issues confronting the water supply and sanitation (WSS) sector. The adequacy of supply has been mapped by the Housing, Urban Development and Public Health Department in 2012 (**Figure 12-1**). The assessment found that Lahore had less than 1% of its population served by functional water supply schemes with other major cities such as Gujranwala, Rawalpindi and Multan having 1-5% coverage. Only 6 districts had more than 20% of the population served by effective water supply schemes. Mapping also shows the significance of groundwater as the main water source in most Districts.

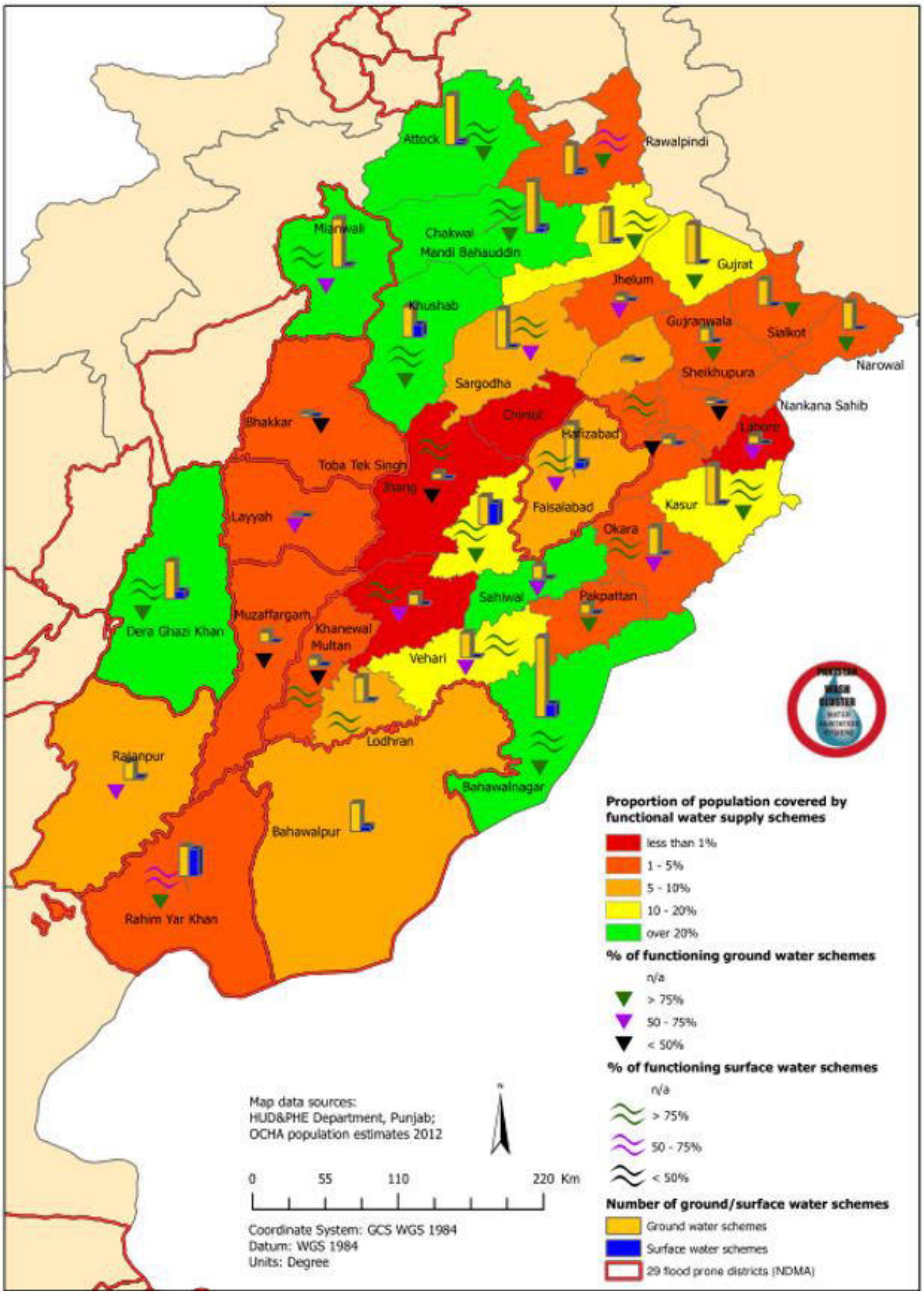


Figure 12-1: Population coverage by Water Supply Schemes (Ground and Surface)

Improved water source infrastructure (piped, motor pump, hand pump, other) is accessible to 94 % of the population, but only 49% of these provide safe water. **Figure 12-2** shows the distribution of households with improved water supply infrastructure in Punjab.

The availability of piped water supply in rural regions is very low, with around 85% of the population dependent on motor and hand pumps, compared to urban regions where about 40% have piped water supply. In rural regions, 88% of water is unfit for drinking.

Operation and management of piped water schemes is commonly poor. Eighty-nine percent of schemes are installed by government, however about 33% of these schemes are not managed by government after installation and as a result they suffer O&M problems. Private service providers face financial losses in covering the O&M cost, due to low tariffs and poor efficiency. Service providers are strongly dependent on government subsidies and external funding to provide better services.

The World Bank concluded that brackish groundwater and poor O&M in rural schemes resulted in poor cost-effectiveness and sustainability. There is also an absence of a regulatory framework, a lack of tools to estimate consumer water demand, and lack public awareness regarding water saving.

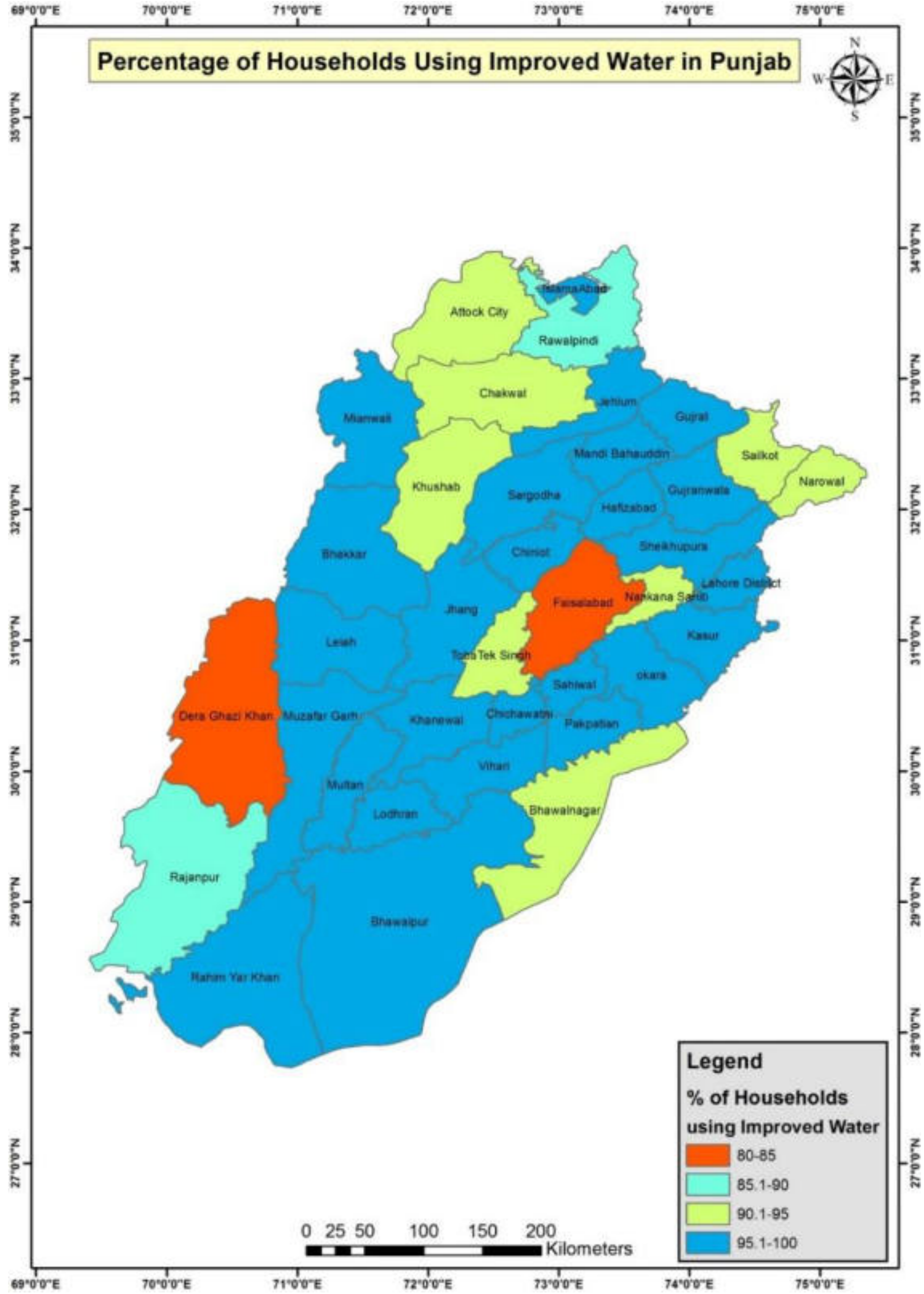


Figure 12-2: District wise proportion of households using improved water source equipment

The provision of good quality drinking water is becoming a serious challenge as the province becomes more urbanized especially in the large cities. Poor quality drinking water is to be found in and around the big cities due to the presence of

toxic synthetic organic chemicals, heavy metals, municipal wastes and untreated sewage. According to the UNICEF, arsenic contamination is common in different parts of Punjab.

12.2.2 WATER SANITATION

Figure 12-3 shows the district wise distribution of households with improved sanitation facilities; 75% of households have access to improved sanitation (67% rural and 92% urban), 8% use unimproved facilities (8% rural, 1% urban), and 17% practice open defecation (25% rural and 1% urban). Moreover, more than 75% households in Punjab (46% urban, 99% rural) dispose of solid waste in open fields. About 57% of the population disposes of freshwater properly (96% in major cities, 88% in other urban areas and 41% in rural areas).

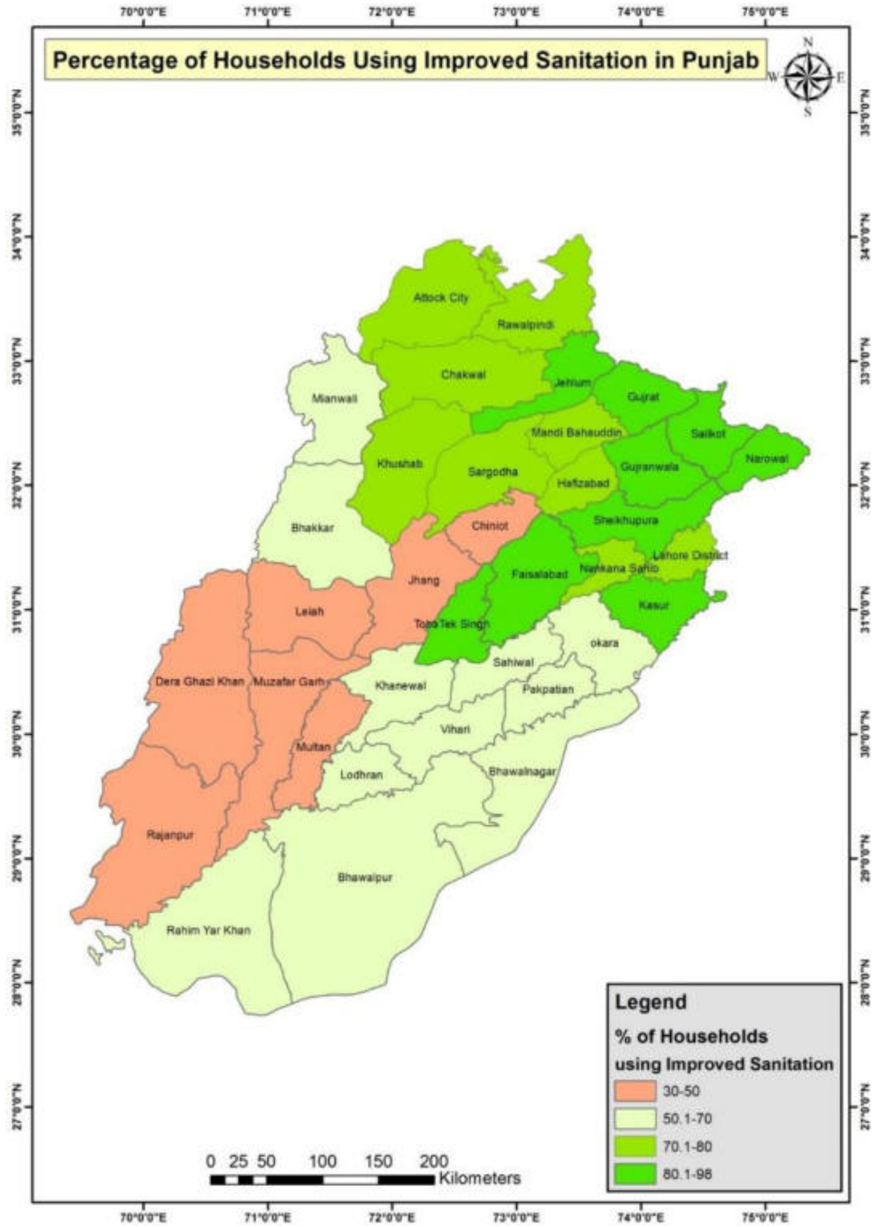


Figure 12-3: District wise proportion of households with improved sanitation facilities in Punjab

Presently, raw sewage in all cities is either used for irrigation purposes or discharged into freshwater bodies through a network of drains, which ultimately return to the rivers. Water from these water bodies and rivers is again used for irrigation and drinking purposes in the downstream areas. This poses very serious environmental concerns and also impacts on the urban and rural ecosystem and human health.

There are closed drainage facilities in 57% of mega and intermediary cities, however in villages and small towns open surface drains are common and their condition is very poor due to neglected maintenance. This poor open drainage systems result in health hazards, insect infestations, unpleasant odours, and damage to buildings/structures due to seepage.

12.2.3 WATERBORNE DISEASE

Major waterborne disease outbreaks are common due to poor drinking water quality and lack of sanitation. Water quality is a significant issue in urban areas with 49% of the water contaminated.

According to UNICEF 20%–40% hospitals in Pakistan have patients suffering from waterborne diseases such as cholera, typhoid, dysentery, hepatitis, giardiasis, and cryptosporidiosis and guinea worm infections. Around 80% of all diseases including polio, diarrheal diseases, jaundice, typhoid, malaria, dengue viral fever and cholera are attributed to unsafe water supply and poor sanitation. The Pakistan National Conservation Strategy estimates that deaths due to water contamination result in a loss of approximately 0.6-1.44% of Pakistan's GDP.

Rural households relying on distant sources of unsafe water (e.g., uncovered wells, rivers, and rain-fed/canal-fed ponds), generally transported by women and children, suffer significantly from waterborne diseases. The spread of waterborne diseases across the province has been mapped by the Urban Unit (**Figure 12-4**).

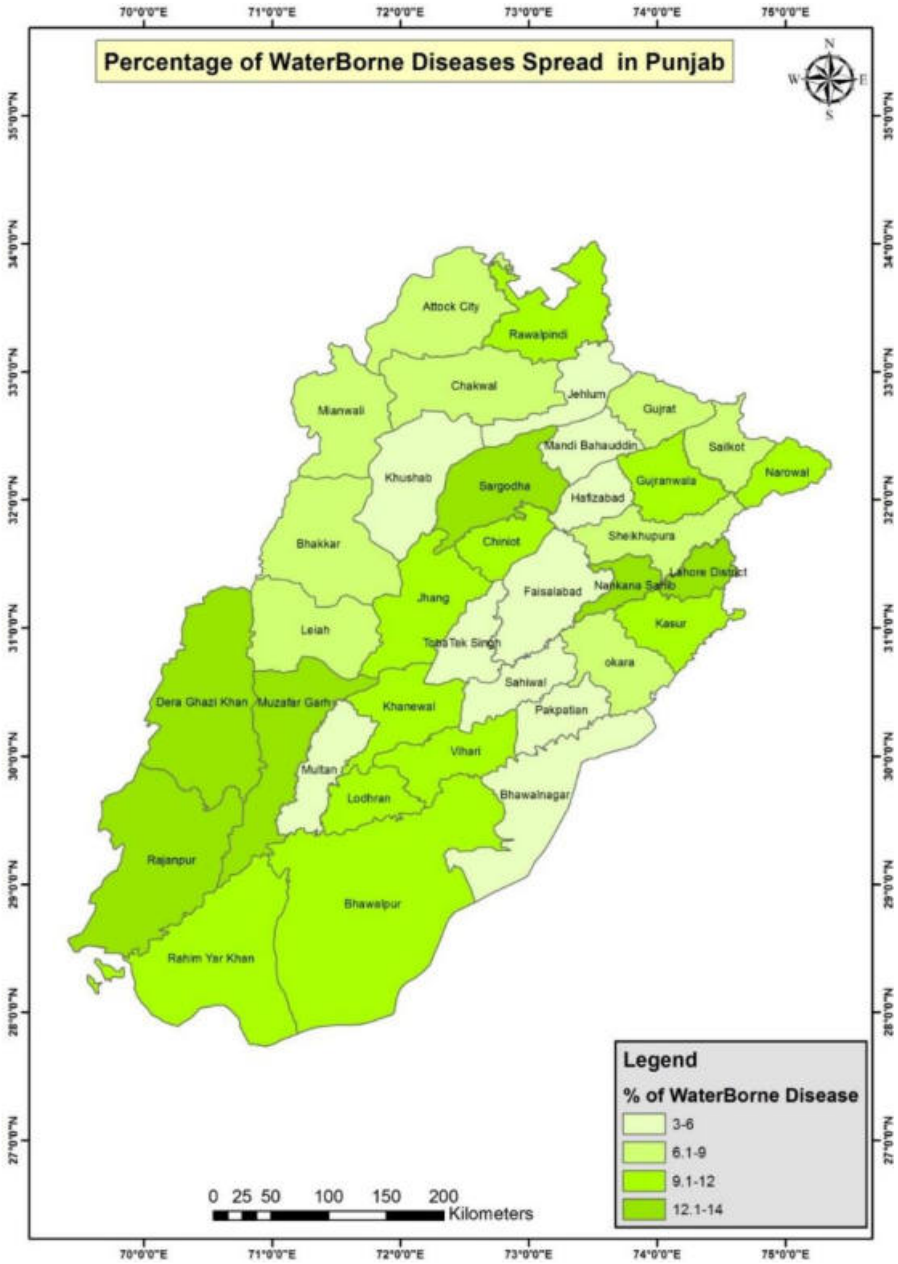


Figure 12-4: District wise distribution of waterborne diseases

12.2.4 INFRASTRUCTURE INVESTMENT

There is a long history of investment in water supply and sanitation by Pakistan with multi-lateral and bi-lateral partners. Significant investments include the following:

i. The 'Lodhran Pilot Project' (LPP) commenced in 1999 which was supported by the World Bank and Japan Social Development Fund to construct low-cost sewerage networks in towns in southern Punjab. The model was later replicated in 100 villages. The project included capacity building of Tehsils Municipal Administration.

ii. The 'Punjab Community Water Supply and Sanitation Sector Project' was supported by the ADB from 2002 to 2011. It provided WSS facilities to about 2,500 rural communities and targeted regions with brackish groundwater, or where water was scarce and rainfall seasonal. It constructed water supply and drainage facilities and provided institutional capacity building.

iii. The Ministry of Environment, from 2004, approved $8.2 million dollars for clean drinking water supply and construction of 445 water purification plants in all Tehsils of Pakistan. The schemes were then later handed over to local municipal administration. A further $168 million was allocated for an additional 6,035 purification plants.

iv. The Ministry of Environment under the 'Medium Term Development Framework (MTDF) 2005-2010' of provided 120 billion rupees for water and sanitation schemes.

v. The ADB, in 2008, provided a sector loan for the Government's poverty reduction strategy outlined in its 10-year perspective Development Plan 2001–2011. The Project took a community-based approach to extend WSS facilities to 54 tehsils in 26 districts of Punjab that faced water scarcity.

vi. Many NGOs, such as Water Aid and Plan Pakistan, have incorporated Community Led Total Sanitation (CLTS) in their strategies and projects. In 2008 about 130 defecation free villages already existed in Pakistan and through CLTS more than 1,500 villages achieved "open defecation free status" by 2009. This figure was expected to reach 15,000 villages by June 2011, covering a third of the rural population of Pakistan.

Primary constraints to the previous urban and rural water and sanitation projects were (Ministry of Water and Power, 2002):

i) The inadequate institutional arrangements for formulating and evaluating strategic options and for monitoring the implementation of national policies and programs

ii) An inconsistent and inadequate approach to funding and regulation

iii) Low tariffs for water and sanitation, varying collection rates, and a lack of a sustainable policy for setting and collecting water charges

iv) An inefficient and non-commercial approach to service delivery

v) Limited private sector involvement in the sub-sector.

The following recommendations (ADB, 2016) were made based on the lessons learned from the regional, multilateral, bilateral, and NGO managed projects in the country:

(i) private sector participation should be promoted

(ii) water supply and sanitation financing arrangements, tariffs and cost recovery need restructuring

(iii) appropriate institutional arrangements for water supply and sanitation services in the smaller cities / towns should be formulated

(iv) maintenance backlog of operational assets with specific reference to existing sewage treatment plants needs to be addressed.

(v) Existing water supply and sanitation networks need to be improved and extended, whilst new networks are required in many areas

(vi) additional surface and groundwater sources are needed for growth in consumption

(vii) new sewage treatment works in line with EPA effluent disposal regulations are needed

(viii) community groups (with male and female members) need to be established to participate in planning and implementation of community-based projects

(ix) construction quality and timely completion of projects would be enhanced be increasing the role of consultants.

12.3 RELEVANT POLICY

Until late in the 21st century, water sector policies in Pakistan were mainly focused on water resources and irrigation. Water supply and sanitation facilities resulted from a top-down approach and were mostly constructed by Public Health Engineering Departments (PHEDs).

A major shift in policy occurred with the formulation of 'Clean Drinking Water for All Program', 'National Drinking Water Policy' and the 'National Sanitation Policy'. These were prepared under the umbrella of the Ministry of Environment as integral parts of the 'Medium Term Development Framework (MTDF) 2005-2010' which had allocated 120 billion rupees for water and sanitation schemes.

12.3.1 NATIONAL SANITATION POLICY-2006 (NSP)

The key objective of the NSP was to ensure the safe disposal of liquid and solid waste and promotion of health and hygiene practices. For habitations of less than the 1000 inhabitants it promoted community-led total sanitation. For larger communities, NSP used a sharing model where, if local government disposal was not available then the wastewater treatment and sewage facilities would be provided by the communities.

12.3.2 NATIONAL DRINKING WATER POLICY-2009

The National Drinking Water Policy aimed to provide safe drinking water at an affordable cost to the entire Pakistani population by 2025. The right to water for drinking precedes all other uses and emphasized the role of women as an active member contributing to the sector. Local governments have responsibility to ensure the supply of drinking water.

Access is defined as "There should be at least provision or supply of 45 and 120 litre per capita per day of drinking water available for rural and urban areas respectively. Moreover, this supply would be within the house or at such a distance that the total time required for reaching the water source, collecting water and returning to home is not more than 30 minutes".

12.3.3 PUNJAB DRINKING WATER POLICY-2011

The drinking water policy aims to provide an adequate quantity of safe affordable drinking water to all citizens by 2020. This was to be achieved by fair resource allocation, political consensus, sector reforms, community awareness and partnership, capacity building of local governments, Private-Public Partnership and improved public health standards throughout Punjab.

12.3.4 PUNJAB SANITATION POLICY-2015

The policy aims to ensure that the entire population has access to safe and affordable sanitation for a quality life by 2025. It envisages improved access to hygienic, affordable, and equitable sanitation facilities leading to a healthy and liveable environment for all. The scope entails management of human excreta, safe disposal of liquid wastes, and promotion of health and hygiene good practices for the improvement of public health and the environment. An integrated approach towards sanitation is to include solid waste management; industrial and other hazardous waste management; wastewater management; drainage management and also the management of drinking and household water supply.

12.3.5 NATIONAL WATER POLICY-2018

This policy is based on the concept of IWRM and provides aspirational direction for all water using sector with the primary objectives to improve availability, reliability and quality of fresh water. It identified drinking and sanitation as the highest priority use of water.

12.3.6 PUNJAB WATER POLICY-2018

The Policy follows the form of the National Water Policy of 2018 with the primary objective of providing clear directions to the provincial government on the sustainable management and development of water from all water sources (rainfall,

surface and groundwater). It includes all water using subsectors and has specific objectives for: increasing water availability, managing groundwater abstraction, improving water quality, enforcing drinking water and sanitation standards, improving water governance, and developing GIS databases.

Urban drinking water and wastewater management measures include: a focus on drinking water and the need for financial sustainability, monitoring and enforcement of drinking water standards; and for wastewater disposal, separating domestic, industrial and agricultural streams for appropriate management and use of stormwater for agriculture and to recharge groundwater.

12.4 INSTITUTIONAL ARRANGEMENTS AND REFORMS

Drinking water and sanitation is the constitutional responsibility of provincial governments and municipal utilities are accountable to both the provincial and local government.

Administratively, Punjab province is divided into 9 divisions, 36 districts and 144 tehsils. In Punjab province, only 5 large cities are identified as urban centers.

In Punjab the Housing, Urban Development and Public Health Engineering Department drew up a roadmap for reforming water utilities in 2006. This resulted in utility responsibilities being based on the population of the urban settlement and reformed utilities for the 5 largest cities to Water and Sanitation Agencies (WASAs) for better service delivery and accountability. The basis of the population classification is shown in **Table 12-1** and responsibilities for WSS is shown in **Table 12-2**.

Table 12-1: Population based classification of urban habitations

AREA	POPULATION
5 LARGE CITIES (LAHORE, FAISALABAD, MULTAN, GUJRANWALA, RAWALPINDI)	1.9 million – 9 million
13 INTERMEDIATE CITIES	0.25 million - 0.8 million
150 + SMALL URBAN SETTLEMENTS:	more than 25k – 0.25 million

Currently, governance in the Punjab province for water supply and sanitation services is regulated by the organisations as shown in **Table 12-2**.

Table 12-2: Responsibilities for WSS at the different levels of governance

LEVEL	RESPONSIBILITY
PROVINCIAL LEVEL:	Public Health Engineering Department (PHED), Department of Local Government
LOCAL GOVERNMENTS LEVEL:	Large cities: WASAs All other areas: TMAs (Tehsil Municipal Authority)
RURAL WATER SUPPLY SCHEMES:	PHED
DEVELOPMENT OF NEW SCHEMES	PHED for others such as Cantonment Board, DHA and Private Housing Societies

In 2010, the Government of the Punjab planned to bring institutional reforms to all WASAs to conserve groundwater and other water bodies i.e. rivers & canals. These reforms were to improve management and service delivery so that the WASAs would be transformed into progressive, accountable, and financially viable institutions. Measures to be addressed

included rationalization of tariffs, installation of meters, community participation, reduction of non-revenue water (leakages) causing contamination in drinking water, and investment in better water storage facilities and rain harvesting.

Tehsil Municipal Authorities (TMAs) have serious capacity issues regarding operations and maintenance. The collection of appropriate tariffs and recovery of operating & maintaining cost is urgent. Installation of flow meters and periodic surveys of users (legal or illegal) is needed. There is also a need to monitor and improve the quality of the services being provided to the consumers. The Government, private sector and donors have taken a range of administrative initiatives to ensure rationalization of tariffs and improvement of capacity in the TMAs.

The water supply schemes for rural populations suffer from insufficient resourcing and investment and require better administrative, technical, and financial support from the Government. It is understood that PHED constructed schemes only serve 32% of the province's 60 million rural population. The rural 'Community Based Organizations' program has shown that communities have capacity to run water supply schemes that are handed over to them. It also found that those that are at present operating & maintaining more than 95% of the functional rural water supply scheme should be given administrative, technical, financial and capacity building support.

The State Bank of Pakistan believes that the water sector in Pakistan is characterized by multiple authorities with overlapping responsibilities and duplication of work and that the problem is not so much water availability but the system of water management and governance (Cooper, 2018). Both the TMAs and the WASAs suffer from inadequate human resources and management system capacity. Wastewater and waste management are serious challenges in both Peshawar and Lahore, the two provincial capitals and the WASAs lack capacity, infrastructure and systems, including functioning wastewater treatment plants.

12.5 URBAN WATER DEMANDS

12.5.1 ESTIMATED 2020 WATER DEMAND

Future water supply demands for each District of Punjab were calculated by tabulating populations from the 2017 census and then applying an annual growth rate of 2.13% as recommended by Bureau of Statistics Punjab to estimate the 2020 population. This shows a rural to urban split of population of 63% and 37% respectively. **Figure 12-5** shows the district wise distribution of rural and urban populations accordingly.

The current (2020) water demand at district level (**Figure 12-6**) is calculated by multiplying the respective rural and urban populations by water demands of 45 l/p/d and 120 l/p/d respectively.

The results show that rural water demand is high (compared to supply) in 27 districts. There are only 9 districts where urban water demand exceeds rural demand. Lahore has 100% urban water demand followed by Faisalabad, Rawalpindi, Gujranwala, Multan, Sheikhupura, Bahawalpur, Sialkot and Sargodha districts.

Figure 12-5: District-wise urban and rural population distribution (2020)

Figure 12-6: District-wise estimated total current water demand (2020)

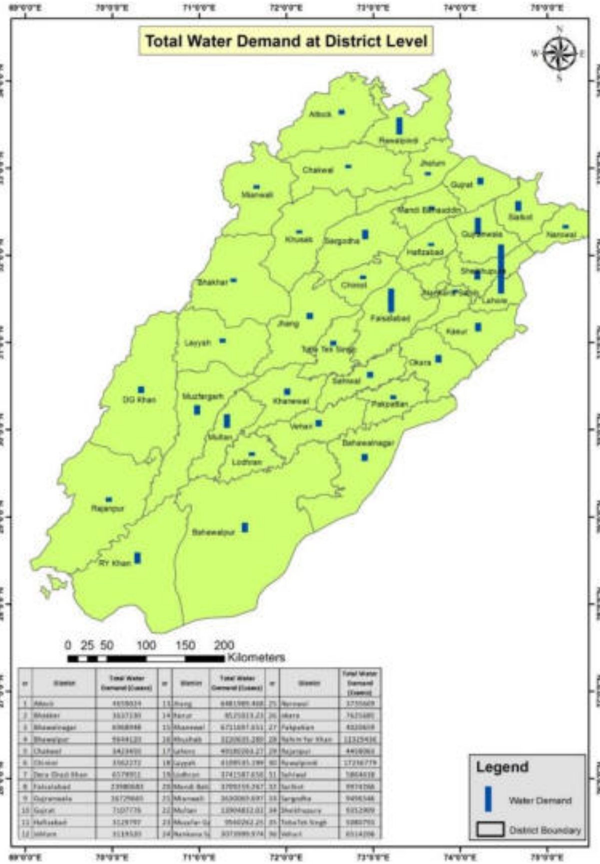
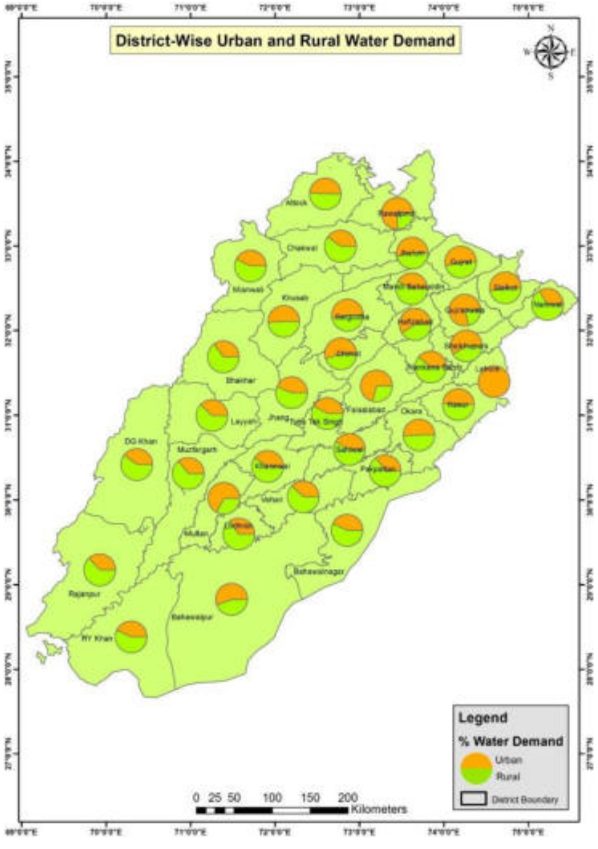


Figure 12-7: District wise rural and urban water demand in 2020



12.5.2 PROJECTED 2030 WATER DEMAND

According to the National Institute of Population Studies, the proportion of urban population of 31.267% from the 1998 census is projected to be 50.07% by 2030, when the total Punjab population is expected to be 135.476 million (**Table 12-3**).

Table 12-3: Projected populations of Pakistan and Punjab

LOCATION	ITEM	1998	2005	2010	2015	2020	2025	2030
PAKISTAN	Population (million)	132.35	155.91	173.29	190.95	208.74	226.51	244.12
	Urban %	32.35	36.99	39.89	42.56	45.04	47.33	49.45
PUNJAB	Population (million)	73.62	86.61	96.21	105.98	115.84	125.7	135.48
	Urban %	31.27	36.31	39.56	42.54	45.27	47.78	50.07

On this basis, the urban water supply demand in 2030 would be 287 million cusecs per day and the rural demand would be 108 million cusecs per day. The rural demand would represent approximately 27% of total domestic water demand in the province (**Figure 12-8**).

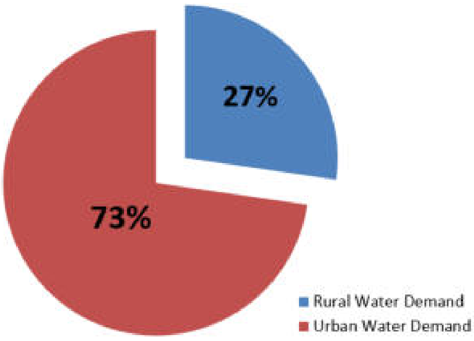


Figure 12-8: Proportion of urban vs rural domestic water demand

12.6 INTEGRATED WATER MANAGEMENT (IWM)

Water utilities around the world have a long and successful history of providing safe, secure and affordable drinking water, wastewater collection and treatment, and drainage services to cities and regions.

However as conventional water sources become depleted and polluted and the impacts of climate change intensify it is clear that the long-standing linear approach of extracting freshwater, treating it, using it, collecting the waste, and disposing of it is not sustainable. As a result, governments and water utilities are working to fully utilize the water resources, maximise re-use and minimize negative environmental impacts in a cost-effective process referred to as Integrated Water Management (IWM).

12.6.1 THE INTERNATIONAL APPROACH

The IWM approach focuses on managing the urban water cycle and aims to realize the full value of all resources for their various uses, while meeting community values of productivity, public health, safety and urban amenity.

IWM is a process that involves all stakeholders in planning and management across the urban and peri urban areas to ensure that the liveability, resilience and sustainability outcomes of the community are maximised.

An IWM approach involves:

- A collaborative process involving all stakeholders in the planning and ongoing management of the urban water cycle, community environmental, cultural, social, and economic needs and values
- Planning of the whole of water cycle with all supply and demand options on the table
- Consideration of all options related to water, wastewater, and drainage services
- Integrating strategic and statutory land use/spatial planning and water planning
- Supporting a recycling economy through maximising efficiency and working towards re generative outcomes
- A fit for purpose approach suited to different urban scales (e.g., precinct, urban catchment, watershed, region, precinct) and context (places and communities)
- Striving for the broader outcomes of sustainable development

There are a range of measures to improve the urban environment and reduce the capital and O&M costs, which are described below:

- Keep stormwater and sewerage streams separate, so they can be processed and reused must appropriately.
- Recycle treated sewerage to uses appropriate to its water quality and health risk.
- Managing the industrial water cycle to reduce water waste and pollution discharge.
- Collecting and utilizing stormwater.
- Improving or create urban wetlands for stormwater filtering, nutrient uptake and aquifer recharge or filling of underground tanks for use on parks and for agriculture.
- Managing 'groundwater recharge-storage-recovery' for later use and to reduce flooding
- Rehabilitating or creating watercourses, wetlands and holding basins along urban drains to slow runoff, reduce flooding and provide urban amenity.
- Use water and greening in urban landscapes to reduce heat, provide resilience to chronic and acute heat events, and improve air quality.
- Support the community through awareness raising, education, participation, hardship programs and other initiatives.

12.7 FUTURE RIVER BASIN AND IWRM DIRECTIONS

The Punjab Water Policy 2018 does not provide a list of recommendations for its drinking water and sanitation section. Its focus, however, is on (i) drinking water and the need for financial sustainability; monitoring and enforcement of drinking water standards; and (ii) wastewater disposal, separating domestic, industrial and agricultural streams for appropriate management. and using stormwater agriculture and to recharge groundwater.

The national and provincial governments have specific, major, and critically important WSS sector investment programs to improve the quality and supply of water to the cities towns and villages of Punjab.

12.7.1 THE INTERSECTION OF URBAN WSS WITH IWRM

The intersection of WSS and IWRM is as follows:

- Prioritise settlements with critical water supply issues so that the RB Plan and Doab plans can consider options for providing surface and groundwater by measures such as changed infrastructure operating rules, new or expanded infrastructure, flood management, aquifer recharge etc.

- Prioritise sections of rivers and aquifers with poor water quality so that wastewater pollution control policies and investments can be targeted
- Prioritise urban areas with drainage and flooding issues to target investments and manage local river flooding
- Prioritise sections of rivers which have high community value such as for recreation
- Develop local IWM plans, works, and measures that include a wide array of options for managing surface and groundwater for the different local uses.
- Adapt the international IWM approach for urban water management to better manage and utilize stormwater and wastewater, thereby reducing demands on existing surface and groundwater sources and to reduce downstream and local water quality and pollution impacts.

12.7.2 PROPOSED ACTION PLAN

An initial action plan is shown in **Table 12-4**.

Table 12-4: Indicative Action Plan for Further studies, thematic and project

PROJECT/ACTIVITY	YR 0-2	YR 3-5	YR 5-10	LEAD AGENCY	INVOLVED AGENCIES
Establish provincial interdepartmental working group for urban WSS and IWM, prepare plan and implement	✓	✓	✓	PPHED	i. Dept of Local Government ii. WASAs iii. Development Authorities; local governments. iv. EPA for point source pollution control and working with industry. v. WRD water allocation and supply for rivers and link canals, groundwater management and MAR, use of water from non-conventional sources.
Identify and prioritise urban centres/habitations with urgent need for additional surface and groundwater supply for inclusion in RB and doab plans and implement remediation plans	✓	✓	✓		
Identify and prioritise urban areas causing significant surface and groundwater pollution for targeted attention and implement remediation plans	✓	✓	✓		
Identify and prioritise urban areas with significant drainage and flooding issues and address	✓	✓	✓		
Identify priority river sections with high value, water based social uses such as recreation and include in RB plans for water supply	✓	✓			
Capacity building on urban IWM based on international best practice and develop practical guidelines for Punjab		✓	✓		
Design and implement 1-2 pilot IWM projects which manage water supply, wastewater disposal, improves urban and river environmental conditions.		✓	✓		

13 THE WAY FORWARD

13.1 INTRODUCTION

Development of river basin plans usually take 1.5 to 2 years and involves considerable data collection, analysis and consultation. It is common for river basin plans to commence with a river basin profile or river basin status report, which provides a snapshot of conditions in the river basin in order to commence work on the most urgent problems. This preliminary plan was prepared as a river basin profile.

The assessment concluded that the Punjab Indus 'River basin' is the appropriate scale for planning and management.

The Doab areas are sometimes referred to as river basins. This is not the case as their inflows and outflows are connected chaotically to and from several different rivers. Doabs are more appropriately treated as land management units where surface, groundwater and land use is planned as one.

13.2 DRIVERS FOR CHANGE

Thematic assessments from earlier chapters demonstrate symptoms of a stressed water resource system which requires improved management to deliver better outcomes to Punjab. Some of the symptoms identified are described in **Table 13-1**.

Table 13-1: Symptoms of stressed water resource conditions and management limitations in Punjab

No	Current Condition	Preferred State
1	Surface water supply is diminishing because of reservoir sedimentation and climate change	Water storages can store allocated volumes with sedimentation managed An adaptive and flexible system of management is in place to respond to water availability trends and extreme events
2	Urban centres with diminishing groundwater supplies	Groundwater quantity and quality are stabilised Groundwater extraction managed to match recharge Demand management and water use efficiency pursued to assist in balancing demand to available water resources
3	Drinking water from rivers, canals and groundwater is detrimental to human health in urban and rural areas	Good quality drinking water is assured from groundwater and surface water. Drinking water standards are met
4	Some river reaches suffer from reduced flows and high pollution levels which affects river uses such as water supply, fishing, recreation, aesthetic uses and ecological value.	River health is good and meets standards for uses agreed with society Environmental water quality standards are met
5	Doabs are not managed sustainability with issues such as falling groundwater, secondary salinity and poor drainage water quality affecting downstream users.	Natural resource conditions in Doabs are stabilised with the water balance controlled, salinity minimised and downstream impacts from poor quality drainage reduced to acceptable levels

No	Current Condition	Preferred State
6	Significant tail end effects in irrigation systems, resulting from limited water control and compliance with water allocations, results in downstream farmers not receiving their water allocation	Water allocations and irrigation systems are managed to ensure allocations are provided to all entitlement holders
7	Low value crops and relatively low productivity are common	Higher value crops are grown, and crop productivity improves to match international benchmarks.
8	There are limited provisions to cope with the effects of climate change which may produce more frequent and severe floods and droughts	Water resources are planned and managed by agencies and farmers to be adaptive and resilient to climate change
9	Watershed and hill torrent areas have serious erosion problems. Desert area living conditions are low, as available water resources cannot be utilised fully.	Soils are stabilised to minimise erosion. Available water resources are used sustainably, recognising the needs downstream users, in these areas.

13.3 IWRM FRAMEWORK AND ROADMAP

Managing the difficult conditions referred to above requires a comprehensive and integrated approach. A parallel report presents a comprehensive IWRM Framework and Roadmap for strengthening Punjab's water resources management. There is much commonality between that Roadmap and the recommendations of this river basin plan, since the Punjab Indus River Basin practically covers the whole Province.

The architecture of the Framework is shown **Figure 13-1** includes function themes aimed at achieving more efficient management of water resources, which are:

- Development of policy and capacity of water resource management institutions
- Development of Water Resource Management Plans
- Collection of background data supported by analysis and use of knowledge management systems for more efficiency and informed management
- Involvement of stakeholders in identifying issues and developing and implementing strategies

The framework includes five sectorial themes:

i. Doab and irrigation management
ii. River health and environmental management
iii. Watershed and Hill Torrent management
iv. Flood risk management
v. Urban water supply and sanitation services.

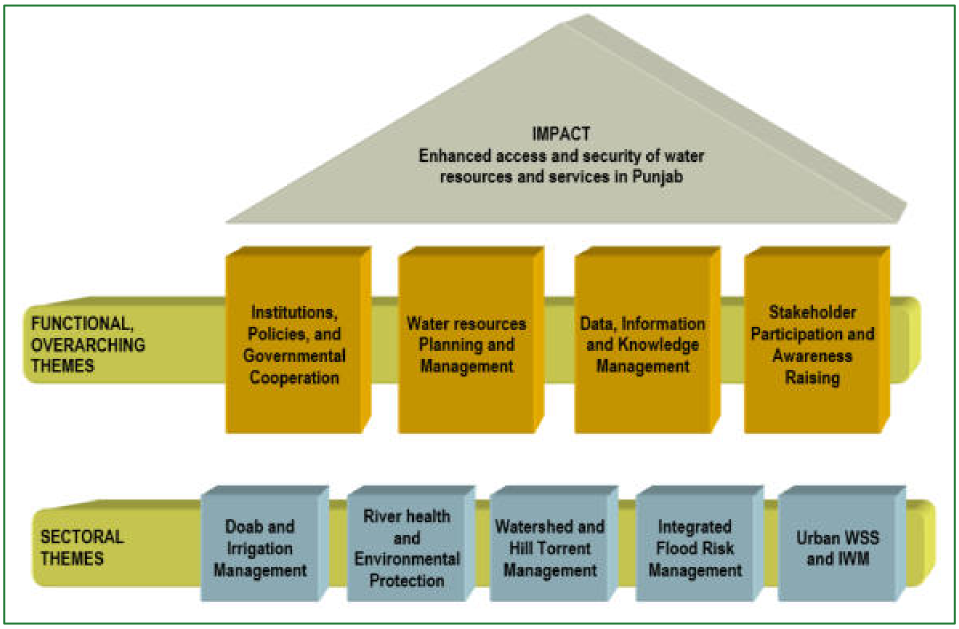


Figure 13-1: Punjab IWRM Framework Architecture

13.4 KEY RESULT AREAS FOR IMPLEMENTATION

The respective thematic chapters provide detailed review of each topic and present recommendations to better management the apparent problems. Clearly it is not feasible to implement these immediately, or all together, as government resources are limited. As a result, a measured approach is required.

The following priority Key Result Areas and their actions have been selected based on an initial assessment of need so as to initiate action on some immediate and then longer-term water resources management objectives/challenges.

KRA 1: Equitable water sharing and climate change (Chapter 5, 7)

Foundation: There is an urgent need to improve water planning, including re-assigning surface water entitlements to achieve equitable access to water and to meet the needs of high priority uses. This requires an improved water allocation process in Punjab, Issues include:

- Urban centres are running out of groundwater,
- Some irrigation commands have an abundance for water (surface and groundwater) compared to others where groundwater is being depleted,
- Some rivers have little or no flow which affects or prevents river uses and degrades environmental conditions.
- Mid-season water allocations are based on forecasts which need to be improved ,
- The population is increasing, requiring additional drinking water and increased food production
- Climate change will reduce water supply, increase crop water demand and in some cases exceed crop temperature tolerances. These will have a significant impact on Punjab water users and adoption of best adaptive measures is required
- Reservoir sedimentation is reducing storage and this needs to be factored into water allocations
- The Punjab water grid (rivers and link canals) provides considerable scope for moving water to high priority uses. The value of additional link canals and associated infrastructure to improve water delivery should be assessed
- Options to improving water use efficiency to address shortages should be investigated.

Actions:

(i) Develop and utilise a model of the Punjab part of the Indus Basin with support from international consultants.

(ii) Review the current hydrological monitoring data, networks and develop an improved monitoring program to enhance data coverage with support from international and national consultants as needed.

(iii) Undertake planning and scenario studies and prepare plans to improve water supply for the different sectors, including rivers, and, increase resilience to climate change and changing water demands.

KRA 2: Sustainable management of Doab irrigation land and water systems (Chapter 6, 7, 11)

Foundation: The Doab land areas in the 5-rivers area of Punjab are interconnected by link canals and the rivers themselves. These areas are also connected to the 2 irrigation areas on the right bank of the Indus river. Groundwater and water balance studies of the command areas show over extraction of groundwater, a heavy reliance on groundwater for irrigation (50% of gross supply), locations with secondary salinity and poorly managed drainage systems.

The impact of climate change will affect the irrigation industry by reducing the surface water supply and increasing the crop water demand which will most likely require a change in water management and crop selection.

Participatory, integrated Land and Water Management Plans that address surface and groundwater management are the key instrument for the sustainable management of Doab irrigation areas to control groundwater use, manage salinity, drainage, conjunctive use, consider options for real water savings and to improve water use efficiency and productivity, water harvesting and groundwater recharge, and, consider the impacts and adaption strategies for climate change.

Actions:

(iv) Develop participatory integrated Land and Water Management plans for Doabs commencing with the Bari Doab utilising groundwater and other appropriate models and urgently develop approaches to address the significant pollution of waters, especially in irrigation canals and drains.

(v) Implement participatory, integrated LWMPs on a pilot basis in priority locations and implement lessons more widely.

(vi) Introduce regulation of groundwater use in two pilot critical areas.

(vii) Develop and implement a groundwater monitoring plan.

(viii) Plan and implement managed aquifer recharge projects in urban and rural locations.

KRA 3: River health and uses (Chapters 6, 8, 12)

Foundation: Rivers and their wetlands and floodplains are an important element of the landscape and provide many services including water supply, fishing, recreation, aesthetic and ecological. In good condition, they also have an assimilative capacity for improving water quality. In Punjab, river condition and health is not considered in any formal way. There are a few disconnected and ad-hoc water quality assessments and riverbank erosion control projects. There are no recognised environmental flows.

Actions:

(ix) Review water quality monitoring data, networks and data processing. Compile a provincial database of data from the relevant agencies and institutions. Design and implement a surface water quality monitoring network across the rivers of Punjab.

(x) Identify significant point and nonpoint source pollution sources and report to PWRC with proposed actions.

(xi) Develop methodology from international experience for assessment of river health and uses.

(xii) Undertake rapid, pilot assessment of the river health and uses of the Chenab River and recommend river flow requirements for inclusion in water allocation.

(xiii) Undertake rapid assessments of the remaining rivers and recommend river flow requirements.

(xiv) Develop a prioritised river health management plan and actions for each river.

KRA 4: Reducing risks and impacts from floods (Chapter 11)

Foundation: The frequency of major flooding has increased with five consecutive extreme flood events, in 2010, 2011, 2012, 2013 and 2014. The severe Indus Basin flooding in 2010 resulted in loss of life, a very large number of affected villages and high flood costs of $10 billion. This is consistent with the expected impacts of climate change. A more comprehensive and systematic risk management approach is required for flood management.

Actions:

(xv) Based on international experience, develop a comprehensive flood risk management approach for Punjab.

(xvi) Build a strong information database including flood models, develop flood maps, develop flood management plans based on a flood risk management approach.

(xvii) Update and implemented improved flood preparedness, protection, forecasting, warning and recovery systems.

KRA 5: Sustainable management of watershed, hill torrent and desert areas (Chapter 10)

Foundation: Non irrigated areas cover about 40% of Punjab and are home to 19 million people. In general, these areas are poor, suffer low productivity and land degradation and are neglected by government. From a river basin perspective, the Pothohar and hill torrent areas are subject to flash flooding, erosion and downstream sedimentation. The hill torrent areas make use of spate irrigation. For Pothohar and the hill torrent areas, watershed management plans are needed to capture and better manage runoff, currently only 3% is captured. In the Cholistan desert area, watering ponds, planation strips and aquifer recharge are options to improve local conditions.

Actions:

(i) On a pilot basis, develop and implement participative, integrated ‘watershed/land and water’ management plans in each area.

13.5 PLAN FINANCING

Many of the proposed activities can be undertaken within the mandate of existing agencies and so it is assumed that these could be implemented using existing government budgets, perhaps with support from consultants.

Others are more complex or less well understood and involve adapting international practices. It is taken that international Development Partners could support these as required and agreed.

13.6 PLAN IMPLEMENTATION ARRANGEMENTS

The Punjab Water Resources Department would be responsible for further developing and implementing the plans and in consultation with the Punjab Water Resources Commission. This would involve:

(ii) Reviewing this plan (Way Forward) and these proposed implementation arrangements.

(iii) Mobilising the River Basin Plan Working Group for oversighting and further developing the specific KRAs, and RB plan. Prepare planning guidelines and workplan,

(iv) Assigning KRAs to responsible agencies. Mostly these could be led by WRD however some, such as river health, will need to involve other departments.

(v) Approaching the national level and Development Partners for assistance.

(vi) Mobilising project.

(vii) Monitoring and reporting progress to PWRC and any external organisations supporting activities.

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APPENDIX A

National Environmental Quality Standards for Municipal and Industrial Effluents

PARAMETER STANDARDS	VALUE
TEMPERATURE	<40^{o}C
PH VALUE (ACIDITY/BASICITY)	6-10
5-DAYS BIOCHEMICAL OXYGEN DEMAND (BOD AT 20OC)	80 mg/l
CHEMICAL OXYGEN DEMAND (COD)	150 mg/l
TOTAL SUSPENDED SOLIDS	150 mg/l
TOTAL DISSOLVED SOLIDS	3500 mg/l
OIL AND GREASE	10 mg/l
PHENOLIC COMPOUNDS (AS PHENOL)	0.1 mg/l
CHLORIDE (AS CL-)	1000 mg/l
FLUORIDE (AS F-)	20 mg/l
CYANIDE (AS CN-)	2 mg/l
AN-IONIC DETERGENTS (2) (AS MBAS) (5)	20 mg/l
SULPHATE (SO4)	600 mg/l
SULPHIDE (S2-)	1.0 mg/l
AMMONIA (NH3)	40 mg/l
PESTICIDES, HERBICIDES, FUNGICIDES AND	0.15 mg/l
INSECTICIDES CADMIUM (4)	0.1 mg/l
CHROMIUM (4) (TRIVALENT AND HEXAVALENT)	1.0 mg/l
COPPER (4)	1.0 mg/l
LEAD (4)	0.5 mg/l
MERCURY (4)	0.01mg/l
SELENIUM (4)	0.5 mg/l
NICKEL (4)	1.0 mg/l
SILVER (4)	1.0 mg/l
TOTAL TOXIC METALS	2.0 mg/l
ZINC	5.0 mg/l

PARAMETER STANDARDS	VALUE
ARSENIC	1.0 mg/l
BARIUM	1.5 mg/l
IRON	2.0 mg/l
MANGANESE	1.5 mg/l
BORON	6.0 mg/l
CHLORINE	mg/l

APPENDIX B

Case Studies of Water Supply in Major and Small Cities of Punjab

To review the current scenario in Punjab province, water supply and sanitation services in two major and two minor cities were examined as a pilot case. In major cities, Lahore and Multan, while in smaller cities, Jaranwala and Khurrianwala were selected respectively. Master plan and other published reports were acquired from concerned departments and agencies i.e. WASA's, TMA's and PHED's.

a. Lahore water supply and sewerage status

Lahore is the capital of Punjab province with a population of around 12.6 million. Rapid migration to Lahore has been observed from the surrounding areas due to the better facilities of education, housing, health, and ample job opportunities. This rapid increase of population demands prompt additional water infrastructure (water supply, sewerage and drainage). Furthermore, unplanned growth of housing in and around Lahore, have no proper water and sanitation facilities which seriously affects the people's health. Wastewater from the city of Lahore is currently disposed, untreated, into the river Ravi. This has seriously degraded the water quality and aquatic life of the river. It has also affected the water quality of underground aquifer, close to river Ravi.

Availability of freshwater has become a serious challenge in Lahore. The current rate of groundwater draw down is faster than previously calculated (1.0 m/y vs 0.6 m/y). Moreover, sewage volumes have are greater than the actual water supplied due to private water tube wells. Currently, Lahore city has an underdeveloped sewer network causing a serious health problem. Poor sewage treatment facilities has been caused by undeveloped collection facilities, lack of sufficient capacity and aging of the existing facilities. Water supply and sanitation services in Lahore city are operated and managed by Lahore WASA, which is the second largest water utility of the country. Water supply of Lahore is purely based on groundwater which comprises a water supply network of 6,212 km fed by 596 tube wells. This water supply system serves almost 8.5 million (78%) cities population. Water supply from all the tube wells is within the national standards for drinking water quality (NSDWQ). However, water losses from the WASA water supply network is reported as 40%. Table 1 summarizes the current water supply and sanitation network.

Table B1: Water Supply and Sanitation Status in Lahore city

Item	Quantity
Population under WASA jurisdiction	77,88,921
Total water supply tubewells	596
Water production	540 MGD (2.45 million m3/day)
Water connections	737,000
Water supply network	6,212Km
Sewerage network	5,187 Km
WASA service area	350 Sq.
Sanitation produced per day	432 MGD
Per capita water demand	315 litres/day
Per capita sewerage produced	252 litters/day

The per capita water demand is calculated as around 315 litres per person per day which is very high and above than the recommended value as per national water policy. However, sewerage produced per capita is 252 litters per day which is the 80% of water demand. The last masterplan was made for Lahore in 1975 and a new one is urgently required and include improvements to the institutional level along with plans for water supply and sewerage system.

b. Faisalabad water supply and sewerage status

Faisalabad is the second largest city of Punjab Province and the third largest of Pakistan. The urban area of Faisalabad city has a population of around 3.4 million which is expected to increase to over 4 million by 2038. Rapid population growth in Faisalabad has made it difficult to secure adequate quantities of water for supply from both infrastructure development and resource development perspectives. Currently, only 62% (2.1 million) of the population has access to municipal water supplied by the Faisalabad (WASA-F). However, the sewerage coverage ratio within the current WASA-F service area is about 80%. Average water supply by WASA-F in the city is 50 mgd which is estimated around 135 litres per capita.

Table B2: Water Supply and Sanitation Status in Faisalabad city

Item	Quantity
Domestic Water Supply Connection	118,274
Domestic Sewerage Connection	296,544
Industry and Commercial Water Supply Connection	2,423
Industry and Commercial Sewerage Connection	21,944
Total Population Served	2.1 million
Water Supply per day	50 mgd
Sanitation Produced per day	150 mgd
Per capita water supply	135 litre/day

The Faisalabad city Masterplan (2018) forecasts water demand increasing to 275 MGD, which is the 2.5 times the current design capacity of 110 MGD. Presently, most households have their own wells, so the per capita consumption from the WASA-F piped water supply is small. According to the surveys, one of the major reasons for the low number of water connections to the WASA-F network is the poor service (low and unreliable water pressure). Obtaining reliable data is difficult however due to the large number of private, non-metered abstractions.

c. Jaranwala water supply and sanitation status

Jaranwala is a small town of Faisalabad district with a population of around 150,380. Presently, twenty-nine tube wells are in operation for the Jaranwala water supply along an approximately 6 km section of the Gogera Branch Canal (GBC). The current design discharge of each tube well is 0.75 cusec (about 76.5 m^3/hour). Per-capita water supply provided to 160,000 citizens of the town is about 227.3 litre/day (Table 3). However, the daily maximum demand is assumed to be 50% higher than the average and the tubewells are operated 16 hours a day in the design settings.

Table B3: Water supply and Demand in Jaranwala city

Item	Quantity	Quantity
Total Served Population	160,000	

Item	Quantity	Quantity
Per Capita water supply	50.0 g/day	227.3 litre/day
Total water demand	8.0 mgd (14.8 Cusecs)	36400 m3/day

In recent years, no significant signs of groundwater decline have been observed around the Gogera branch canal (GBC) whereas, steadily decreasing water level is due to the short duration of tube well operation for water supply to Jaranwala city resulting from the limited coverage (about 4 and half hours per day on average). The groundwater in the deeper portion of this area is brackish, and only seepage water from the GBC is freshwater and targeted for drinking. The revised design criteria issued in 2008 specified that the water intake tubewells in such a case (shallow wells or skimming wells) should operate for less than 8 hours per day.

d. Khurrianwala water supply and sewerage status

Khurrianwala is a small town with an estimated population of 35,292 situated north-east of Faisalabad city. Tehsil Municipal Administration (TMA) is responsible for water supply and sanitation services. Presently only 16% (22,300) of the population falls in the service zone of water supplies. Current water supply operations are just 2 hours per day along with the supply of filtered water to citizens around 4 hours per day. Population and per capita water consumption & water demand has been illustrated in the **Table B4**.

Table B4: Khurrianwala City Water Supply and Demand

Item	Quantity
Total Population in Service Area	22,320
Total Served Population	3,640 (16%)
Demand (day average)	530 m3/day
Consumption (day average)	370 m3/day
Physical Loss	30%
Per Capita Consumption	101 litres/day
Per Capita Demand	145

It has been estimated that the present water consumption (domestic use) is 100 litres per person per day assuming a physical loss of around 30%. However, it has been reported that actual average water demand per capita is 145 litres.

e. Summary

Table 5, shows the per capita amount of water supplied by the respective agencies in the major and small cities. It has been observed that actual per capita water demand is not fulfilled by any municipality and results in utilization of private motor pumps for groundwater extraction. Actual per capita water demand in Lahore is very high according to the recommended water supply as per water drinking policy i.e. 120 l/p/d. Currently water supply by WASA Lahore is 315 l/p/d which is not enough to cater the water needs of population evidenced by private motor pumps are being used in parallel to satisfy the water needs .For Faisalabad city per capita actual water demand has been reported as 340 l/p/d, however current water supply by WASA-F is only around 135 l/p/d. This huge difference between existing water supply and demand

definitely results in high private groundwater extraction. In the case of small towns, Jaranwala a very high water demand is reported similar to Faisalabad i.e. 340 l/p/d, whereas in Khurrianwala town water demand is found close to the recommended value of the drinking policy. On the other hand, reported values of sewerage produced in Lahore and Faisalabad are 252 l/p/d and 270 l/p/d respectively, which is almost 80% of the water demand.

Table B5: Cumulative Water supply, Demand and Sanitation status

Item	Lahore	Faisalabad	Jaranwala	Khurrianwala
Water supply per Capita	315 L/d	135 L/d	227 L/d	101 L/d
Water Demand per Capita	-	340 L/d	340 L/d	145 L/d
Sewerage Production per Capita	252 L/d y	270 L/d	-	-

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