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WATER RESOURCES MANAGEMENT IN PUNJAB, PAKISTAN

Dr. Muhammad Nawaz Bhutta

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By

Dr. Muhammad Nawaz Bhutta[1]

ABSTRACT

The total contribution of the agricultural economy in Punjab is about 25% of GDP and employees 50% of labour force. The Punjab has the largest contiguous irrigation systems in the world which is facing a number of challenges. Based on the review of previous studies it is concluded that:

- All the canal commands do not provide water to meet the peak crop water requirement.
- The models at the doab scale are useful to improve planning and management of surface and groundwater resources. This will require increased capacity of irrigation agencies to manage and regulate water resources.
- The remaining fresh water in canal commands and the water available for reuse is insufficient to meet crop water requirements.

It is not possible to provide additional water for agriculture to meet 2050 demand because new resources of water are harder to find. The expansion in irrigated area will not be a feasible strategy. The improved investment in monitoring, modelling and management of this vital resource is justified for the economic wellbeing of rural Punjab and to meet food security needs in Punjab. Improved production practices, more productive and higher value crops and varieties, and reduced non-beneficial losses of water will be required to meet the future 2050 agriculture water demand. 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 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. A more holistic approach towards water management and conservation needs to be proposed.

1. INTRODUCTION

1.1 Punjab Irrigation System

The Punjab Irrigation system is the largest contiguous irrigation systems in the world. The irrigation infrastructure mainly comprises 13 barrages / headworks, 25 main canals (3,993 miles long with total off-take capacity of 120,000 cusec), 528 miles long 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, 55 small dams and an extensive network of surface drains(6,122 miles long), 2,100 miles' flood embankments are being maintained. The system is serving 8.5 ha (20.78 million acres) of culturable command area (CCA) through 58,000 outlets. Cropping intensity has been gradually increased from 75% to 150% mainly due growth of private tubewells. The irrigation system which constitutes lifeline for the agriculture economy of Punjab is subjected to major water

[1] Water Resources Engineer, 164 K-1 WAPDA Town, Lahore, 03004754050, nawazbhutta04@gmail.com

sector challenges including infrastructure due to ageing and system design and institutional constraints due to not keeping pace with the changing environment and poor water governance. The major challenges include: (i) growing water shortages; (ii) progressive deterioration of irrigation infrastructure; (iii) low water productivity; (iv) lack of transparency and inequities in water distribution; (v) gaps in governance and trust; (vi) progressive deterioration of water quality of canals, drains, rivers and groundwater due to disposal of untreated industrial and municipal effluents; and (vii) over exploitation of groundwater.

1.2 Objectives

The objectives of this paper are:

i. Assess availability of water resources in Punjab;

ii. document water demands in different sectors; and

iii. Future challenges and options for water resources management.

1.3 Punjab Irrigation Sub Basins

Punjab can be divided into 7 sub basins as listed in **Error! Reference source not found.**. Each sub-basin has independent irrigation canals and drainage system.

Table-1: Sub-basins of Punjab

Sub-basin	Canals	CCA (ha)	Population
Thal Sub Basin	Thal Canal (Mohajir Br.) Thal Canal Thal Flood Water Canal Muzaffargarh Canal Rangpur Canal	1,435,778	11,353,468
Chaj Sub Basin	Upper Jhelum Canal Lower Jhelum Canal	833,653	9,016,508
Rechna Sub Basin	Upper Chenab Canal Lower Chenab Canal Haveli Canal Raya Branch	1,900,405	29,066,627
Bari Doab Sub-basin	CBDC Upper Depalpur Lower Depalpur Pakpattan Canal LBDC Sidhnai Canal Mailsi Canal	2,398,492	34,226,828
Bahawalpur Sub-basin	Fordwah Canal Eastern Sadiqa Canal	1,517,572	11,464,031

Sub-basin	Canals	CCA (ha)	Population
	Bahawal Canal		
	Qaim Canal		
	Punjnad Abbasia Canal		
DG Khan Sub-basin	DG Khan Canal	364,217	4,192,403
CRBC Sub-basin	Chashma Right Bank Canal	97,125	675,756

1.4 Major Challenges

The major challenges include: (i) growing water shortages; (ii) progressive deterioration of irrigation infrastructure; (iii) low water productivity; (iv) lack of transparency and inequities in water distribution; (v) gaps in governance and trust; (vi) progressive deterioration of water quality of canals, drains, rivers and groundwater due to disposal of untreated industrial and municipal effluents; and (vii) over exploitation of groundwater.

2. REVIEW OF EXISTING INFORMATION

The review of documents includes:(a) CWRAS World Bank, Islamabad 2005 (b) HALCROW 2006 Punjab Irrigated Agriculture Project (c) Basharat 2013 Command scale integrated water management in response to spatial climate variability in LBDC (d) Lahmeyer and NDC 2013 Groundwater monitoring modelling, modelling and management LBDC (e) Canal Water Re-Allocation Analysis Draft Report March 2021 Hashmi and Prathapar (f) Water availability, use and challenges in Pakistan, FAO 2021.

2.1 Water Balance and Evapotranspiration 2005[1]

Authorized Canal Water Allowance were used to conduct the comparative analysis of relative E_t per unit Cropped Area and water availability. There was a large variation in Authorized Canal Water Allowance. Therefore, the canal commands were categorized in three categories, and presented as under:

i. The first category represents the Water Short Canal Commands with Lowest Authorized Canal Water Allowance of < 400 lps/1000 ha with relative index between 1-2.

ii. The second category represents the Water Adequate Canal Commands with Intermediate Authorized Canal Water Allowance of 400-600 lps/1000 ha with relative index between 2-3.

iii. The third category represents the Water Excess Canal Commands with Higher Authorized Canal Water Allowance of > 600 lps/1000 ha with relative index of > 3.

The three categories have significant variability in terms of Authorized Canal Water Supply per unit of command area, as it varied between 200-1115 lps/1000 ha. These wide variations demanded that canal categories be formed to address the issue of Authorized Canal Water Allowance in line with evapotranspiration and potential cropping intensity (Error! Reference source not found.).

1 Shahid Ahmed 2005 Water Balance and Evaporation, Background paper, CWRAS, World Bank.

Table-2: Relative Evapotranspiration and Relative Authorized Canal Water Allowance

Canal ID	Canal Name	CCA (ha)	Authorized Full Supply Discharge(m^3/sec)	Authorized Canal Water Allowance (lps/1000 ha)	Potential ET/Crop Area (mm)			Relative Et Per unit Cropped Area	Relative Authorized Canal Water Allowance
					Kharif	Rabi	Annual		
Water Short Canal Commands with Lowest Canal Water Allowance (< 400 lps/1000 ha)									
1	Upper Chenab	451012	90	200	605	384	989	1.05	1.00
2	Lower Jhelum	614488	150	244	740	412	1152	1.22	1.22
3	Upper Jhelum	220094	54	245	604	432	1036	1.10	1.23
4	Thal	773843	213	275	778	389	1167	1.23	1.38
5	Central Bari Doab	265700	73	275	623	398	1020	1.08	1.38
6	LCC East	647502	347	281	718	399	1117	1.18	1.41
7	LCC West	588614			693	405	1098	1.16	
8	Sadiqiah	424850	139	327	954	465	1419	1.50	1.64
9	Lower Bari Doab	675667	248	367	735	444	1180	1.25	1.84
Water Adequate Canal Commands with Intermediate Canal Allowance (400-600 lps/1000 ha)									
10	Abbasia	96139	40	416	946	449	1394	1.48	2.08
11	Lower Depalpur	247718	113	456	765	547	1313	1.39	2.28
12	Upper Depalpur	141711	65	459	737	465	1202	1.27	2.30
13	Punjnad	551926	297	538	993	494	1487	1.57	2.69
14	Rangpur	139769	77	551	809	435	1245	1.32	2.76
15	Fordwah	173111	98	566	902	468	1371	1.45	2.83
Water Excess Canal Commands with Higher Canal Allowance (> 600 lps/1000 ha)									
16	Muzaffargarh	331764	235	708	843	434	1278	1.35	3.54
17	Marala Ravi	63615	57	896	585	360	945	1.0	4.48
18	Qaim	17121	17	993	912	501	1413	1.50	4.97
19	Dera Ghazi Khan	368546	411	1115	854	472	1327	1.40	5.80

The analysis of all three categories of the canal commands indicated that the water adequate category has modest variability in Et (1202-1394 mm) and authorized canal water allowance (416-566 lps/1000 ha). The highest variability in E_t (945-1413 mm) and in authorized canal water allowance (708-1115 lps/1000 ha) was in water excess category. Therefore, there are chances that water productivity is lowest in water excess category thus providing an opportunity for improving productivity, as the cost-effectivity of interventions will be highest. The doubling factor of E_t within each category of canal command indicated that water allocation is not based on evapotranspiration, potential cropping pattern or potential cropping intensity. All the canal commands having short, adequate and excess water allocations still do not provide water to meet the peak crop water requirement. Water in certain periods is in excess and short at peak demand especially for the short and adequate water allowances.

2.2 LBDC Water Balance Halcrow,2006[1]

Water balance to assist determining values for two major unknowns, (i) the proportion of rainfall that runs off; and (ii) evaporation / evapotranspiration from non-cropped areas is carried out in Error! Reference source not found..

Table-3: Water Balance over Project Area (annual volumes)

Item	Inflows (MCM)	Outflows (MCM)	Remarks
Rainfall	1,813		
LBDC Canal inflows at Barrage	4,943		
Crop Consumptive use		6,423	
Outflow through MP Link		336	
Evaporation and ET from non-cropped area of 36,420ha		166	Estimate that E + ET is about 25% of ETO (1,822mm)
Surface Runoff		242	Estimate as about 13.5% of total precipitation.
Storage (from declining water table)	411		
Totals	7,346	7,346	

The annual surface runoff of 242 MCM equates to about 13.5% of total rainfall and about 40% of the design drainage capacity (which covers only about 1/3 of the total project area). This therefore seems a reasonable estimate of total run-off. From water balance the following may be concluded:

- Canal supplies diverted at Balloki (4,943 MCM) are lower than crop consumptive use requirements (6,423 MCM).
- Seepage from canals and application efficiency is estimated at 46%
- Pumping of groundwater is essential to meet crop consumptive use requirements.
- The present decline of the water table of 0.37m (1.2ft) / year contributes 411 MCM annually, about 9% of the present canal supply.
- Rainfall contributes significantly to the water available, although some 13.5% of precipitation is thought to leave the Project area as surface drainage outflows.
- Annual Evaporation and ET from the non-cropped area of about 36,420ha are about 456mm, 25% of ETo (1,822mm).

2.3 Water Balance of LBDC- 2013[2]

A model of the Lower Bari Doab canal command was used to evaluate long term irrigation cost inequities due to increasing groundwater depletion towards the tail end (Basharat, 2013 and Basharat and Tariq 2013). The model was calibrated over a period of eight years from Kharif 2001 to 2009 with seasonal time steps (Kharif and Rabi). The

1 HALCROW 2006 Punjab Irrigated Agriculture Project.

2 Basharat 2013 Command scale integrated water management in response to spatial climate variability in LBDC.

total recharge (including groundwater returns) for 8.5 years is 28.9 BCM (23.45 MAF) and tubewell abstraction is 33.3 BCM (27.02 MAF). Values per year for these two parameters are 3.4 BCM (2.759 MAF) and 3.9 BCM (3.178 MAF) respectively, indicating that groundwater abstraction is higher than the recharge to the aquifer. The groundwater budget component due to evaporation is relatively small due to the watertable being deep in most of the command areas (Basharat and Tariq, 2013). Decreasing rainfall and increasing crop water requirement towards the tail-end, is resulting in greater groundwater depletion downstream from canals particularly at the tail end of canals. Annual water balance for LBDC is given in Error! Reference source not found.. Net water balance is negative 706 MCM (-0.572 MAF) or -0.35 m.

Table-4: Water balance for LBDC (Basharat 2012)

Source	Total Volume (MCM)	Infiltration/ Recharge		Crop consumptive use (MCM)	
		percent	MCM	percent	MCM
Canal	4849	44.12	2140	48.75	2689
Groundwater	4164	16	370	64.58	2689
Rainfall	2320	24	948	60.6	1406
		Total	3458		
Annual GW storage loss		3458- 4164 =-706 MCM (-0.572 MAF)			**-0.35 m**

2.4 Water Balance of LBDC 2013[1]

A model of the Lower Bari Doab (LBDC) developed with funding from Asian Development Bank as part of the Lower Bari Doab canal improvement project (Lahmeyer and NDC, 2013) was used to estimate the water balance (Error! Reference source not found.). They found a negative groundwater balance of -0.28 m (-0.474 MAF).

Table-5: Water balance for LBDC (Lahmeyer and NDC 2013)

Source	Total Volume (MCM)	Non-crop use	Infiltration/ seepage (MCM)	Crop consumptive use (MCM)
LBDC	4,457	181	2,283	6345
SM Link	336			
Agri. TWs	4,549		1,065	
Domestic TWs	32			
Rainfall	1,813		651	
		Total	3,999	
Annual GW storage loss		3,999- 4,581= -582 MCM (-0.474 MAF)		-0.28 m

The LBDC model was used to determine the impact of different scenarios of canal water availability and groundwater abstraction to show the impact of surface and groundwater resources in LBDC.The main finding from the scenario runs showed that reducing

[1] Lahmeyer and NDC 2013 Groundwater monitoring modelling, modelling and management LBDC.

tubewell pumping and increasing canal water supplies seems to be the only effective way of arresting the current pace of negative water balance in large areas of LBDC.

The models at the doab scale are useful for the Irrigation Department to improve planning and management of surface and groundwater resources. As the share of surface water decreases and groundwater levels continue to decline in the lower regions of the doabs there will be increased pressure on government agencies to find socially and technically acceptable solutions as well as to give due consideration to environmental needs. This will require increased capacity of irrigation agencies as well as institutional reform to manage and regulate groundwater resources.

2.5 Hashmi and Prathapar 2021[1]

Water balance components for the 26 canal commands of Punjab was estimated. The water balance BIG PICTURE informs two significant water sources, the canal (river) and rainfall. The Canal Water Supply is 69 BCM. Gross rainfall 34 BCM, of which an estimated 16.8 BCM is effective. Together, the total water available within the canal command is 85.8 BCM. A minor source is fossil groundwater, and it is estimated to be 0.77 BCM. Aquifers within the canal command play a critical role in recycling recharge from canal water and rainfall. The net discharge from aquifers of 0.77 BCM will deplete the fossil water in the future if it continues. A general water balance assessment for canal commands shows that domestic, industrial, livestock, and environmental demands can easily be met with available rain and canal water. However, the remaining fresh water in canal commands and the water available for reuse is insufficient to meet crop water requirements.

2.6 FAO 2021

This working paper takes stock of Pakistan's water resource availability, delineating water supply system and its sources including precipitation and river flows, and the impact of increasing climatic variability on the water supply system. In particular, the paper focuses on the current water usage and requirements in the agricultural sector, and how changing climatic conditions will affect the consumption patterns. With inflows expected to become more variable in the coming years, the severity of climatic extremities will become more pronounced, driving up water demands in addition to the demand increase from a rising population and urbanization. Over extraction of groundwater resources is also disturbing the water calculus and pushing the country towards a critical demand-supply gap. Pakistan's water sector remains vulnerable to the impacts of climate change. To ensure Pakistan is adequately prepared to deal with the changing climatic realities, it is important to understand the nexus between water availability, agricultural productivity, and climatic variability. The current paper has endeavoured to highlight the same indicating the existing availability of water based on a single river system which is Indus Basin System and its tributaries, future projections of water requirements for crops, livestock, forest, rangelands, ecological and municipal sectors, and the challenges Pakistan faces in accommodating the increasing demand for water from competing sectors. Further, limited storage capacity, a debilitated infrastructure, and poor water conservation practices that are contributing towards the degradation of water quality and loss. In light of the analysis conducted in this paper, it is clear that due to competing pressures of water demand from different sectors and a widening demand-supply gap, there is a need to guide the shift from irrigation to water management to address the challenges that come with increasing climatic variability and

1 Hashmi and Prathapar 2021 Canal water re-allocation analysis.

water scarcity. Some key recommendations are proposed signalling the need to adopt a more holistic approach towards water management and conservation, which takes into account the available resources, its usage, challenges and projected water requirements in the future and what needs to be done to ensure Pakistan is able to boost its agricultural productivity without drying out its water resources.

3. CURRENT SITUATION IN BASIN AND SUB-BASINS

3.1 Sources of Water

3.1.1 Areal rainfall

Rainfall data have been collected from agriculture statistics of Punjab Annual Rainfall in sub-basins of Punjab for the period 2009 to 2020 is given in Error! Reference source not found.. Mean, maximum and minimum values of each sub-basin are also given. Rechna and Chaj sub-basins have higher rainfall than other sub-basins. Bahawalpur sub-basin has the lowest rainfall.

Table-6: Annual Rainfall in Sub-basins (mm)

Year	Thal	Chaj	Rechna	Bari	Bahawalpur	DG Khan	CRBC
2009	253	254	361	170	67	34	26
2010	569	490	619	321	133	204	157
2011	535	536	527	427	178	372	374
2012	358	391	454	322	140	259	208
2013	270	454	599	352	89	254	246
2014	304	523	689	376	88	204	178
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
Mean ER	118	233	243	172	70	119	96
Max	569	716	689	503	303	486	425
Min	110	166	159	107	61	34	26

3.1.2 Surface water

a) Punjab Basin

The canal water diversions during the period 2007 to 2020 indicated that the canal diversions were quite variable and ranges from 43.5 to 51.25 MAF with an average value of 49.5 MAF (Error! Reference source not found.). The apportioned canal supplies are usually not available. The shortages in river flows are shared among the provinces as per apportioned allocations.

b) Sub-basins

Annual canal diversions at canal head for seven sub-basins are given Error! Reference source not found.. Year 2007-08 has the highest canal diversions and year 2017-18 has the lowest canal diversion during this period. Standard deviation and coefficient of variation are also calculated for each sub-basin for this period. Chaj, Rechna and Bari sub-basins have relatively reliable supplies as the coefficient of variation is up to 5 percent. CRBC has the highest variation due to its location at tail of the CRBC system as head reach is in Khyber Pakhtunkhwa province.

Table-7: Sub-basins Annual Canal Diversions at Head (MAF)

Year		Thal	Chaj	Rechna	Bari	Bahawalpur	DG Khan	CRBC	Total Punjab
2007-08		8.89	3.723	10.076	11.802	12.386	3.45274	0.918	52.690
2008-09		7.59	3.715	9.728	11.614	10.879	2.88613	0.825	48.298
2009-10		7.86	4.034	9.536	11.339	11.061	3.09971	0.691	48.911
2010-11		6.56	3.968	9.776	12.249	11.830	2.33492	0.458	48.591
2011-12		7.95	4.227	9.927	12.042	11.442	2.83895	0.678	50.554
2012-13		7.15	4.193	9.323	11.647	10.243	2.30442	0.760	46.859
2013-14		7.98	4.363	9.750	12.262	11.758	2.89308	0.933	50.883
2014-15		7.99	3.954	9.136	12.294	13.186	3.17351	0.770	52.020
2015-16		7.41	4.280	9.860	11.547	13.110	2.56246	0.606	51.038
2016-17		7.33	4.089	9.900	12.484	13.035	2.85133	0.734	51.967
2017-18		6.06	3.806	9.142	11.042	10.472	2.26191	0.770	44.788
2018-19		6.72	3.941	9.301	10.899	11.294	2.54537	0.753	47.431
2019-20		8.16	3.826	8.532	11.444	12.996	2.51204	0.597	49.756
Mean	MAF	7.512	4.009	9.538	11.743	11.822	2.747	0.730	49.522
	mm	652	599	719	614	971	940	937	
Maximum		8.893	4.363	10.076	12.484	13.186	3.453	0.933	51.251
Minimum		6.058	3.715	8.532	10.899	10.243	2.262	0.458	43.552

3.1.3 Groundwater for Agriculture

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 groundwater development started with the construction of hydro-power dams on the Indus river system – Mangla and Tarbela. The government provided a policy support in favour of provision of electricity for pumping of groundwater for agricultural uses in 70s. The development of cost-effective tubewell technology and availability of well drilling services in the private sector was the major reason for the development of groundwater in the province. The increase in electric tariff, removal of subsidies, voltage fluctuations and load shedding forced farmers to install diesel-operated pumping systems and this is a major factor in the rapid development of tubewells in the province. However, most of the diesel operated tubewells are low to medium in discharge, from that of the electric tubewells. There were 1,100,841 tubewells in the Punjab province during 2017-18 and out of these 944,890 tubewells are being operated with diesel-powered engines, representing around 86% of total number of tubewells. The only possibility to reduce the

higher growth rate of tubewells development in the province is to introduce efficient practices of water use in all sub-sectors – domestic, industrial, commercial and agriculture.

Groundwater pumpage/extraction have been collected from agriculture statistics of Punjab. Present annual groundwater pumpage for agriculture in Punjab Sub-basins are given in Error! Reference source not found..

Table-8: Sub-basin wise Annual Groundwater Extractions

Sub-basin	Thal	Chaj	Rechna	Bari	Bahawalpur	DG Khan	CRBC	Total
GW Pumpage (MAF)	6.731	4.649	10.932	10.775	8.120	1.786	0.617	43.611
GW Pumpage (mm)	584	526	717	560	667	611	792	

The management of groundwater has long been neglected, and with increasing demand for water, PID will need the capacity and institutional support to manage its vast fresh groundwater resources for a sustainable future.

3.1.4 Wastewater

Around 4.9 MAF water is currently being used in the province for domestic, industrial and commercial purposes. Out of this around 3.3 MAFare used for domestic and 1.62 MAF are used for industrial cum commercial uses. Around 80% can be recovered as effluent from domestic water (if the sewerage network is not leaky or soaked in to groundwater through soaking pits) and 60% from the industrial and commercial uses (PWP and GWP 2000[1]). 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 of 501 cusecs in Punjab (WAPDA 2005[2]). Thus, total wastewater available in Punjab is around 3.77 MAF, which has to be taken as a resource. This is a sizable amount of water which has to be separated from storm water, so that these can be managed through cost-effective treatment (Error! Reference source not found.). The estimation of storm water from urban and agricultural area is difficult due to lack of measurements.

In urban areas, the storm water, 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 storm water (urban and rural), sewage and industrial effluents. In the new schemes and infrastructure, there is a need to enforce a policy to handle and manage these 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 storm water separately. Currently, in rural areas, the sewage and commercial effluents are disposed in to the village ponds which were developed for stock water purposes and having allocation for canal supplies under the Warabandi system. Stock-water is equally important like the irrigation water 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 the groundwater. Out of total diseases of livestock, around 66% are water borne, which is higher than human (60%). The

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

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

PID/WRD can enforce a reform that in village ponds, where sewage is disposed, the water allocation from canal water will be terminated. This simple tool can help to manage the quality of stock-water ponds; and these ponds can also serve as recharge ponds. Ducks can be introduced by the village community in these ponds for aeration and managing water quality as oxidation ponds. Landscape around the stock-water pond will help to reduce the sediment load in the inflows of the runoff during the rainy season and provides environment of semi-constructed wetlands.

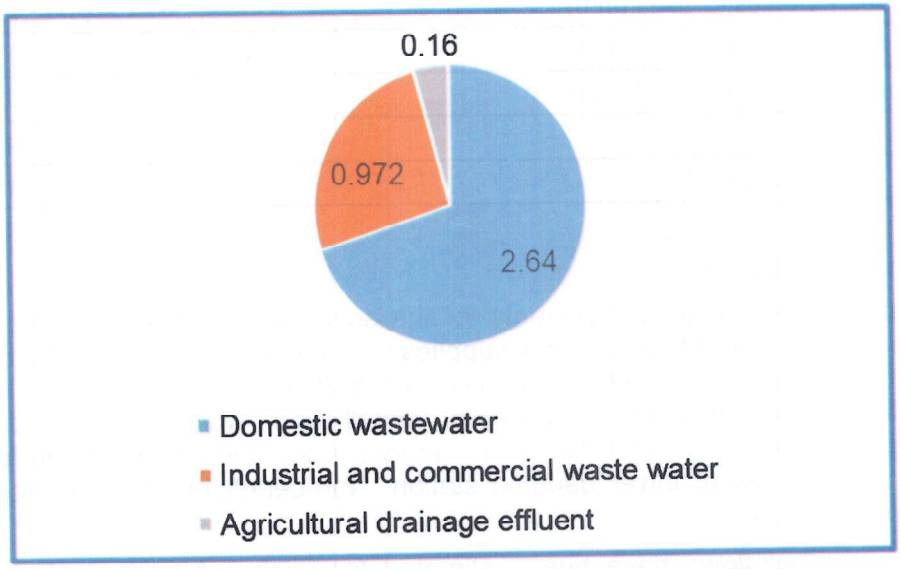


Figure-1: Punjab's availability of wastewater in MAF

3.2 Punjab Basin Water Budget

Punjab basin water budget components are given in Error! Reference source not found.. Total crop use is 855 mm which consist of 277 mm from canal, 401 mm from groundwater and 177 from rainfall. In addition, groundwater is also proving 48 mm for domestic purpose and 23 mm for industrial uses. In this way total groundwater use is 472 mm. Total inflows are 723 mm from canals and 177 mm from rainfall. Total outflows are 941 mm. Net water balance is -41 mm in Punjab Basin.

Table-9: Punjab Basin Water Budget Components

No	Parameter	Value
i)	CCA (ha)	8,547,242
ii)	GW Pumpage (mm)	636
a) Inflows		
i)	Canal Head (mm)	723
ii)	Effective Rainfall (mm)	177
Total inflows		900

No	Parameter	Value
b)	**Outflows**	
i) -	Canal water Crop use (mm)	277
ii) -	GW Crop use (mm)	401
iii) -	Effective Rainfall (mm)	177
iv) -	Domestic uses (mm)	48
v) -	Industrial uses (mm)	23
vi) -	Non-beneficial loss (mm)	15
Total outflows		941
c)	**Balance (mm)**	-41

3.3 Sub-basins Budgets

Estimated water budget components for the seven sub-basins are presented in Error! Reference source not found.. Canal supplies data have been collected from PID. Rainfall and groundwater pumpage have been collected from agriculture statistics of Punjab. No agricultural drainage is functional except rainfall runoff which has been counted far by adding only effective rainfall. No measurement is recorded at drains outfalls; however, these are counted at lower gauging station. Non-beneficial loss has been added for waterlogged areas.

Inflows and out flows have been estimated for each sub-basin in Error! Reference source not found.. Net water balance varies from -77 mm for Chaj Doab to +127 mm for DG Khan. Evaporation ponds have been constructed and maintained in Bahawalpur sub-basin which are disposing 0.23 MAF annually[1]. Therefore, non-beneficial losses of Bahawalpur are high than other sub-basins.

Table-10: Sub-basins Water Budget Components

Sub-basin	Thal	Chaj	Rechna	Bari	Bahawalpur	DG Khan	CRBC
Population	1,353,468	1,016,508	2,066,627	4,226,828	1,464,031	1,192,403	375,756
CCA (ha)	1,435,778	833,653	1,900,405	2,398,492	1,517,572	364,217	97,125
GW Pumpage (mm)	584	695	717	560	667	611	792
i) Inflows							
Canal Head (mm)	652	453	719	614	971	940	937
Effective Rainfall (mm)	118	233	243	172	70	119	96
Total inflows (mm)	770	686	962	786	1041	1059	1033
ii) **Outflows**							
Canal water Crop use (mm	250	230	275	235	372	360	359
GW Crop use (mm)	368	438	452	353	420	385	499
Effective Rainfall (mm)	118	233	243	172	70	119	96
Domestic demand (mm)	33	44	63	59	31	47	29
Industrial demand (mm)	16	22	31	28	15	23	14

[1] Bhutta M.N., M.F. Niazi and A. Nazir 2002, Environmental Impact of Disposal Of Drainage Effluent To Evaporation Ponds

Sub-basin	Thal	Chaj	Rechna	Bari	Bahawalpur	DG Khan	CRBC
Non-beneficial loss (mm)	21	11	0	0	48	29	15
Total outflow (mm)	782	764	1018	805	1061	932	991
iii) **Balance (mm)**	-12	-77	-57	-19	-20	127	42

The water budget for the seven sub-basins indicates deficiency of water availability, which is in line with the estimate of past studies. The above estimate may need to be adjusted as improved monitoring data becomes available, as there are inherent uncertainties is estimating pumping accurately for over 1 million tubewells. The water budget is a crucial aspect for improving water management in the doabs and sub-basins of Punjab. This highlights the need for investing in improved analysis of the water budget for each sub-basin through the development of computer models. The total contribution of the agricultural economy in Punjab is about 25% of GDP and employees 50% of labour force. Therefore, improved investment in monitoring, modelling and management of this vital resource is justified for the economic wellbeing of rural Punjab and to meet food security needs in Pakistan.

4. Projections for 2050

4.1 Population Projections for 2050

Population of the province was around 73.6 million in 1998, which has increased to 110.8 million in 2020 (Error! Reference source not found.). Punjab is an urbanized and industrialized province of Pakistan, after Sindh. The population density is 495 persons per km^2. The urban and rural population is equally divided with a targeted population growth rate of 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 will be 23.6% in the next three decades 2020-2050.

4.2 Water Demand Projections

4.2.1 Domestic water demand projections

Currently around 3.3 MAF (4 billion m^3) water is used for domestic purposes. 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 (**Error! Reference source not found.**). The projections made for 2025 indicates that increase of 0.3 MAF (0.4 billion m^3) would be required to meet the demand in 2025. The projections made for 2050 indicates that increase of 2.1 MAF (2.6 billion m^3) would be required to meet the demand in 2050.

The additional amount of water needed in 2025 seems a small amount of water (i.e. 9%, 0.3 MAFB) to meet the demand of the domestic sub-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.

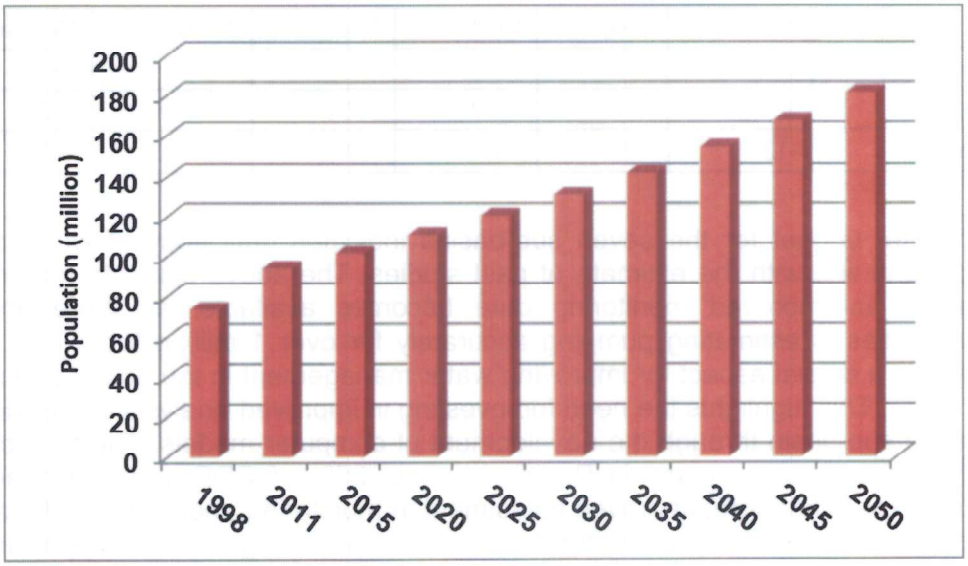


Figure-2: Punjab Population and Projects

(Data Source: Pakistan Population Census Reports)

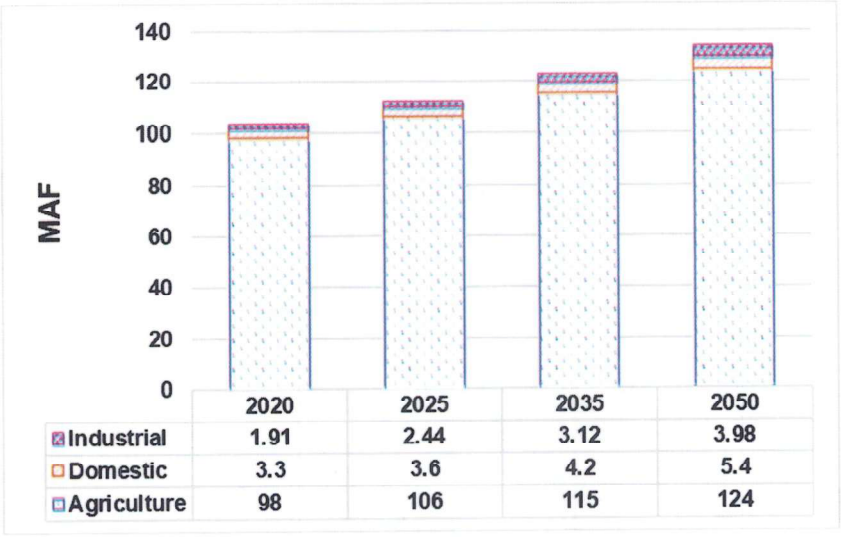
4.2.2 Agriculture water Demand projections

Currently, agriculture sub-sector of water use consumes 98 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 (**Error! Reference source not found.**) 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 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.

4.2.3 Industrial Water Demand Projections

The current water use in industrial and commercial sub-sector is 1.91 MAF (2.36BCM), 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) as shown in Error! Reference source not found.. The growth rate of 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 sub-sector of water use will be met out of the savings made in water use in the agriculture sub-sector. The strategy for making savings in water use shall be prepared.



	2020	2025	2035	2050
Industrial	1.91	2.44	3.12	3.98
Domestic	3.3	3.6	4.2	5.4
Agriculture	98	106	115	124

Figure-3: Punjab's water use projections

(Data Source: IRSA, PID, GOPu and PWD 2012[1])

5. CONCLUSION

Following conclusions can be drawn from the previous sections:

i) All the canal commands having short, adequate and excess water allocations still do not provide water to meet the peak crop water requirement.

ii) Net water balance of majority of canal commands and sub-basins are negative.

iii) Reducing tubewell pumping and increasing canal water supplies seems to be the only effective way of arresting the current pace of negative water balance in large areas of Punjab.

iv) A general water balance assessment for canal commands shows that domestic, industrial, livestock, and environmental demands can easily be met with available rain and canal water. However, the remaining fresh water in canal commands and the water available for reuse is insufficient to meet crop water requirements.

v) A more holistic approach towards water management and conservation needs to be proposed.

vi) Total inflows for Punjab Basin are 723 mm from canals and 177 mm from rainfall. Total outflows are 941 mm. Net water balance is -41 mm in Punjab Basin.

vii) Inflows and out flows have been estimated for each sub-basin in Table 10. Net water balance varies from -77 mm for Chaj Doab to +127 mm for DG Khan.

viii) Pumping of groundwater is essential to meet crop consumptive use requirements.

ix) The 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 of irrigation agencies as well as institutional reform to manage and regulate groundwater resources.

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[1] PWD. 2012. Situation of population in Punjab. Population Welfare Department, Government of Punjab