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Challenges for groundwater-irrigated agriculture and management opportunities in Punjab province of Pakistan

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Abstract
Pakistan has one of the world's largest contiguous irrigation canal networks which was initiated by the British during the early nineteenth century, and its continuous expansion significantly altered the hydrological balance of the Indus River Basin (IRB) in Pakistan. During the pre-irrigation era, the water table in the IRB was very deep which rose up with the introduction of canal network. Seepage from the earthen canals caused the dual menace of waterlogging and salinity and different Salinity Control and Reclamation Projects (SCARPs) were implemented. With the growing food and fiber requirements, use of groundwater increased over the time. Currently, in Punjab province groundwater is contributing about 45-50% towards irrigation through 1.2 million tube-wells, putting the aquifer under stress. As water table deepens, the cost of extraction increases. Besides its use for irrigation, groundwater is used for drinking, industrial and commercial requirements. In many areas, the unplanned and over-pumping has caused intrusion of saline water into fresh groundwater areas. This paper describes the historical development and current challenges for sustainable use and management of groundwater. Some initiatives by the Government are described, with available opportunities. A new research project that considers the potential of artificial aquifer recharge as part of the management has also been discussed.

Keywords: Groundwater, irrigation, recharge, Punjab, Pakistan

Introduction
Water has played an important role in the economic, social and cultural development of civilizations. The oldest dwellings around the world were established along the banks of rivers, creeks, lakes, springs, swamps and other water bodies (Cathcart, 2009) [5]. In the South Asia regions, the introduction of small pumps and drilling rigs around 1960-70 brought a green revolution by using groundwater as a source of irrigation, which lead to tremendous increase in private tubewells and irrigated areas in the region (Mukherji & Shah, 2005; Qureshi, 2008; Shah, 2009) [47, 49, 53]. Another example is of the civilization of the Indus Valley, where more than 4000 years ago populations established and grew along the banks of the rivers and expanded latter (Bhutta & Smedema, 2007; Javaid & Falk, 2015; Young *et al*., 2019) [4, 33, 48, 55]. The Indus River has a total length of 2900 km and a drainage area of approximately 966,000 km^2 having major tributaries: the rivers Jhelum, Chenab, Ravi, Sutlej, and Beas in the east and the Kabul River to the west. The source of inflow to these rivers originates from snow and glacial melt, with additions from rainfall in the catchment areas (Qureshi, 2018; Qureshi & Ashraf, 2019) [50, 52]. The Indus Basin is underlain by an extensive unconfined aquifer that covers about 16 million ha of surface area, of which 6 million ha are fresh and the remaining 10 million ha are saline (Bakshi & Trivedi, 2011; Haider *et al*., 1999) [32, 10, 39]. The IRB- one of the world's largest basin- has arid to sub-arid climate with an average rainfall of 240 mm, mostly in monsoon months (July-September (Qureshi, 2018) [50]. The major use of the waters of The Indus River System (IRS) in Pakistan is agriculture, which accounts for around 22% of the country's gross domestic product, more than 60% of foreign exchange earnings, and employs about 45% of the overall labor force. Agriculture in Pakistan is, perhaps more than anywhere else in the world, dependent on irrigation. Irrigated agriculture in Pakistan currently relies on, both surface water and groundwater (Hassan *et al*., 2019).

Pakistan is moving from water-stressed to water-scarcity status, mainly due to rapidly increasing population coupled with climate changes, and other challenges for water sector (GoP MoPD&R, 2014; Qureshi & Ashraf, 2019) [52]. It is projected that, by 2025, the shortfall of water requirements will be around 32%, which will result in food shortages in Pakistan (ADB, 2002) [1]. As per estimates by (WB, 2019) [28], more than 300 million people will be living in Pakistan by 2047 (the 100 years of the country) which will increase the water demand by 60%. Since its inception in 1947, Pakistan has been facing water sector challenges which have led to more pressure on groundwater reserves on the country. Different accords, policies, and regulation have been promulgated but the situation continued to be deteriorated due to lack any integrated, holistic and comprehensive regulatory or policy framework. Although population and economic growth are the main drivers of water scarcity, climate change will exacerbate the gap between demand and supply of water. The largest water demand will be in the agriculture sector and the fastest rates of water demand growth will be in the industrial and domestic sector. With this situation in mind, the Government of Pakistan has endorsed the "National Water Policy 2018" (GoP, 2018) [7] which has prescribed many reforms and investment priorities to ensure the water and food security in the country. It has outlined a platform for dialogue between the major stakeholders (provinces) and have provided them to formulate their own regulatory and implementation plans as per their own requirements and circumstances.

This paper provides a brief description of water use in the IRB, current challenges for sustainable use of groundwater for irrigated agriculture in Punjab province and some of the initiatives by the Punjab Government regarding groundwater management in the province. Available opportunities and a managed aquifer recharge (MAR) project has also been discussed.

The indus river basin nad canal irrigation

Irrigation in the Indus River Basin has been recorded dating back to the Indus Civilization in the Sub-continent. The remains of ancient civilizations of Indus valley indicate that the inhabitants of this fertile IRB practiced irrigation were mainly dependent on irrigated agriculture for their livelihood, using wells and river spills during the flood season (Gilmartin, 2015; Kamal *et al*., 2012) [36, 43]. During the period between the 18th and the middle of the 19th centuries, many inundation canals were built by various emperors and minor rulers in the IRB. The recorded history of irrigation as an established practice can be traced as far back as the 8th century when Arab conquerors of the Sindh Province differentiated between the irrigated and non-irrigated lands to levy land taxes. Some inundation canals were constructed by Moghuls which were not primarily meant for irrigation but were used to water the Royal gardens and parks. Two examples of such ancient canals are Western Jamna Canal, Hasli Canal and Shah Nehr (PID-MIP, 2017) [19]. Soon after taking their rule over Sindh and Punjab in the Sub-continent, British rulers embarked upon the construction of a large canal network in the IRB. Old inundation canals were first improved, then gradually converted to regulated perennial systems by means of weirs and barrages constructed across the rivers. These works led to the development of the world's largest integrated canal network, which provides water to 33 million acres of land in the IRB.

The modern era of irrigation canals network in IRB started in 1854 with the establishment of a Directorate of Canals under the supervision or the Chief Engineer, Irrigation Works. This was followed by the construction of the first weir-controlled perennial irrigation channel; the Upper Bari Doab Canal, off-taking from the river Ravi at Madhopur in 1859, and the Sirhand Canal from the river Sutlej at Rupar in 1872 (PID-MIP, 2017) [19]. The main irrigated part of the Indus Basin in Pakistan is in the Punjab province. 'Punjab' means "The Land of Five Rivers". From east to west these rivers are Sutlej, Ravi, Chenab, Jhelum, and Indus. The flat stretches of land between two rivers have been called "doab", meaning land between two waters/rivers. These doabs are Bari (between rivers Beas and Ravi), Rechna (between rivers Ravi and Chenab), Chaj (between rivers Chenab and Jhelum) and Thal (between rivers Jhelum and Indus). The plains of these doabs have been formed by alluvial deposits brought by these rivers while flowing from Himalayan Mountain Ranges and are very fertile. In order to develop the land in the doabs an extensive and intricate network of irrigation canals was constructed by the British during the 1900s, during their rule over the Subcontinent. In Rechna Doab (Punjab Province), the Lower Chenab Canal (LCC) was converted to weir control and extended during the years 1892-1900, with a discharge capacity of 368 m3/s, and covered an area of 1.13 million hectare (MH). During the pre-irrigation era (Figure 1), the water table in the IRB was very deep which rose up with the introduction of canal network (Figure 2). Seepage from the earthen canals caused the dual menace of waterlogging and salinity and different Salinity Control and Reclamation Projects (SCARPs) were implemented Ahmad (1995).

The fertile soils and irrigation water caused the area in the Indus Basin to blossom into lush green fields rapidly and investments made in the construction of canals network, barrages and headworks were paid off within a few years of the introduction of the canal network in the Basin (Hassan, 1993) [12]. The period of prosperity brought by canal irrigation was rather short-lived, however (Hassan & Bhutta, 1996) [13]. Canal based irrigation encouraged the expansion of agriculture and brought with its new problems of waterlogging. Seepage from the irrigation system and percolation from irrigated fields caused the water table to rise continuously, reaching critical conditions for a substantial area, especially in the Punjab province. This led to the dual menace of waterlogging and salinity and crops were seriously affected over a wide area. In some areas, the water table rise was 24.4 m or even more with an average rate of rising of 0.46 m/year (Soomro, 1975) [27]. As reported by PID-MIP (2017) [19], the average water table rise varied in Punjab province between 0.5 to 2.0 ft./year (0.15 to 0.61 meter/year). During the pre-canal system, the irrigation relied on inundation canals which supplied water through narrow strips along the riverbanks during the flood season only. By the construction of barrages and reservoirs, increasingly more river water was diverted, and increasingly more land was irrigated (Bhutta & Smedema, 2007) [4, 33]. Soomro (1975) [27] reported that waterlogging was first noticed in the upper regions of Rechna Doab in the Punjab Province of Pakistan after a few years of the opening of Lower Chenab Canal. Bhutta & Smedema (2007) [4, 33] have recorded that the first signs of waterlogging and salinization in the IRB were reported in 1851 in the Western Jammu area Command (the area to be irrigated by a certain canal) followed by similar reports from other Punjab area. This waterlogging led to the need for a parallel drainage system network. To alleviate the twin menace of waterlogging and salinity, the Water and Power Development Authority (WAPDA) was established in 1958 and Salinity Control and Reclamation Program (SCARP) was conceived, planned and implemented by adopting surface and subsurface drainage projects in the country. The first Salinity Control and Reclamation Project (SCARP-I) was implemented in 1960-63 and almost 61 such projects were completed (Hassan, G.Z, Hassan, F.R & Akhtar, A. 2017) [15, 16]. SCARP consisted of horizontal drainage (surface and sub-surface tile drainage) and vertical drainage (tube wells). A total of 10,196 tube wells, 8,260 in fresh groundwater and 1,936 in saline groundwater areas, were installed. The number of operable tube wells, however, decreased to around 9,000 by 1994, with annual pumpage of about 6 MAF. The total length of surface drains in the province is 8,980 Km (PID-MIP, 2017) [19]. SCARP tube wells succeeded in curbing waterlogging problems in most areas.

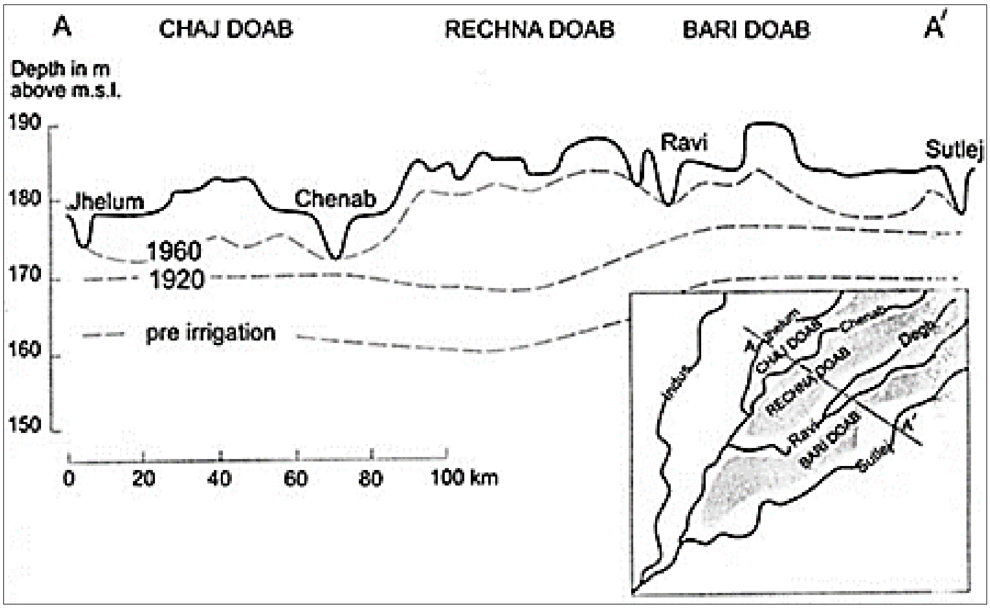

Fig 1: Groundwater table rise in Punjab along section AA/ (Ahmed N. 1995)

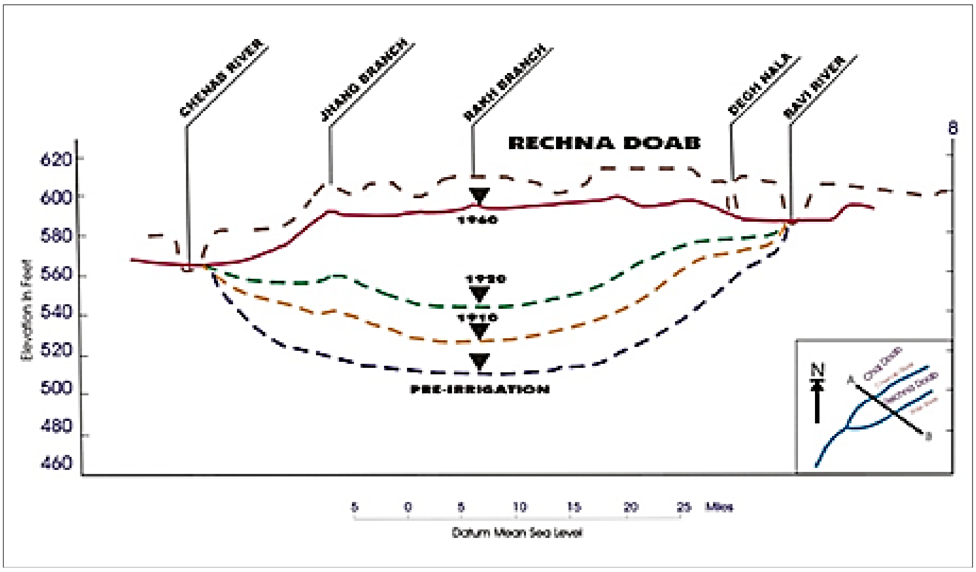

Fig 2: Historical groundwater levels in Rechna Doab, Punjab, Pakistan

Groundwater use in the IRB

In the early history of Indus Valley, the groundwater was by being used by the people for their livelihood/drinking and other requirements. (Shah, 2007) [25] has reported that shallow wells and muscle-driven lifting devices have been in vogue in many parts of the world for millennia. In British India (which included India, Pakistan and Bangladesh) such use of groundwater accounted for over 30% of irrigated land even in 1903 when only 14% of the cropped area was irrigated (DSAL 2019) [19]. Initially open wells, step-wells, Persian-wheels and hand pumps were used for extraction of groundwater for different purposes, latter on during 1960-70s, the introduction of tube well technology brought a green-revolution in the Indus valley (Cheema *et al.*, 2014; Mekonnen *et al.*, 2016) [35, 46]. (Panhwar, 1969) [18] reported that in the Sindh province of Pakistan the groundwater was historically pumped using a bucket-rope-pulley system to bail out the water from open wells and Persian wheel was introduced during 1960. In the Punjab province, there was only one million-acre-feet (MAF) pumpage of groundwater in 1965 mostly through Persian wheels which reached to 12 MAF in 1970 via increased public tube wells. The modern use of groundwater for irrigation started with the installation of public tube wells in the 1960s, soon to be followed by an explosive tube well development by private farmers growing at the annual rate of 1–2% (Bhutta & Smedema, 2007) [4, 33]. (Shah 2007) [25] and (Cheema *et al*., 2014) [35] reported that groundwater has become the mainstay of irrigated agriculture in many parts of Asia, especially in South Asia and the North China Plain. Between them, India, Pakistan, Bangladesh, and North China use over 380-400 km^3 of groundwater per year which is more than half of the world's total annual use. However, the use of groundwater for irrigation is of little importance in South-east Asia and southern China, which have abundant surface water. (Khan *et al*., 2008) [44] have observed that nearly all of India, northern Sri Lanka, Pakistan (Punjab and Sindh i.e. IRB), and the North China Plain represent regions where groundwater has attained a unique and increasingly critical role in supporting a dynamic smallholder irrigated agriculture, has become a source of livelihood. While the bulk of the rest of the world's groundwater use is for urban and industrial sectors, most South Asian groundwater use is in agriculture (Watto, 2015) [54].

As outlined above, just after the introduction of SCARP tubewells in the public sector during the 1960s, there have been rapid advances in private groundwater development in the Punjab Province (PID-MIP, 2017) [19]. The demand for additional irrigation water arising from increased cropping intensities and changes in cropping patterns triggered a tremendous growth of private tube wells. The number of private tube wells, as such, increased from 28,746 in 1965, to 147,995 in 1979, to 213,408 in 1986 to 386,526 in 1994 and aggregates to around 1 million during 2017 . The number of private wells in Punjab has now grown to 1.2 million (GoPb, 2017) [7] and current pumpage from the aquifer has exceeded the limit of balanced recharge of 43 MAF (PID, 2018) [19]. The economic value of a unit of groundwater is much more than the canal water because of its availability as to when and where required although its quality generally is poor, and it is far more expensive. Provision of subsidies by the government and introduction of modern technology has made it possible to continue and sustain private tube well development in the province. The total pump age from private tube wells has gradually increased from 3.27 MAF in 1965 to 32.10 MAF in 1985-87 and at present, it is estimated that public and private tube wells are contributing about 40-50% of the total irrigation water requirements for the agriculture sector. Haq, Qureshi, & Sufi 2018) [50] have reported that Pakistan is extracting about 50 MAF from the aquifers. In fresh areas, it has crossed the sustainable limit of safe yield. This over-mining and pollution of aquifers have resulted in secondary salinity and the presence of fluorides and arsenic in water, which in turn is degrading the quality of agricultural lands and creating health issues.

The rate of rising of the water tables reached its peak in the 1940-50s and waterlogging reached its peak with some time lag of 15-25 years i.e., 960-80's. To monitor the rising groundwater tables, some 14 lines of open water table observation wells (called provincial well-lines) were installed across the doabs of Punjab by WAPDA's organization called SCARP Monitoring Organization (SMO). Some records of groundwater levels are available since 1882, but systematic observations started in 1886. In Sindh 3600 water table observation pipes were installed in the command of Sukkur Barrage and recording started in 1932 (Bhutta & Smedema, 2007) [4, 33].

Floods In Irb

Flood plays havoc in most parts of the world, causing large scale damage to human lives, their infrastructure, and the environment (ASCE, 2010) [31]. Recent global climatic changes have exacerbated the frequency and intensity of occurrence of floods in different regions and including IRB of Pakistan (Siddiqui & Kamal 2018) [26]. The Major factors in floods in the IRB are inadequate surface water storage capacity for absorbing flood peaks, chronic and increasing threat of encroachments in flood plains, inadequate discharge capacity of some of barrages/bridges, inadequate financial resources, poor maintenance of existing flood infrastructure, poor flood plain management, lack of early flood forecasting and early warning systems, complexity in operational procedures, distorted natural drainage network, lack of awareness and capacity, lack of coordination, poor disaster preparedness, inadequate structural and non-structural measures. Therefore, the IRB in Pakistan has remained under the threats of floods and droughts and the climatic changes during the last decades. Floods occur usually in summer season (July - October), therefore damages to agriculture sector are mainly to the crops of wheat approaching harvest {Kazi, 2013 #928; Mustafa, 2011 #2535}

Historically, the IRB of Pakistan has faced about 24 severe historical flood events during the years 1950, 1955, 1956, 1957, 1959, 1973, 1975, 1976, 1977, 1978, 19981, 1983, 1984, 1988, 1992, 1994, 1995, 2010, 2011, 2012, 2013, 2014, 2015 and 2016. The 2010 flood was the worst ever in the basin in which about 1,985 people lost their lives, 1.6 million houses were damaged/destroyed, and 17,553 villages with an area of 160,000 km^2 was affected (Siddiqui & Kamal, 2018) [26].

Flooding is the most damaging natural disaster in the world, with average annual losses exceeding US$40 billion which have been increasing due to population growths in flood plains further exacerbated by more storms due to climatic changes and the old lived flood infrastructure. On the one hand, floods cause huge damages but on the other side, these impact the groundwater, wetlands, soil fertility positively, that is, flood waters also present opportunities for Pakistan. (Opperman, 2014; Zakir-Hassan *et al*., 2021) [17, 48, 57] has outlined some of the benefits of floods. The connection between rivers and floodplains makes river-floodplain systems among the most productive and diverse ecosystems on the planet. Throughout Africa, Asia, and Latin America, river-floodplain systems support productive fisheries improve soil fertility for better agriculture and supplement food security for millions of people in tinny rural communities in the region. Floodplain ecosystem services include sequestration of nutrients and sediments to improve downstream water quality, groundwater recharge, reduction of flood risk, productive fisheries, wildlife habitat, open space, and recreation. The opportunities for groundwater recharge are particularly interesting. (Zakir-Hassan & Hassan, 2018) [56] carried out a research study in Rechna and Chaj Doabs to evaluate the impact of flood 2014 on groundwater recharge. The study concluded a watertable rise of 0.77 ft. and 2.57 ft. in Chaj and Rechna Doabs, respectively. The volume of water recharged to aquifer has been estimated as 1.20 million-Acre-Feet (MAF) and 1.90 MAF with a future potential to divert flood water to the underground aquifer of 4 MAF and 14 MAF in Chaj and Rechna Doabs, respectively. The Punjab Irrigation Department (PID) is responsible for flood mitigation at the provincial level and has been taking a wide spectrum of activities in this regard. (PID-MIP, 2017) [19] has outlined the existing flood protection infrastructure which consists of a 2688 km of earthen embankments, 697 spurs and stone studs which protect/safeguard the infrastructure, agricultural crops, cities and some reaches of the riverbanks against erosion by the river action. Recently a project has been launched to recharge the depleted aquifer using flood water in Southern parts of the province. Division of the Punjab into different groundwater monitoring zones is shown in Figure 3.

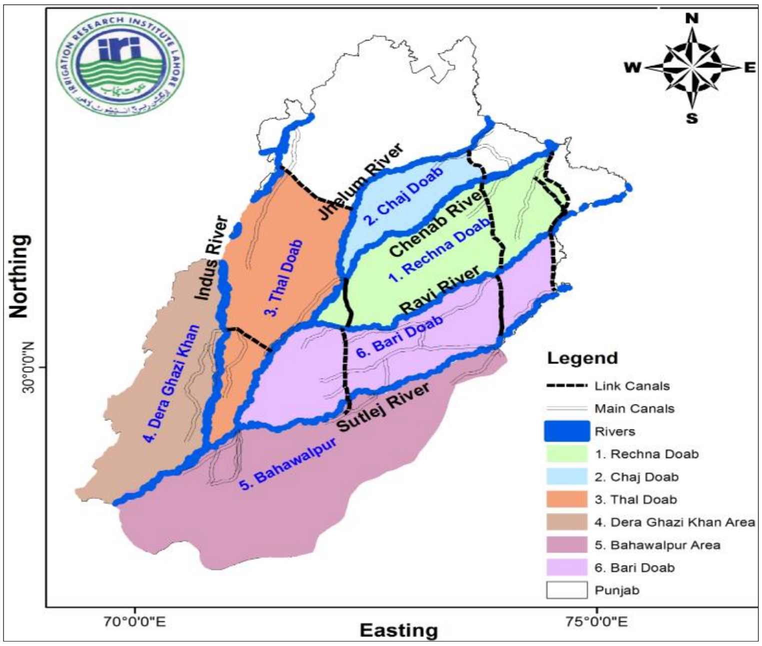

Fig 3: Map showing location of different sub-basins for groundwater management

Challenges for groundwater in IRB

Depletion of Aquifer

Due to ever increasing demand of water is almost all sector, groundwater reservoir is under continuous stress and water levels in the aquifer are dropping at very alarming rates in some parts of the Indus Basin. Lahore the provincial capital for Punjab is the urban example where groundwater levels are falling at rates of about 3 ft per year. Overall map of depth to groundwater table In Punjab is shown in Figure 4.

Deterioration of groundwater quality

Groundwater is deteriorating with time due to many factors like domestic, agricultural and industrial effluents, being discharged into water bodies without treatment. Over-extraction of groundwater is also a threat which is causing intermixing of fresh and brackish zones. Groundwater quality in Punjab province is shown in Figure 5.

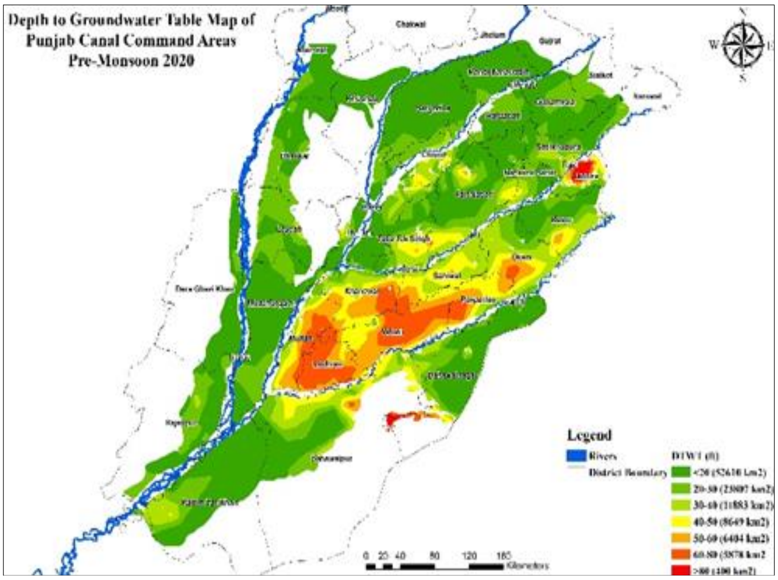

Fig 4: Map showing depth to water table status in Punjab (2018)

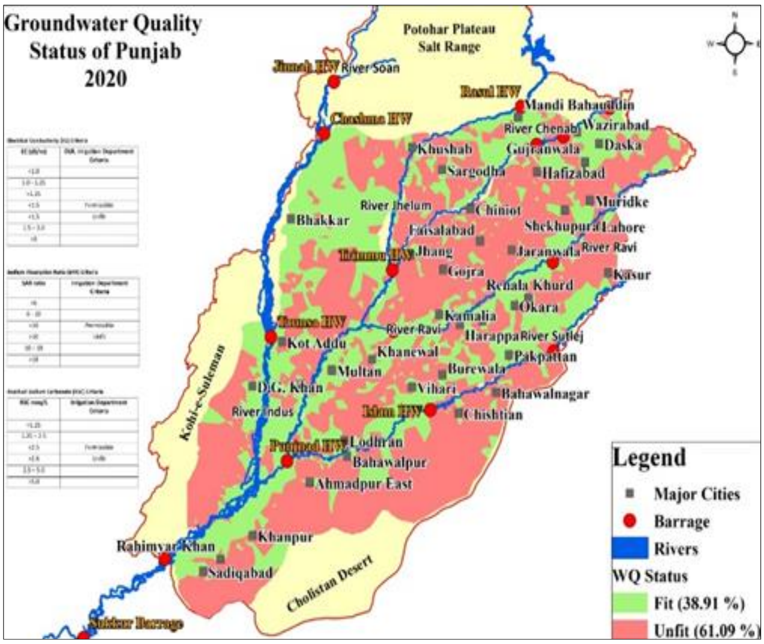

Fig 5: Deteriorated status of groundwater quality for irrigation in Punjab province of Pakistan

Inadequate monitoring of groundwater
Without proper monitoring, management of groundwater is not possible. At present only the canal commanded areas in the province are covered with monitoring wells which covers approximately 50% areas. Both quality and levels monitoring network are inadequate and need to be strengthened.

Regulatory framework
Holistic regulations with proper and integrated implementation mechanism are imperative to manage this precious resource. At present anybody can install tube well and start extracting groundwater. Over depleting groundwater levels have imposed adverse impacts of the costs. Some of the challenges for groundwater in Punjab are enlisted in Box 1.

Box 1

Challenges for groundwater Management in IRB

i. Extensive extraction of groundwater (1. 2 M tube wells only in argic-sector) has placed Pakistan at 4th position among the largest global groundwater users.
ii. Abnormal lowering of water table in sweet groundwater zone, due to unplanned and non-scientific pumping, for example 2.5 ft/year in Lahore and 0.5 to 1 ft/year in rural areas especially in easter river basins.
iii. Deterioration of groundwater quality due to intermixing of fresh and brackish groundwater due to saline groundwater intrusion in the fresh areas
iv. Increasing domestic, industrial and agricultural effluents are serious threats for groundwater pollution. Currently about 90%, 80% and 50 water requirements in drinking, industrial and agricultural requirements being met from groundwater.
v. Increasing cost of groundwater pumping with decline in water table is putting extra financial burden on farming communities and taking this natural resource out of their bounds.
vi. Rural livelihood and thus food security in IRB is under sever threats.
vii. Concerns regarding sustainability of agriculture due to secondary soil salinization due to use of brackish groundwater for irrigation is reducing land productivity
viii. Over consumption/skimming of upper freshwater layer is being pumped beyond sustainable limits.
ix. Overall water supply-demand gap is widening due to which pressure on groundwater in increasing.
x. Groundwater budget i.e., recharge and pump age is in danger zone.
xi. Highly in-efficient use (less than 60%) of surface water is also a challenge indirectly for groundwater.
xii. Being a hidden resource, there is quite lack of awareness among the stakeholders about groundwater use and availability. There is myth among the common man that groundwater is unlimited resource.
xiii. Multiple users, complexity in defining the entitlements, no one custodians.
xiv. Water pricing, implementation of holistic regulatory framework are impediments for sustainable use of groundwater. Anybody can install any number of tube well anywhere and can pump as much as he likes.
xv. Lack of appropriate capacity and coordination among the groundwater/water institutions and overlapping of resources are other barriers for management of groundwater.
xvi. Implementation of groundwater regulation without consultation of end users at grassroots level is a big challenge.
xvii. Increasing population has demanded more food and fiber, to cope with this cropping intensity has increased from 67% to 150% or more during last 6-7 decades, which has increased pressure on groundwater many folds.

Continuously increasing population (4% annual growth rate) has increased pressure of water resources and Pakistan is running towards water scarcity (Lytton *et al*., 2021; Qureshi & Ashraf, 2019) [52]. Due to limited availability coupled with extreme spatial and temporal variability of surface water, use of groundwater has increased rapidly during last four to six decades (Chandio *et al*., 2012; Cheema *et al*., 2014) [35]. The aquifer underlying the IRB is confronted many sustainability challenges further aggravated by climatic changes (Ahmad *et al*., 2011; Iqbal *et al*., 2017; Qureshi *et al*., 2009) [30, 41, 51].

Some initiatives by the Government

Realizing the importance of water resources, current scarcity challenges and issues government has taken some measures and corrective steps to handle the situation. Especially for groundwater management, development and sustainable use some projects have been initiated and completed by Government of the Punjab, especially by the international donors. Some of these projects and some initiatives are enlisted in Box 2.

Box 2
Some Groundwater Projects and regulation in Punjab

- Punjab Private Sector Groundwater Development projects PPSGDP-1998-2002- funded by World Bank
- Groundwater Monitoring-Modeling and Management under LBDCIP (2013) funded by ADB.
- Groundwater monitoring and Management under PISIP- 2015 funded by JICA
- LWR-2005-144- Optimizing Canal and Groundwater use Management in Rechna Doab-2015 funded by ACIAR
- LWR/ 2014/074- Developing approaches to enhance farmer water management skills in Balochistan, Punjab and Sindh in Pakistan
- LWR 2015/036 - Improving groundwater management to enhance agriculture and farming livelihoods in Pakistan-2021 funded by ACIAR
- Punjab Water Policy 2018
- Punjab Water Act 2019
- Punjab Water Resources Commission 2020
- Punjab Water Services Regulatory Authority 2020
- Geo-referencing of existing tube wells in Punjab 2021
- Monitoring of groundwater (levels and quality) biannually from about 3000 points and aquifer mapping throughout the province
- Strengthening the monitoring network (addition of more 2000 observation wells) 2021
- Installation of real time data loggers for groundwater monitoring 2021
- Recharge of Aquifer for Groundwater Management in Punjab (Old Mailsi Canal)-Punjab Govt. funded MAR project
- Study on impact of flood water on groundwater recharge
- Awareness raising about groundwater governess and management.

Keeping in view the situation of groundwater in the Province, the Punjab Government has taken steps including the recent approval of Punjab Water Policy and Act, 2019. Even before this policy, a Groundwater Management Cell was established in the Irrigation Research Institute (IRI) that has initiated seminars/workshops with groundwater stakeholders to raise awareness of the issues and build their capacity to adapt. A range of research studies, surveys, and investigations are also occurring, seeking to delineate groundwater challenges and their sustainable solutions:

- The Punjab Irrigation Department has installed approximately three thousand piezometers across the irrigation area to monitor groundwater levels manually twice a year.
- Observed data on groundwater level and quality are analyzed using different models like MODFLOW and GIS tools. Maps of groundwater quality and levels are prepared to demarcation different zones. A map of depth to the water table of Punjab for the year 2018 is shown in Figure 4.
- Mapping of the aquifer showing aerial and vertical profile extent and potential (quality and quantity) and demarcation of hydrogeological zones in Punjab for resource assessment, is underway.
- Filling the gaps to strengthen the groundwater monitoring network in Punjab, development of mathematical groundwater simulation models
- Preparation of groundwater management plans at the basin and sub-basin level,
- Strengthening the institutional setup, capacity building and awareness raising among the stakeholders about groundwater management, use of information communication technologies/loggers for this purpose, Punjab province has been divided into different sub-basins keeping in view the hydrogeological boundaries.

IRI (2009) and IRI (2013) conducted a field survey and investigation study by the installation of sixty exploratory boreholes in the field at various critical sites in Punjab to explorer the groundwater quality and soil stratification to observe the impact of surface drains and other potential threats for groundwater. Wherein it was observed that surface water bodies especially drains are playing a vital role in contamination of groundwater. A study was conducted for groundwater investigation in Faisalabad area using Groundwater Model (MODFLOW) where tile drainage and surface drainage networks are functional, and groundwater is brackish for which one of the causes is heavy industrial pollution in the area (IRI, 2012). It was observed that with the -depletion of groundwater levels, the cost of pumpage increases which puts the extra financial burden of the framers and energy issues arise. Pollution due to fuel burning during operation of more tube wells is another threat.

Among the findings of these activities are some that suggest further investigation of aquifer recharge could contribute to positive management of groundwater in the IRB. These studies have indicated that groundwater levels are falling at an average rate of 1-2 ft/year in some areas of Rechna Doab (bounded by Ravi River and Chenab River). Recharge potential in Rechna doab during October 2010 and June 2012 was found out as 15.80 and 16.381MAF respectively. Flood water contributes significantly towards recharging the aquifer average rise in Rechna doab during flood 2014 is 2.57 ft/season. The total recharge of GW during flood season 2014 in Rechna Doab was 1.90 MAF (IRI (2015). During field investigations, it was observed that different factors like availability of surface water, soil strata, site availability/suitability, quality of surface and groundwater, a suitable recharging method are the imperative factors which need to be evaluated before taking up any recharge project to augment the depleted aquifer. Aquifer storage and recovery characteristics also need to be evaluated to ensure proper aquifer storage and recovery (ASR) mechanism.

Mar-an option for Aquifger sustainability

Most of the natural groundwater recharge in Punjab province is contributed by irrigation water losses through conveyance and fields while the share of rainfall to aquifer recharge is only some 10% (Bhutta & Smedema, 2007) [4, 33]. Therefore, the areas where a shortage of surface water has cropped up due to the Indus Water Treaty between India and Pakistan, the recharge to the aquifer has decreased significantly.

The groundwater budget in Punjab is in danger zone through pumping more than is being recharged to the aquifer. At the same time, in urban areas, natural recharge has been reduced by as rainfall water goes to surface drains or enters the sewerage system and causes the problem of flooding and/or choking the disposal network during wet events seasons. Similarly, in agricultural areas during monsoon rains, when lands are generally saturated and need no canal irrigation, the rainfall water in suitable depressions and natural drains is available. Some of this water could be diverted and injected to the underground reservoir - a process called artificial aquifer recharge. Artificial recharge can take place through direct and indirect methods and most of the country use artificial recharge to obtain different objectives like (i) the maximization of storage (including seasonal, long-term, and drought or emergency water supplies), (ii) physical management of the aquifer, (iii) water quality management, (iv) management of water distribution systems, (v) ecological benefits.

The Punjab Government is experimenting with artificial aquifer recharge. Potential sites for conducting the experimentation on artificial recharge were based on scientific reasoning. Keeping into consideration the available data, status of groundwater in the province was reviewed. General criteria for selection of a potential site for artificial recharge of the aquifer can include the parameters like depth to the groundwater table, groundwater quality, surplus surface water available for recharge, soil strata/seepage rates, quality of surface water to be recharged, groundwater pumpage. In view of these factors, a site near Islam Headwork on Sutlej River, near Vehari has been identified for recharging the flood water in the bed of the old Mailsi Canal.

A CSE study of mar-old Mailsi canal

The Mailsi Canal has been off taking from Islam Headworks since 1928. This channel having a length from RD 0+000 to RD 160+241 (32.05 Miles) falls within the jurisdiction of Islam Headworks Division. It is an earthen channel with the non-perennial system. The Design parameters of Mailsi Canal are given in Table 1 and the location of experimental sites is shown in Figure 6.

Table 1: Design parameters of Mailsi Canal

Sr. No.	Description	Content
1	Bed width	155 ft.
2	FSD	10.30 ft.
3	Discharge	4883 Cusecs.
4	Free Board	2.50 ft.
5	Longitudinal Slope	0.10 Per 1000 RFT
6	Width of the left bank	25 ft.
7	Width of Right bank	15 ft.
8	Total Length (RD)	160+241 (32.05 Miles)

Canal has become almost dry since 1965 and water supply has been arranged by constructing Links Canals in Pakistan. Due to non-availability of water supply in River Sutlej at Islam Head works, Mailsi Canal was curtailed and was became abandoned. It has been observed that the site physically is suitable for groundwater recharge as water table is more than 16 m deep, soils are fertile and the area is food basket for the province and country, cropping intensity is high up to 129%, groundwater mostly is sweet, and flood water can be made available for recharge through the Islam Headworks. There is an urgent need for recharging as cost of pumpage has increased many folds; an example of one farmer tube-well has been shown in Figure 7. Local stakeholders have shown willingness; suitable place (bed of old canal) is available for any desired artificial interventions for recharging the aquifer. The existing network of piezometers has been upgraded in the proposed study area by filling the gaps to have streamlined monitoring system for groundwater behavior. Depth to the water table is being monitored since 2015. Hydrographs of some selected observation wells on a biannual basis are shown in Figure 8a and 8b. A map of the proposed study area with major features has been shown in Figure 9. Increasing trend of irrigation tubewells by farmers is shown in Figure 10.

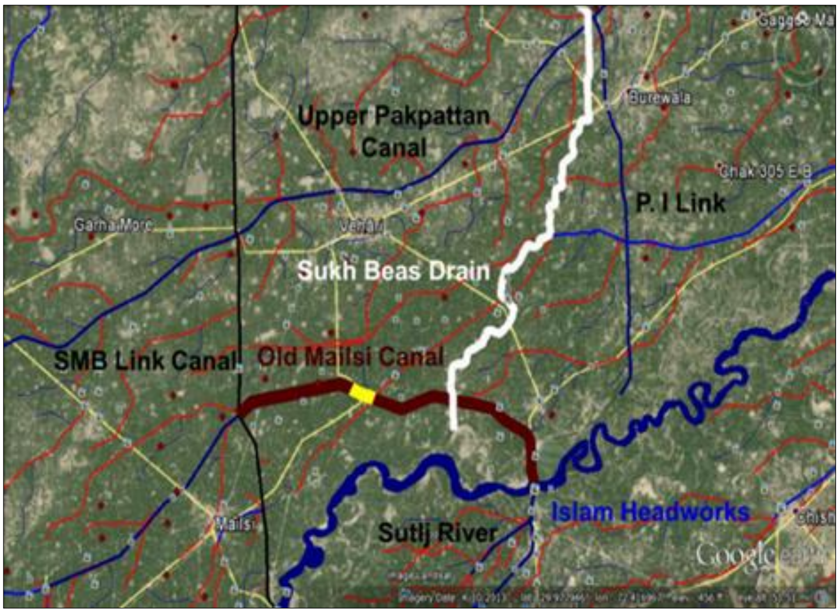

Fig 6: Location of proposed experimental site at old Mailsi Canal

Fig 7: Over-depleted well with high pumping cost in District Vehari, Punjab, Pakistan

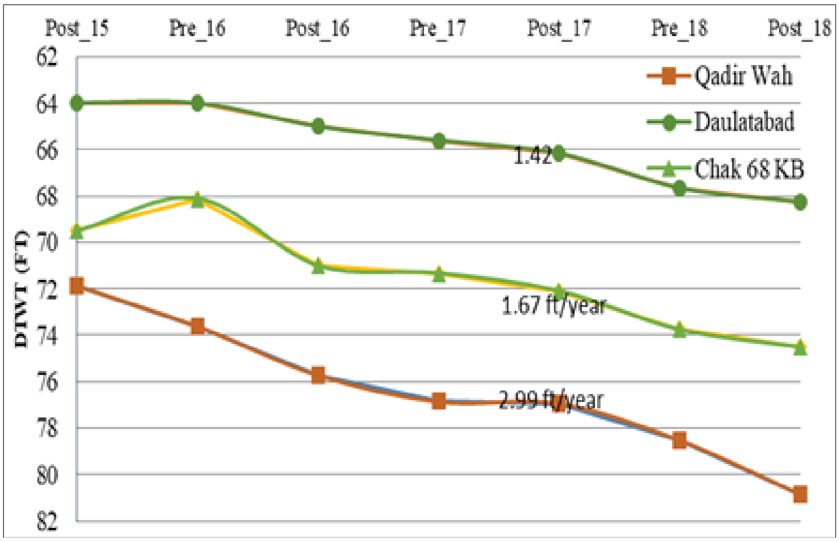

Fig 8a: Hydrographs of selected piezometers in district Vehari, Punjab, Pakistan

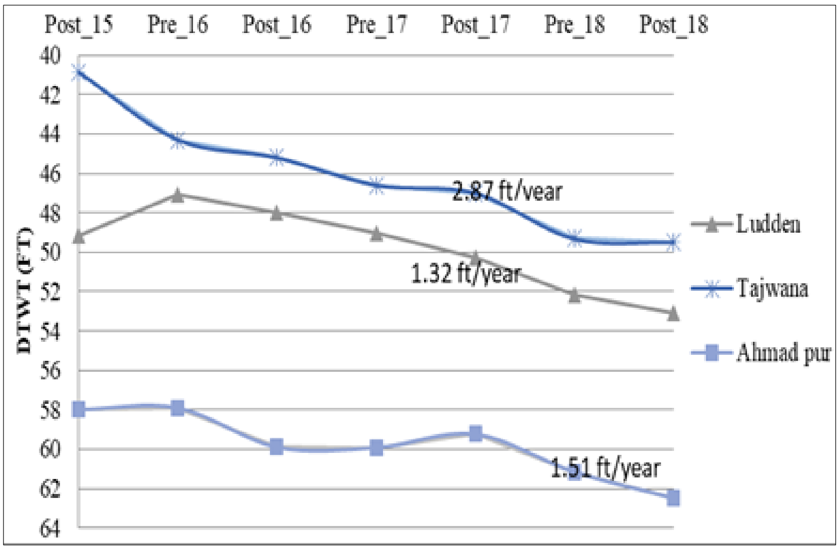

Fig 8b: Hydrographs of selected piezometers in district Vehari, Punjab, Pakistan

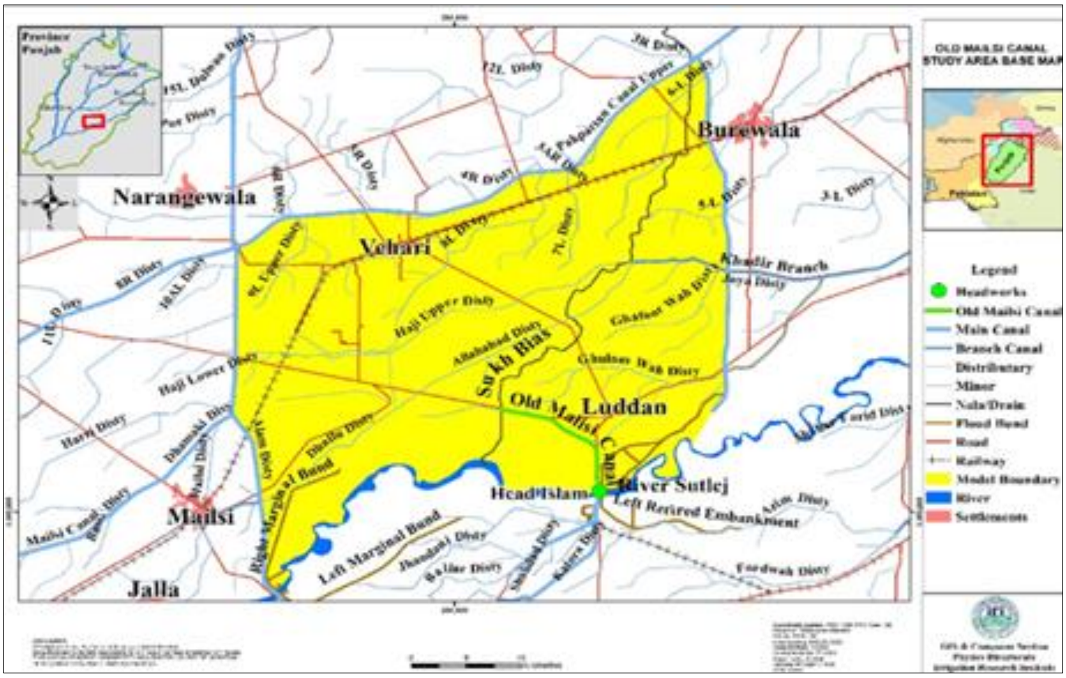

Fig 9: Area identified for artificial recharge of groundwater district Vehari, Punjab Pakistan

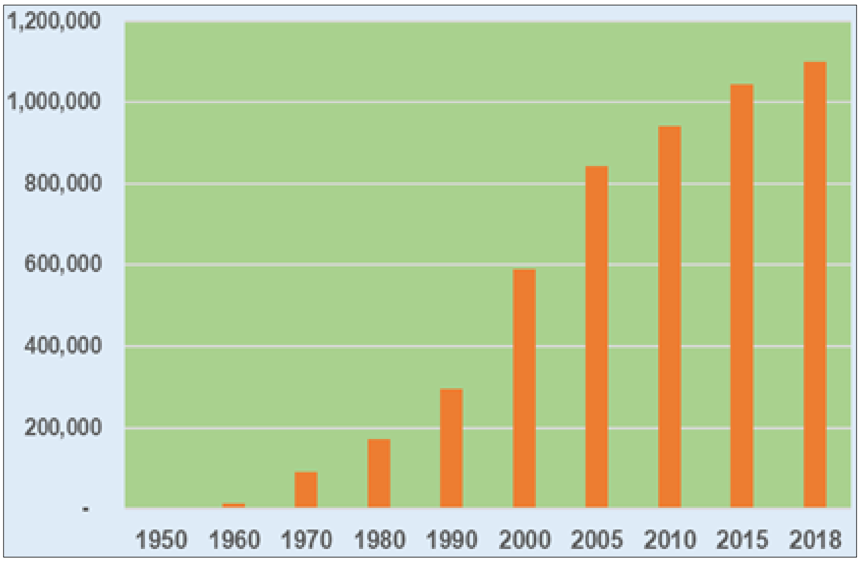

Fig 10: Increasing trend of private tubewells in Punjab- Pakistan

The Irrigation Department of Punjab Government has planned a project for artificial recharge of the aquifer in the bed of old Mailsi Canal. Initially, the first 45 RDs of the canal have been taken for experimentation of the recharge using flood water. A number of recharge wells will be used to enhance the recharge rate. About 144 recharge wells have been constructed in the bed of the canal. A suitable technique will be developed for replication in other similar location in the Indus Basin. Use of scientific models like GIS and MODFLOW are being used to evaluate the impact of MAR on the water table rise. Regular monitoring of groundwater levels and quality in the study area needs to be continued. to investigate the study properly. After experimentation on the recharge, the methods/technique developed can be upscaled for other similar locations in the province. Some available options are enlisted in **Box 3.**

Box 3
Options for sustainable management of groundwater

- Groundwater Recharge- natural and artificial- using flood water
- Rainfall harvesting and recharging the aquifer
- Strengthening the monitoring network of groundwater levels and quality.
- Institutional setup for groundwater management
- Formulation of long-term policy implementation framework
- Public awareness through mass media campaign, seminars, workshops, walks etc.,
- Capacity building of all stakeholders (planners, managers, users etc.)
- Controlling cropping pattern and intensities would be the best option for groundwater governance in depleting areas
- Fresh assessment of crop-water requirement, cropping patterns and intensities, and existing allocations
- Resource assessment on basin scale
- Groundwater management interventions
- Identification of groundwater recharge areas and water availability.
- Modernization of groundwater monitoring (tools/equipment, methods- use of IoTs)

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i. The point of views expressed in the paper are of the individuals and do not reflect the responsibility of any organization
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iii. No external financial support has been sought for this study.
iv. All relevant data has been made part of the paper. However, for any information/clarification corresponding author can be approached.

References
1. ADB. Water Resources Strategy Study: Draft Report Vol. 1., Asian Development Bank, Islamabad, Pakistan; c2002.
2. Ahmaad N. Groundwater Resources of Pakistan. (Revised and enlarged edition), published by Shahzad Nazir: 61- B/2 Gulberg III, Lahore, Pakistan; c1995.
3. Bhutta MN. Vision on Water for Food and Agriculture: Pakistan Perspective. Paper presented at the Regional South Asia Meeting on Water for Food and Rural Development, New Delhi, India, June 1999, 1-3. New Delhi, India.
4. Bhutta MN, Smedema LK. One hundred years of waterlogging and salinity control in the Indus valley, Pakistan: a historical review. Irrigation and Drainage. 2007;56(S1):S81-S90. Doi:10.1002/ird.333
5. Cathcart M. The water dreamers: the remarkable history of our dry continent. Melbourne: Text Publishing Company; c2009.
6. GoP-MoPD&R. Pakistan-Vision. Ministry of Planning, Development & Reform, Govt of the Pakistan, Islamabad; c2025.
7. GoP. National Water Policy, Ministry of Water Resources, Government of Pakistan, Islamabad; c2018.
8. GoPb. Punjab Development Statistics: Bureau of Statistics, Govt of the Punjab, Lahore Pakistan; c2017.
9. DASL. Digital South Asia Library; c2019. https://dsal.uchicago.edu/statistics/1894_excel/
10. Haider G, Prathapar SA, Afzal M, Qureshi SA. Water for Environment in Pakistan. Paper presented in the Global Water Partnership Workshop, 11 April 1999, Islamabad, Pakistan; c1999.
11. Haq IU, Qureshi MS, Sufi AB. Irrigation water for an evergreen revolution in Pakistan: 8TH Asian Regional Conference of ICID on “Irrigation in Support of Evergreen Revolution" May 2-4, Kathmandu, Nepal; c2018.
12. Hassan GZ. Evaluation of the groundwater resources of Faisalabad, Pakistan, M. Engg Thesis No No: IR-92-11 Asian Institute of Technology (AIT) Bangkok, Thailand; c1993.
13. Hassan GZ, Bhutta MN. A water balance model to estimate groundwater recharge in Rechna Doab, Pakistan. Irrigation and Drainage Systems. 1996;10(4):297-317.
14. Hassan GZ, Hassan FR. Groundwater reservoir as a source of flood water storage: A case study from Punjab, Pakistan: 8th Asian Regional Conference of ICID on “Irrigation in Support of Evergreen Revolution" May 2-4, Kathmandu, Nepal; c2018.
15. Hassan GZ, Hassan FR, Akhtar S. Impact of drainage effluents on groundwater quality- a case study from Lahore Pakistan: Presented at 13th International

Drainage Workshop of ICID, 4 – 7 March, Ahwaz, Iran; c2017.
16. Hassan GZ, Hassan FR, Shabir G. Food security challenges under climatic changes and groundwater-energy nexus- case study of Punjab-Pakistan: 23rd International Congress on Irrigation and Drainage-ICID, 8-14 October 2017, Mexico City, Mexico; c2017.
17. Opperman JJ. A flood of benefits: Using green infrastructure to reduce flood risks: The Nature Conservancy, Arlington, Virginia; c2014. www.nature.org.
18. Panhwar MH. Groundwater Hyderabad & Khairpur Division: Superintending Engineer Agricultural Machinery Southern Zone Tando Jam, Sind Pakistan; c1969.
19. PID-MIP. Manual of irrigation practice (MIP) Vol I: Punjab Irrigation Department, Govt of the Punjab, Lahore Pakistan; c2017.
20. PID. Punjab Water Policy: Punjab Irrigation Department (PID), Government of The Punjab, Lahore, Pakistan; c2018.
21. PWP. Supplement to the Framework for Action (FFA) for Achieving the Pakistan Water Vision 2025. Pakistan Water Partnership, Islamabad, Pakistan Pakistan; c2001.
22. Qureshi AS. Challenges and Opportunities of Groundwater Management in Pakistan. In Groundwater of South Asia, 2018, 735-757.
23. Qureshi AS, Akhtar M, Shah T. Role of changing energy pricing policies on groundwater development in Pakistan. Journal of Applied Irrigation Science. 2004;39(2):329-342.
24. Qureshi AS, Shah T, Akhtar M. The Groundwater Economy of Pakistan. IWMI Working Paper No. 64. Colombo, Sri Lanka International Water Management Institute (IWMI); c2003.
25. Shah T. The Groundwater Economy of South Asia: An Assessment of Size, Significance, and Socio-ecological Impacts. CAB International 2007. The Agricultural Groundwater Revolution: Opportunities and Threats to Development (M. Giordano and K.G. Villholth); c2007.
26. Siddiqui QTM, Kamal A. A foresight for flood disaster management in Pakistan: 8TH Asian Regional Conference of ICID on “Irrigation in Support of Evergreen Revolution" May 2-4, Kathmandu, Nepal; c2018.
27. Soomro AB. A review of problem of waterlogging and salinity in Pakistan: Master Thesis No 915, Asian Institute of Technology (AIT) Thailand; c1975.
28. WB. Pakistan: Getting More from Water: by William J. *et al*, International Bank for Reconstruction and Development, The World Bank Group 1818 H Street NW, Washington, DC 20433 USA; c2019.
29. WWF. Pakistan's Waters at Risk: Water andHealth-Related Issues in Pakistan and Key Recommendations: World Wide Fund for Nature, Lahore, Pakistan; c2007.
30. Ahmad Z, Ashraf A, Fryar A, Akhter G. Composite use of numerical groundwater flow modeling and geoinformatics techniques for monitoring Indus Basin aquifer, Pakistan. Environ Monit Assess. 2011;173(1-4):447-457. Doi:10.1007/s10661-010-1398-3
31. ASCE. So, you live behind a levee; What you should know to protect your home and loved ones from floods: American Society ofCivil Engineers, USA Retrieved from; c2010.
32. Bakshi G, Trivedi S. The Indus Equation: Strategic Foresight Group, Andheri West, Mumbai 400 053, India: www.strategicforesight.com. Retrieved from; c2011.
33. Bhutta MN, Smedema LK. One hundred years of waterlogging and salinity control in the Indus valley, Pakistan: a historical review. Irrigation and Drainage. 2007;56(S1):S81-S90. Doi:10.1002/ird.333
34. Chandio AS, Lee TS, Mirjat MS. The extent of waterlogging in the lower Indus Basin (Pakistan): A modeling study of groundwater levels. Journal of Hydrology. 2012;426-427:103-111. Doi:10.1016/j.jhydrol.2012.01.017
35. Cheema MJ, Immerzeel WW, Bastiaanssen WG. Spatial quantification of groundwater abstraction in the irrigated Indus basin. Ground Water. 2014;52(1):25-36. Doi:10.1111/gwat.12027
36. Gilmartin D. Blood and water: The Indus River Basin in modern history. Oakland, California University of California Press; c2015.
37. GoP-MoPD&R. Pakistan-vision 2025: Ministry of Planning, Development & Reform, Govt of the Pakistan, Islamabad Retrieved from; c2014.
38. Pandey R, Chaurey R, Solanki ERHK, Kumar S, Singh RM. Groundwater prospectus mapping using well points based on remote sensing and GIS techniques in a micro-watershed. Int. J Geogr Geol. Environ. 2022;4(1):145-153.
39. Haider G, Prathapar SA, Afzal M, Qureshi SA. Water for Environment in Pakistan. Paper presented in the Global Water Partnership Workshop, Islamabad, Pakistan; 11 April 1999.
40. Hassan GZ, Allan C, Hassan FR. Historical sustainability of groundwater in Indus Basin of Pakistan: Paper presented at the 3rd World Irrigation Forum of ICID, 1-7 September, Bali, Indonesia; c2019.
41. Iqbal N, Hossain F, Lee H, Akhter G. Integrated groundwater resource management in Indus Basin using satellite gravimetry and physical modeling tools. Environ Monit Assess. 2017;189(3):128. Doi:10.1007/s10661-017-5846-1
42. Dr. Uvaraj S. GIS based analytical hierarchy process (AHP) and frequency ratio (FR) models for groundwater potential zone mapping. Int. J Geogr Geol. Environ 2021;3(2):83-91.
43. Kamal S, Amir P, Mohtadullah K. Develoment of integrated Indus river basin managemnet (IRBM) for Indus Basin-Challenges and opportunities: A WWF_Pak Publication, WWF, Lahore, Pakistan; c2012.
44. Khan S, Rana T, Gabriel HF, Ullah MK. Hydrogeologic assessment of escalating groundwater exploitation in the Indus Basin, Pakistan. Hydrogeology journal. 2008;16(8):1635-1654. Doi:10.1007/s10040-008-0336-8
45. Lytton L, Ali A, Garthwaite B, Punthakey JF, Saeed B. Groundwater in Pakistan’s Indus Basin Present and Future Prospects: World Bank, Washington, DC. Retrieved from; c2021.
46. Mekonnen D, Siddiqi A, Ringler C. Drivers of groundwater use and technical efficiency of groundwater, canal water, and conjunctive use in

Pakistan’s Indus Basin Irrigation System. International Journal of Water Resources Development. 2016;32(3):459-476. Doi:10.1080/07900627.2015.1133402
47. Mukherji A, Shah T. Groundwater socio-ecology and governance: A review of institutions and policies in selected countries. Hydrogeology journal. 2005;13(1):328-345. Doi:10.1007/s10040-005-0434-9
48. Opperman JJ. A flood of benefits: Using green infrastructure to reduce flood risks: The Nature Conservancy, Arlington, Virginia; c2014. www.nature.org.
49. Qureshi AS. Sustainable groundwater management in pakistan: Challenges and opportunities- corrected version. Irrigation and Drainage. 2008;57:1-10.
50. Qureshi AS. Challenges and Opportunities of Groundwater Management in Pakistan: In A. Mukherjee (Ed.), Groundwater of South Asia, 2018, 735-757.
51. Qureshi AS, McCornick PG, Sarwar A, Sharma BR. Challenges and Prospects of Sustainable Groundwater Management in the Indus Basin, Pakistan. Water Resources Management. 2009;24(8):1551-1569. doi:10.1007/s11269-009-9513-3
52. Qureshi RH, Ashraf M. Water security issues of agriculture in Pakistan: Pakistan Academy of Sciences (PAS), Islamabad, Pakistan. 2019;41:41.
53. Shah T. Groundwater Governance in South Asia: Taming the Anarchy: IWMI, Colombo, Sri Lanka; c2009.
54. Watto MA. The Economics of Groundwater Irrigation in the Indus Basin, Pakistan: Tube-well Adoption, Technical and Irrigation Water Efficiency and Optimal Allocation. (PhD), PhD Thesis, The University of Western Australia; c2015.
55. Young WJ, Anwar A, Bhatti T, Borgomeo E, Davies S, Garthwaite III WR, *et al*. Pakistan: Getting More from Water: International Bank for Reconstruction and Development, The World Bank Group 1818 H Street NW, Washington, DC 20433 USA; c2019. Retrieved from http://www.worldbank.org/water
56. Zakir-Hassan G, Hassan FR. Groundwater reservoir as a source of flood water storage: A case study from Punjab, Pakistan: 8TH Asian Regional Conference of ICID on “Irrigation in Support of Evergreen Revolution" May 2-4, Kathmandu, Nepal; c2018.
57. Zakir-Hassan G, Hassan FR, Shabir G, Rafique H. Impact of Floods on Groundwater: A Case Study of Chaj Doab in Indus Basin of Pakistan. International Journal of Food Science and Agriculture. 2021;5(4):639-653. Doi:10.26855/ijfsa.2021.12.011
58. Javaid A, Falk T. Incorporating local institutions in irrigation experiments: evidence from rural communities in Pakistan. Ecology and Society. 2015, 20(2). Doi:10.5751/es-07532-200228
59. GoP. National Water Policy. Ministry of Water Resources, Government of Pakistan, Islamabad; c2018.