Solar Irrigation in Pakistan

A Situation Analysis Report

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International Water Management Institute

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About SoLAR

Solar Irrigation for Agricultural Resilience (SoLAR) in South Asia aims to sustainably manage the water-energy and climate interlinkages in South Asia through the promotion of solar irrigation pumps (SIPs). The main goal of the project is to contribute to climate-resilient, gender-equitable, and socially inclusive agrarian livelihoods in Bangladesh, India, Nepal and Pakistan by supporting government efforts to promote solar irrigation. This project responds to government commitments to transition to clean energy pathways in agriculture. All countries in this project have NDC commitments to reduce greenhouse gas (GHG) emissions and SIPs can play a significant role in reducing emissions in agriculture.

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Project

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List of Abbreviations

ABAD	Agency for Barani Areas Development
AEDB	Alternative Energy Development Board
BCM	Billion cubic meters
CCA	Canal Command Area
DTW	Depth to Water
FAO	Food & Agriculture Organization
GWS	Ground Water Storage
HEIS	Higher Efficiency Irrigation System
HEIS	High Efficiency Irrigation System
IBIS	Indus Basin Irrigation System
IWASRI	International Waterlogging and Salinity Research Institute
LIP	Lower Indus Plain
MAF	Million Acre Feet
OFWM	On Farm Water Management
PARC	Pakistan Agriculture Research Council
PCRWR	Pakistan Council of Renewable Energy Technologies
PEC	Pakistan Engineering Council
PIPIP	Punjab Irrigated-Agriculture Productivity Improvement Project
PV	Photo Voltaic
SIPs	Solar Irrigation Pumps
SPIS	Solar Power Irrigation System
SSCs	Supply and Service Companies
UIPA	Upper Indus Pain Aquifer
ZTBL	Zarai Taraqiati Bank Limited
GoP	Government of Pakistan

Executive Summary

This report presents a synthesis of Pakistan's groundwater situation, including a proliferation of groundwater pumps since the 1980s. It also highlights the issues around renewable energy transition and describes how the SDC-SoLAR (Swiss Development Corporation-Solar Irrigation for Agricultural Resilience) project led by the International Water Management Institute (IWMI) aims to navigate these complex issues through its research activities.

Pakistan has one of the largest contiguous irrigation systems in the world, called the Indus Basin Irrigation System (IBIS). In the 1980s, high groundwater table led to problems of soil salinization. This problem was addressed through energy subsidies and the import of Chinese manufactured pumps which promoted groundwater abstraction to lower water tables. Thus, there was a remarkable growth in the number of private tube wells in the country, and the overwhelming majority of diesel pumps were used to extract groundwater. Later, farmers started to observe a fall in the amount and quantity of groundwater, especially in the tail end of canal command areas. Mostly in river basins, farmers preferred to use surface water due to better quality and lower costs. With time as farmland for water-thirsty crops like sugarcane and rice increased, the shortfall between supply and water demand increased.

Consequently, groundwater abstraction kept on increasing. This development led to many adverse policies and environmental implications, among which the most prominent are falling groundwater levels and CO_2 emissions from diesel pumps. Uncurbed use of groundwater has led to a substantial increase in cropping intensity; however, agricultural productivity remains low in Pakistan.

In the recent past, solar pumping technology has emerged as an alternative to diesel and electric pumps. Still, water professionals in Pakistan are concerned that converting pumps to PV solar will result in indiscriminate pumping and eventually lead to further groundwater depletion. Pakistan does not have a specific policy on solar technology for groundwater pumping in agriculture. However, the country does have several policies that have a bearing on solar technology for groundwater pumping in agriculture. The National Water Policy makes several references to groundwater pumping. The objectives of this national policy in terms of groundwater aims to regulate groundwater withdrawals for curbing over-abstraction and promote aquifer recharge. It also aims to develop hydropower to increase the share of renewable energy. After the 18th Amendment in the Constitution, governance and management of water resources are devolved to provinces. Each Province has embarked on different trajectories to deliver on the National Water Policy. All the provincial governments have planned and/or launched subsidized solar irrigation pump schemes, mostly coupled with High-Efficiency Irrigation Systems (HEIS), especially in Punjab and Sindh. Until now, only Punjab province has succeeded in implementing its program to some extent, whereas in Khyber Pakhtunkhwa and Sindh provinces, the programs are at pilot stages, while in Baluchistan, programs have not materialized at all.

Many farmers have installed Solar Irrigation Pumps (SIP) through private investments. Currently, the Photo Voltaic (PV) market is dominated by Chinese products. The dominance of Chinese products is attributed to price competitiveness with similar products from western countries, extensive customer outreach through dealership networks, and the significant variation in product quality/pricing that caters to different economic classes of customers. There is a lack of awareness about the quality of PV and the benefits of high-quality products. The implementation and dissemination of quality standards for PV are expected to reduce price sensitivity and increase the procurement of high-quality PV products.

SIPs provide a promising alternative to diesel pumps. Still, marginal farmers cannot invest due to high initial costs and the low discharge capacities of SIPs compared to diesel-powered pumps. The provincial governments have tried to promote SIPs through High-Efficiency Irrigation Systems (HEIS). This is one of the primary reasons for the slow adoption rate as the farmers are not ready to shift from flood irrigation to HEIS techniques. Another challenge is that the costs of solar-powered pumping systems increase rapidly with an increase in pumping depth and discharge. For depths greater than 100 feet, the cost of solar tube wells increases significantly and becomes uneconomical. On the other hand, if water tables are shallow, SIPs provide a low operating cost alternative to marginal farmers struggling with slim profit margins due to high diesel fuel prices or excessive electricity load shedding.

The SDC-SoLAR project addresses some of the policy-relevant questions around SIPs through its research activities. Through the work on measuring groundwater extraction behaviour of SIP farmers, the project hopes to contribute to the ongoing discourse on threats to groundwater due to over-pumping linked to zero marginal cost of electricity. Through its pilot on providing options to farmers to sell electricity back to the grid (simulated through heat sinks), the project aims to provide a workable solution to the potential groundwater over-extraction problem. Finally, the project also hopes to demonstrate that a well-designed precision surface irrigation system can help farmers make efficient use of groundwater without having to invest in highly capital intensive high-efficiency irrigation systems (HEIS).

1. Introduction

Population growth, economic and technological development influence water use and demand for agricultural products in the Indus Basin Irrigation System (IBIS) in Pakistan. Urbanization has increased the domestic water demand; moreover, industrial water use has risen due to economic development, but agricultural water demand still dominates other sectors. Groundwater contributes a significant proportion of the total water supply to every sector in Pakistan.

In the past 33 years, the national water use of Pakistan has increased by 20 per cent from 153.4 billion cubic meters (BCM) in 1975 to 183.5 BCM in 2008 (FAO 2012). On the other hand, the population has increased by 156 per cent. Therefore, there is a growing divergence in demand (increasing population) and supply (water availability); thus, the water shortage has risen in the last three decades.

In 1960, the signing of the Indus Basin Water Treaty led to the construction of dams and irrigated agriculture expanded over 16 million hectares in Pakistan (Lytton et al., 2021). This expansion in the irrigation system led to seepage from the canal system, which resulted in the development of a shallow groundwater table, giving rise to waterlogging and salinity in many areas. To solve this problem, the government launched the Salinity Control and Reclamation Project (SCARP) scheme in the canal irrigated areas of Pakistan. Under this program, the government installed large-capacity tube wells to control the level of groundwater. During drought and surface water shortages of 1996-2001, the government gave subsidies to farmers for groundwater pumping, which led to an increase in groundwater abstraction.

During the 35 years from 1976 to 2012, groundwater contribution in agriculture increased many folds from 31.6 BCMs to 59.95 BCM (FODP, 2012). The development of large dams stopped since 1976, so the agricultural growth and intensification were driven mainly by tube wells rapid expansion. Across the country, there are approximately 1.3 million tube wells, of which 83% are diesel-powered; most of these tube wells are installed at shallow depths, between 12-18 meters. In the recent past, the growth of electricity tube wells has slowed down due to a rise in the electricity tariff and power outages. Though tube wells provided drought resilience and increased cultivated area, it has decreased groundwater table since 1989. It has caused an upward movement of saline water. Despite intense groundwater use, agricultural productivity remains low in Pakistan, i.e., wheat production is 1.08 kg/m^3 in Pakistani Punjab, compared to 1.42 kg/m^3 in Indian Punjab.

Although extensive groundwater use has protected against drought and addressed the problem of waterlogging and increased cropping intensity, over-abstraction of groundwater has led to the depletion of groundwater aquifer in some areas and salinity in others (Basharat and Tariq 2014). Especially the farmers at the tail end of the canals do not get sufficient canal water, so they have to rely solely on groundwater. The quality of groundwater is poor, which exacerbates the issue of salinity. s. Solar pumping technology has emerged as an alternative to diesel and electric pumps in the last few years. Still, water professionals in Pakistan are concerned that converting pumps to PV solar will result in indiscriminate pumping and eventually lead to further groundwater depletion.

Solar-powered irrigation systems provide a promising alternative to diesel-powered tube wells, but adopting this technology at scale has been fraught with many challenges in Pakistan. On the one hand, farmers cannot invest in solar due to high initial costs and the low discharge capacities of solar pumps compared to diesel-powered pumps. Secondly, more than 90% of the irrigation in Pakistan is carried out through flood irrigation and not with the piped flow of high-efficiency irrigation systems (HEIS). Despite efforts by provincial governments to promote solar through HEIS, most farmers are not prepared to shift from flood irrigation to HEIS techniques.

Replacing diesel pumps with solar irrigation pumps can significantly bring down CO_2 emissions. Current estimates state that diesel-powered tube wells contribute almost 5.025 million metric tons of CO_2 emissions annually (FAO, 2019). Punjab is promoting solar technology by providing a 60% subsidy on installing a HEIS system and an 80% subsidy for a solar system if coupled with HEIS. However, this program requires farmers to use solar pumps only with HEIS, and this combination may not be appropriate for certain existing cropping patterns. The government of Khyber Pakhtunkhwa has also initiated projects through their Directorate of Agricultural Engineering to provide a 50% subsidy on SIPs to be used in rain-fed and water-scarce areas. The Sindh government has launched several schemes to install solar-powered tube wells and pumping stations to strengthen the province’s agriculture sector. To date, PKR 802 million has been earmarked for providing SIPs and tube wells at subsidized rates to farmers, but the success of this program is yet unknown. Finally, in Baluchistan, the only Province where tube wells are connected to the grid, these pumps consume 900 MW of power annually. They are depleting the water table rapidly due to prolonged drought conditions and excessive groundwater pumping. The Baluchistan government is providing PKR 23 billion in electricity subsidies to farmers using grid-connected tube wells. In 2017, the federal government and Baluchistan agreed to replace 30,000 grid-connected tube wells with SIPs to decrease the burden on the provincial government. But, to date, this project has not materialized.

Pakistan's private sector has played a vital role in promoting SIPs. Until recently, there were very few subsidy programs for SIPs wherein only large-scale farmers could afford to invest in SIPs, which were again provided by the private sector. The majority of farmers who adopted SIPs were large-scale farmers who used their funds. Given the large landholdings of these farmers (> 10 ha) and deepwater tables (> 25 meters in places where SIPs have been installed, the farmers have purchased large-sized SIPs greater than 5 HP. These systems cost between USD 9,000-20,000, but prices have been falling rapidly in recent years.

This situation analysis of SIPs in Pakistan is divided into six sections. After the introduction (Section 1), in section 2, the national outlook of groundwater use is described by looking at the depth of groundwater, seasonal fluctuations, and the variability in groundwater quality in the Indus Basin. In section 3, policies and legislation related to SIP are mentioned at the provincial and federal levels. In section 4, public and private stakeholders are highlighted. In section 5, opportunities and challenges related to SIPs are discussed. The report ends with a conclusion in section 6.

2. National Outlook of Groundwater Use

Pakistan has one of the largest contiguous irrigation systems globally, irrigating about 17 million ha (Mha). Agriculture consumes more than 93% of water in Pakistan whereas, the water use efficiency is very low and ranges around 40% (PCRWR, 2020). The country is dependent on groundwater as the predominant water source, where groundwater provides over 60% of water for agriculture, more than 90% of water for domestic and almost 100% water for industrial sectors (PCRWR, 2020). Groundwater has played a significant role in increasing the overall cropping intensity in Pakistan from about 63% in 1947 to 150% in 2015 (Khan et al., 2016).

Figure 1 shows about 0.71 million tube wells in the country in 2001-02, which increased to 1.32 million in 2013-14, at an average annual growth rate of about 4.9%.

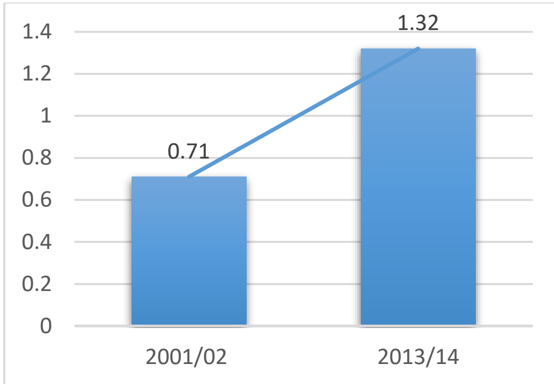

Figure 1: Number of tubewells in Pakistan (millions) and average annual growth in number of tube wells

As for share by Province, figure 2 shows, Punjab accounts for 78% of the total tube wells installed in the country during 2013-14, followed by Sindh (17.5%), Baluchistan (3.2%) and Khyber Pakhtunkhwa (1.2%) (Pakistan Bureau of Statistics, 2015).

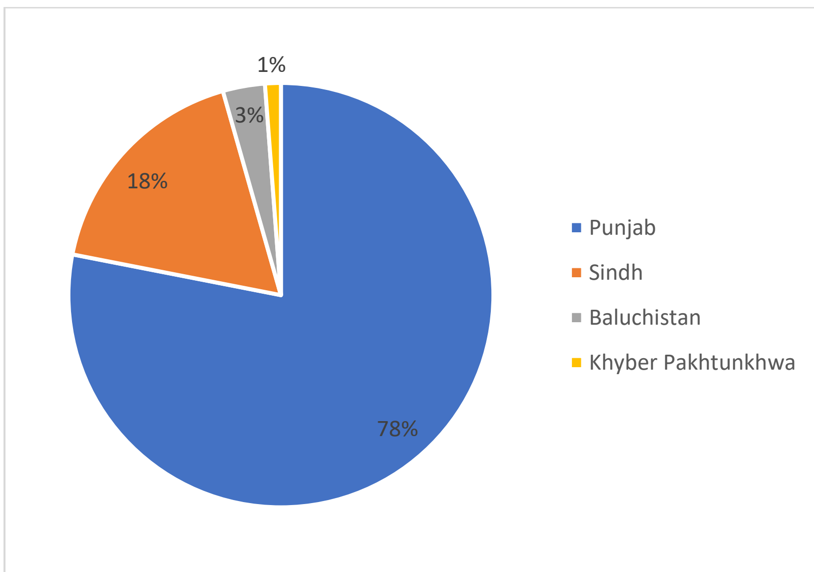

Figure 2: The percentage share of tube wells, by Province (2013/14)

Across Pakistan, 20% of the total area is irrigated by tube wells, and 44% is irrigated by a combination of canals and tube wells. Even though Punjab has the largest agricultural land, it is Baluchistan which has the highest percentage (38%) of land irrigated by tube wells, followed by Sindh at 21%, Punjab at 20% and Khyber Pakhtunkhwa at 12% (figure 3) (Pakistan Bureau of Statistics, 2014).

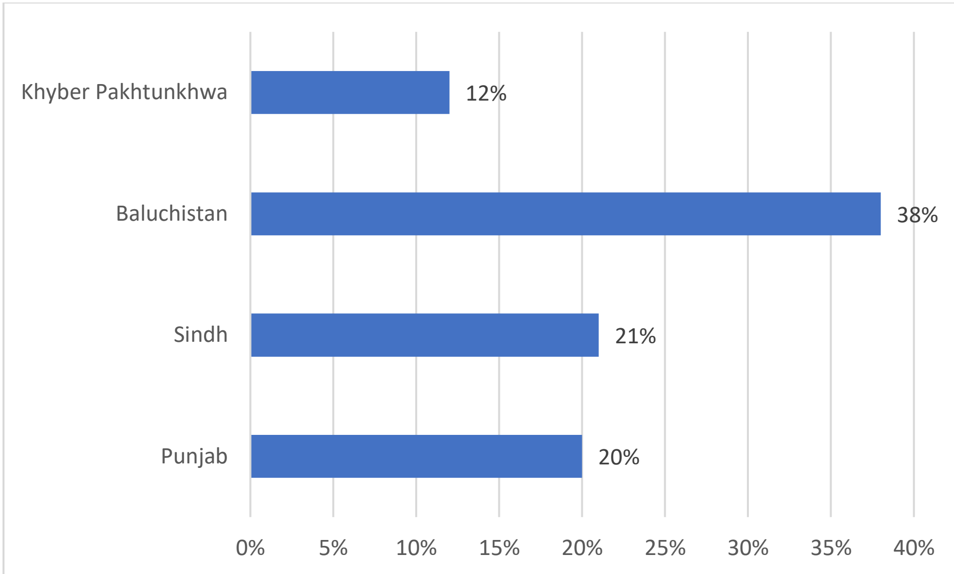

Figure 3: Agricultural Land Irrigated by Tube wells (%)

Over the last three decades or so, a spectacular increase in the number of private tube wells in the country has had many adverse policy and environmental implications. In many areas, high water tables used to be a significant threat till the 1980s. However, with a steep increase in the development of private tube wells, water levels have now declined. About 2.5 million farmers who depend on tube well for irrigation extract groundwater through privately owned tube wells or buy water from their neighbours (Pakistan Bureau of Statistics, 2014). The pace at which the groundwater exploitation has unfolded has added complexity to its management. Their behavioural pattern concerning groundwater use is highly dynamic. Farmers understand little about any adverse interaction, which is likely to result from the unsystematic and erratic nature of groundwater pumping. Their major interest is to pump more water to meet the rising crop water requirements.

2.1 Depth and fluctuations of groundwater levels

According to International Waterlogging and Salinity Research Institute (IWASRI), the area, which falls under Depth to Water (DTW) ≤1.5m, is classified as waterlogged. In contrast, DTW of 1.6-3.0m is termed as likely to be waterlogged (Basharat et al., 2014). Based on IWASRI Classification (as shown in figure 6), the groundwater depletion issue mainly exists in Lower Bari, followed by some parts of Rechna doab in Punjab. Particularly, the areas of Lodhran, Multan, Khanewal, Vehari, Pakpattan districts show high groundwater depletion, whereas the regions of Sahiwal, Chiniot, Toba Tek Singh and Lahore districts are partially depleted (Khan et al., 2016). According to Khan et al. (2016), the groundwater salinity increases with depth in the four doabs (Thal, Chaz, Rachna, Bari). However, the spatial pattern remains the same. The extensive groundwater pumping in Punjab province has helped address the menace of waterlogging and salinity (Figures 4 and 5), but at the same time, overexploitation has resulted in depletion in many parts of the Upper Indus Plain (UIP).

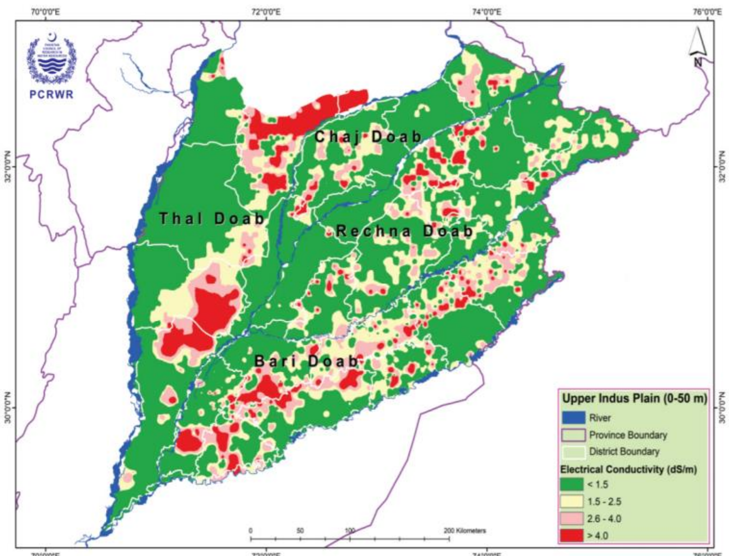

Figure 4: Groundwater quality from 0-50 m depth in the Upper Indus Plain

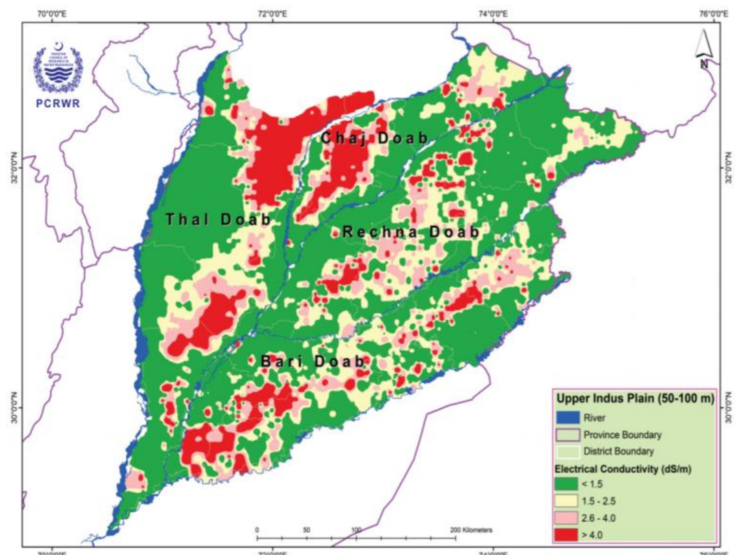

Figure 5: Groundwater quality from 50-100 m depth in the Upper Indus Plain

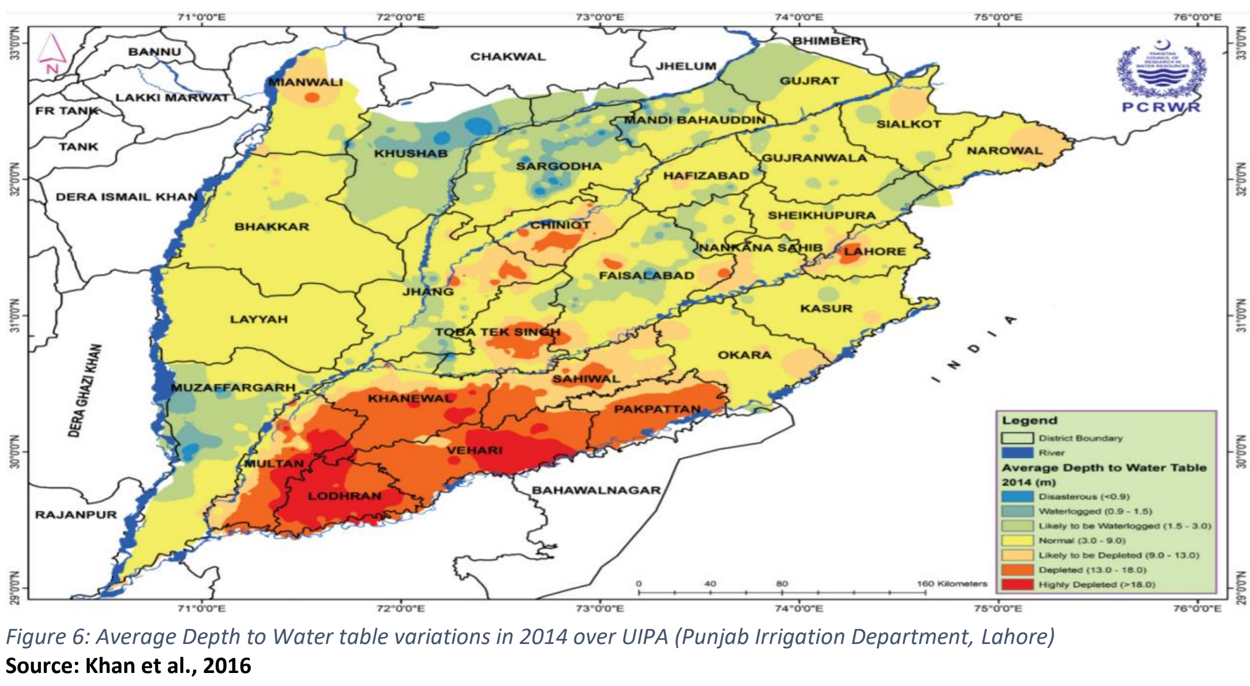

Figure 6: Average Depth to Water table variations in 2014 over UIPA (Punjab Irrigation Department, Lahore)
Source: Khan et al., 2016

In 2013, about 98% of the Lower Indus Plain (Figure 7) had an average annual depth to the water table that ranged from 0.2 to 3.0m. Out of which, an area of about 51.3% falls under waterlogging conditions having DTW less than or equal to 1.5m. The deepwater table (>3 m) was only in some of the Rohri and

Nara canal regions, where fresh groundwater was pumped for agriculture. The waterlogging is visible in the Indus Deltaic region of Sindh, where the River Indus joins the Arabian Sea (Iqbal et al., 2020).

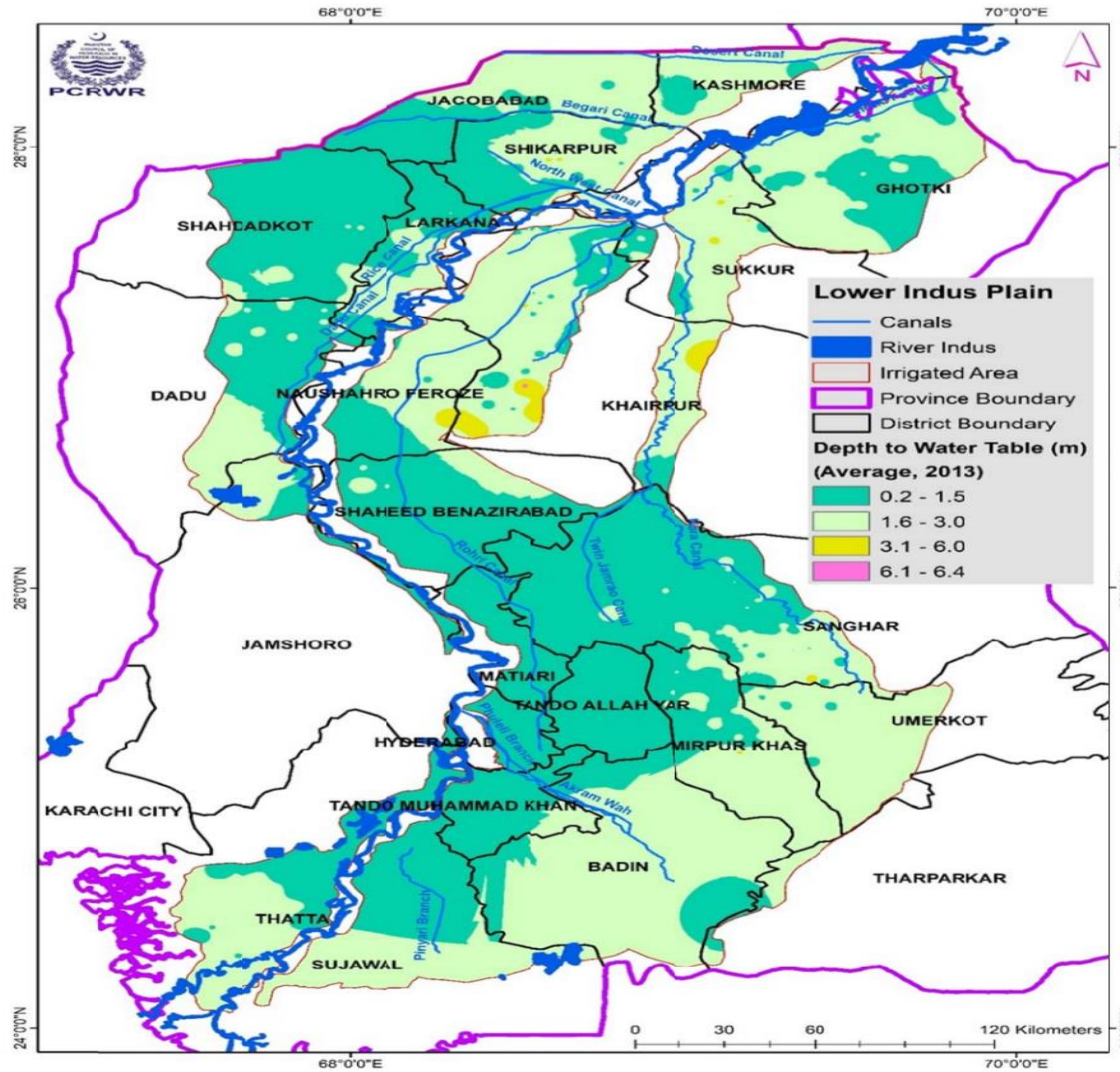

Figure 7: Spatial variations in depth to the water table in Canal Command Area of Sindh in 2013
Source: Iqbal et al., 2020

Pakistan Council of Research in Water Resources used NASA GRACE Satellite data to produce maps of monthly groundwater changes in the Indus River Basin. In figures 8 to 10, Orange and yellow indicate areas where groundwater might be depleted, while blue and green highlight areas where groundwater is replenished.

Figures 8 and 9 show the monthly Groundwater Storage (GWS) variations over Upper Indus Plains during February and March 2017, whereas the GWS variations in April 2017 is shown in Fig. 10. According to

PCRWR (2017), monthly GWS analysis indicates that groundwater storage seemed to have a linearly decreasing trend from February to April 2017. On the other hand, groundwater storages computed from the change in groundwater levels were at their peak in October 2016 (57.8 km^3). This decrease in storage is attributed to the low rainfall (post-monsoon) plus pumping effect during the lean season of surface water availability. From February to April 2017, it was observed that the groundwater storage has decreased with an average rate of 0.37 km^3/per month with a total loss of about 1.1 (km^3). A significant change in groundwater storage has been noticed in the areas of lower Bari, Rechna, Chaj and Thal doabs (i.e., high cropping intensity hugely dependent on conjunctive water use).

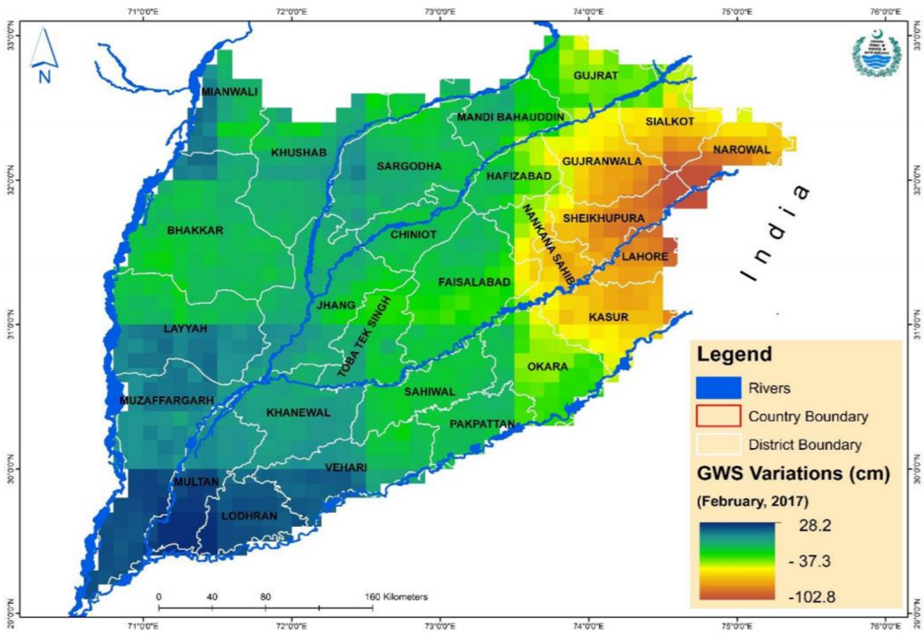

Figure 8: Monthly GWS variations over Upper Indus Plain during February, 2017

Source: http://www.pcrwr.gov.pk/

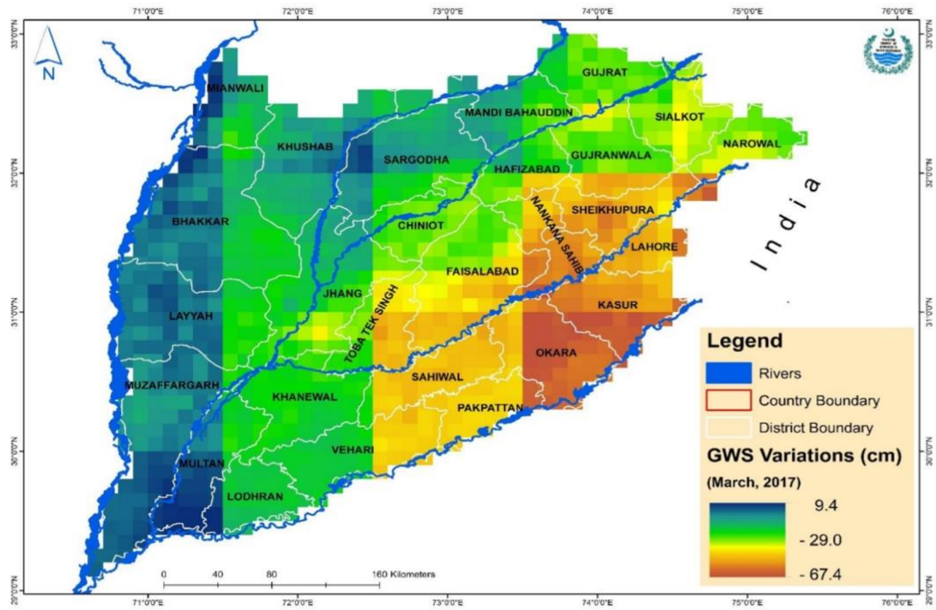

Figure 9: Monthly GWS variations over Upper Indus Plain during March, 2017
Source: http://www.pcrwr.gov.pk/

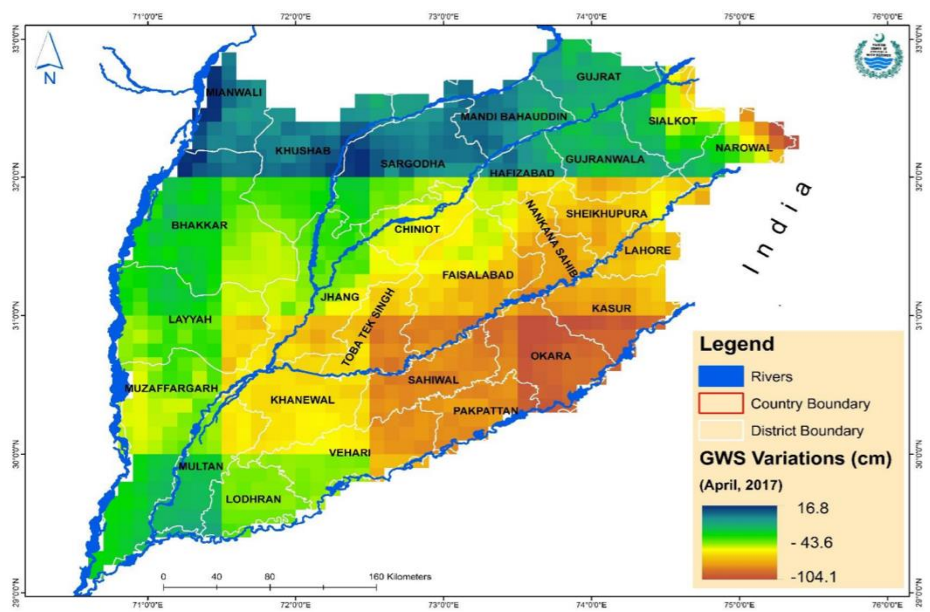

Figure 10: Monthly GWS variations over Upper Indus Plain during April 2017
Source: http://www.pcrwr.gov.pk/

According to PCRWR (2017) monthly GWS analysis, as shown in figure 11 below, the resultant changes in groundwater storage over Upper Indus Plain from February, March and April 2017 are approximately estimated as -9.1 km^3, - 26.2 km^3 and -31.3 km^3, respectively.

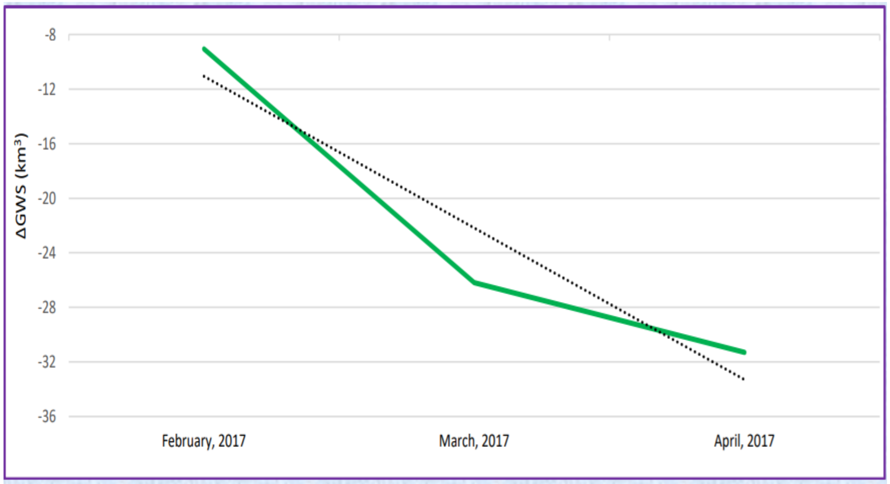

Figure 11: Mean Monthly GWS variations over Upper Indus Plain from February-April, 2017
Source: http://www.pcrwr.gov.pk/

The seasonal variations in Depth to Water (DTW) before and after the monsoon periods are very significant in the Lower Indus Plain (LIP) (Basharat et al., 2014). Due to the reduction in canal flows during the Rabi season, the additional irrigation requirements are met through groundwater abstraction, resultantly, an increase in depth to the water table. During the pre-monsoon period in 2015, the GIS mapping (Figure 12) suggests that the area covered by DTW >1.5 m has increased from 39% (post-monsoon, 2014) to 89% (pre-monsoon, 2015).

Whereas figure 13 shows, the area under DTW from 1.5-3.0 m has increased up to 72%, which was 32% in post-monsoon, 2014. This increase in area coverage is augmented by reducing recharge due to decreased canal flows in the Rabi season coupled with groundwater pumping to meet additional irrigation requirements. However, in certain areas, the depth to the water table has increased up to 16m due to groundwater pumping. These are the pockets of fresh groundwater availability in the districts of Larkana, Naushero Feroz, Shaheed Benazirabad, Matiari and Tando Allah Yar (Iqbal et al., 2020).

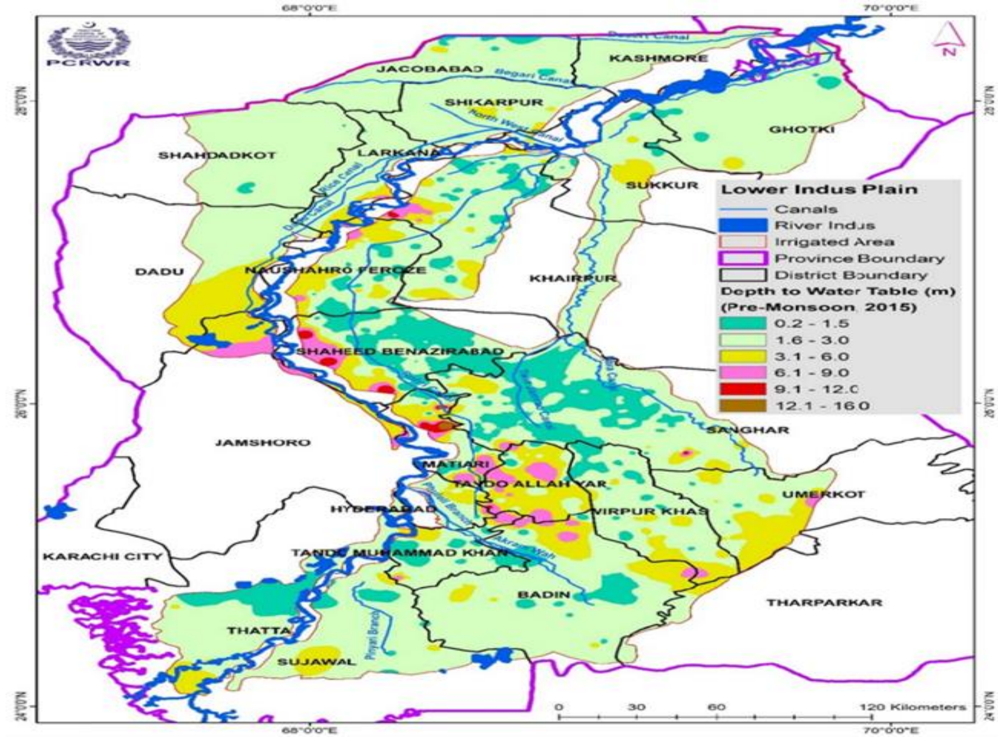

Figure 12: Spatial variations in depth to water table in Canal Command Area of Sindh in 2014 (pre-monsoon)
Source: Pcrwr.gov.pk. 2020.

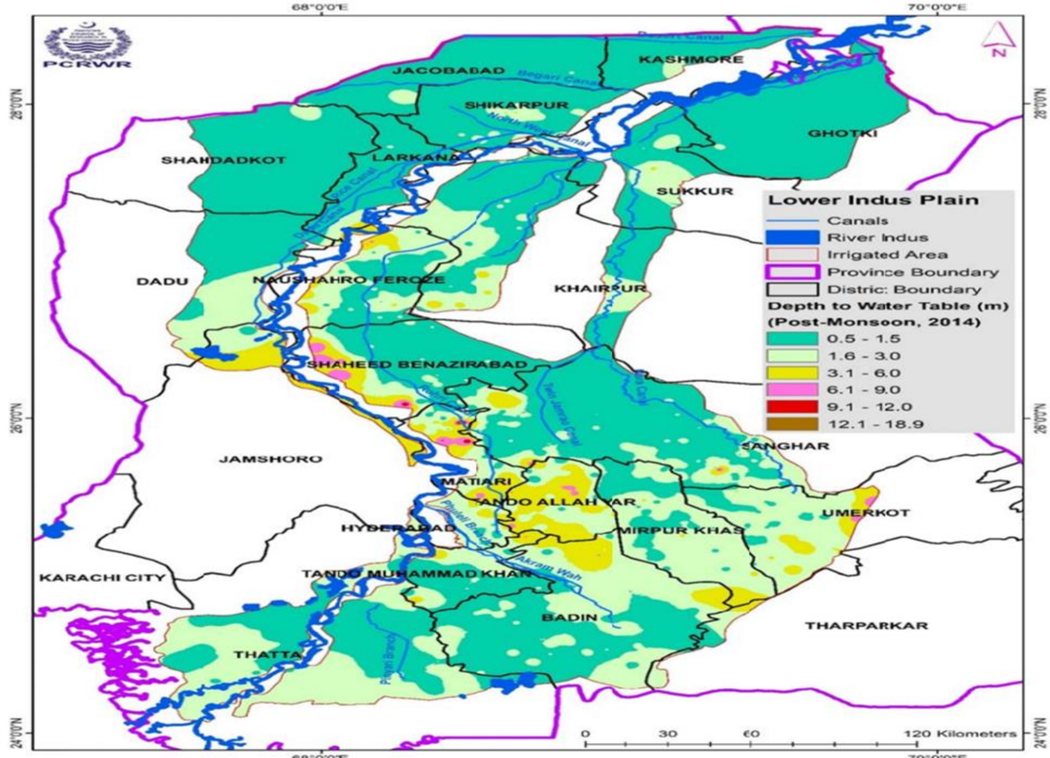

Figure 13: Spatial variations in depth to the water table in Canal Command Area of Sindh in 2014 (post-monsoon)
Source: Pcrwr.gov.pk. 2020.

In areas of Baluchistan, there is a decline in the groundwater table; this is attributed to extensive groundwater abstraction and inefficient use of the pumped water. The excessive groundwater abstraction has lowered the water table by up to 5m per annum in some valleys, causing groundwater mining, especially in Quetta, Pishin, Mastung and Mangochar (Table 1). This results from irrational and highly inefficient water use for irrigation where water losses are immense (Ashraf and Sheikh, 2017).

Sub-Basin	Period	Average Decline in Water Level (m)
North Quetta	1969 - 1989	4.58
	1989 - 1996	4.27
	1997 - 2000	4.39
South Quetta	1967 - 1988	2.44
	1988 - 1996	1.83
	1997 - 2000	2.44
Pishin	1976 - 1989	3.97
	1989 - 1996	6.4
	1997 - 2000	6.71
Mastung	1976 - 1989	6.4
	1989 - 1996	2.78
	1997 - 2000	4.27
Mangochar	1976 - 1990	15.25
	1990 - 1996	28.89
	1997 - 2000	6.1

Table 1: Groundwater decline in areas of Baluchistan
Source: Ashraf and Sheikh (2017)

2.2 Quality of Groundwater

The groundwater quality is divided into four water quality zones: freshwater (4.0 dS/m) from 0 to 300m depth at an interval of 50m depth. The groundwater quality maps were verified from USGS maps (work done in the 1950s by WAPDA) and Drainage Atlas of IWASRI/WAPDA.

Figure 14 shows that in Thal doab, the upper 50m layers are mainly underlain by groundwater's fresh quality, except for some parts of the Khushab, Layyah and Muzaffargarh districts. Most of the areas of Mianwali, Bhakkar, Jhang, Layyah and Muzaffargarh districts are under fresh groundwater quality. The area under the Thar desert is underlain by the fresh quality of groundwater that has not been exploited so far. This area has a great potential to enhance agricultural productivity and the 'country's future food security (Khan et al., 2016).

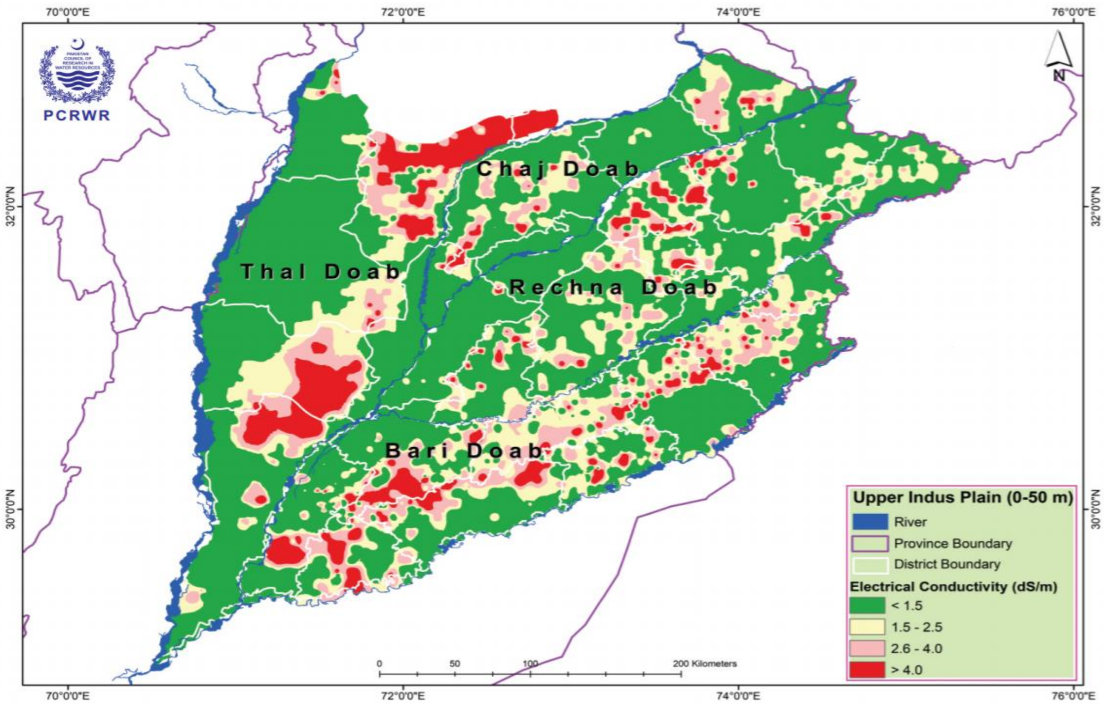

Figure 14: Groundwater quality from 0-50 m depth in the Upper Indus Plain
Source: Khan et al., 2016

In Lower Indus Plain, the extent of groundwater salinity further increases and intensifies below Hyderabad towards the Indus Delta due to sea-water intrusion and the prevalence of more fine strata (loam and clay). The groundwater of usable quality is found in shallow pockets in parts of Kashmore, Shikarpur, Ghotki, Sukkur, Khairpur, Naushero Feroz and Shaheed Benazirabad. The extent and intensity of hydro-salinity further increase with depth (Figures 15 and 16) (Iqbal et al., 2020).

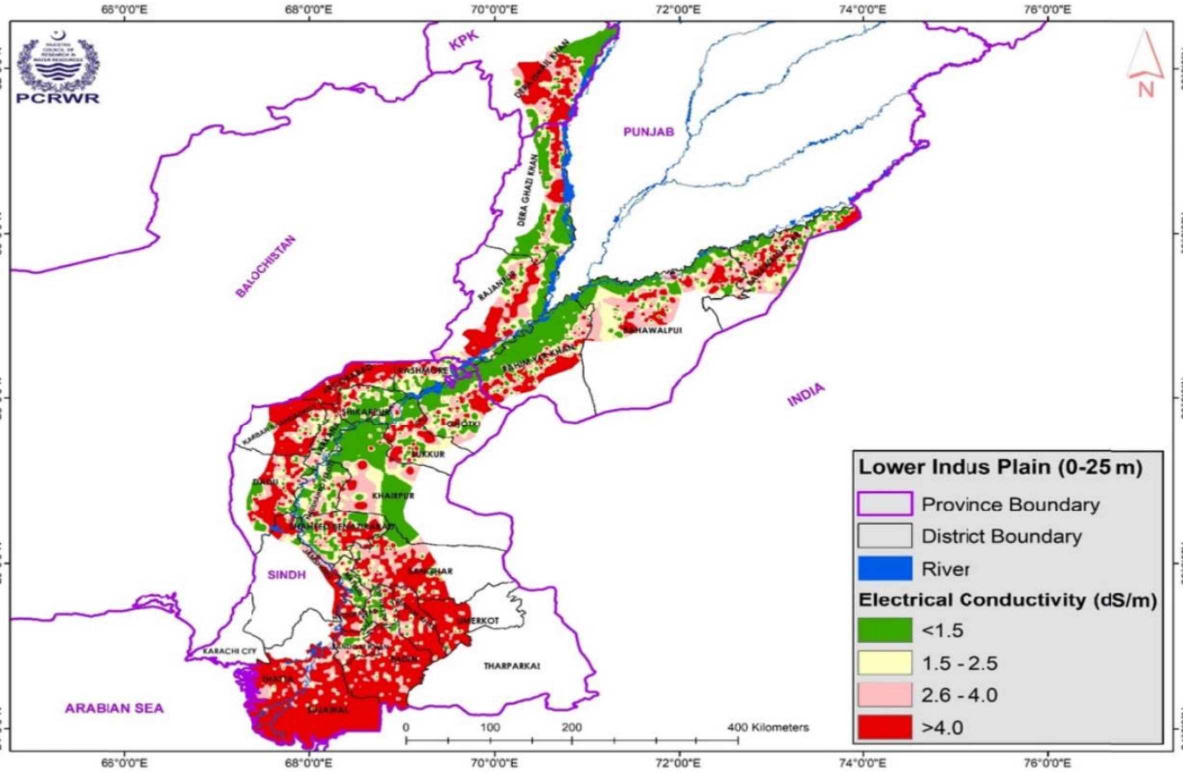

Figure 15: Groundwater Quality at 0-25 m; Lower Indus Plain
Source: Iqbal et al., 2020

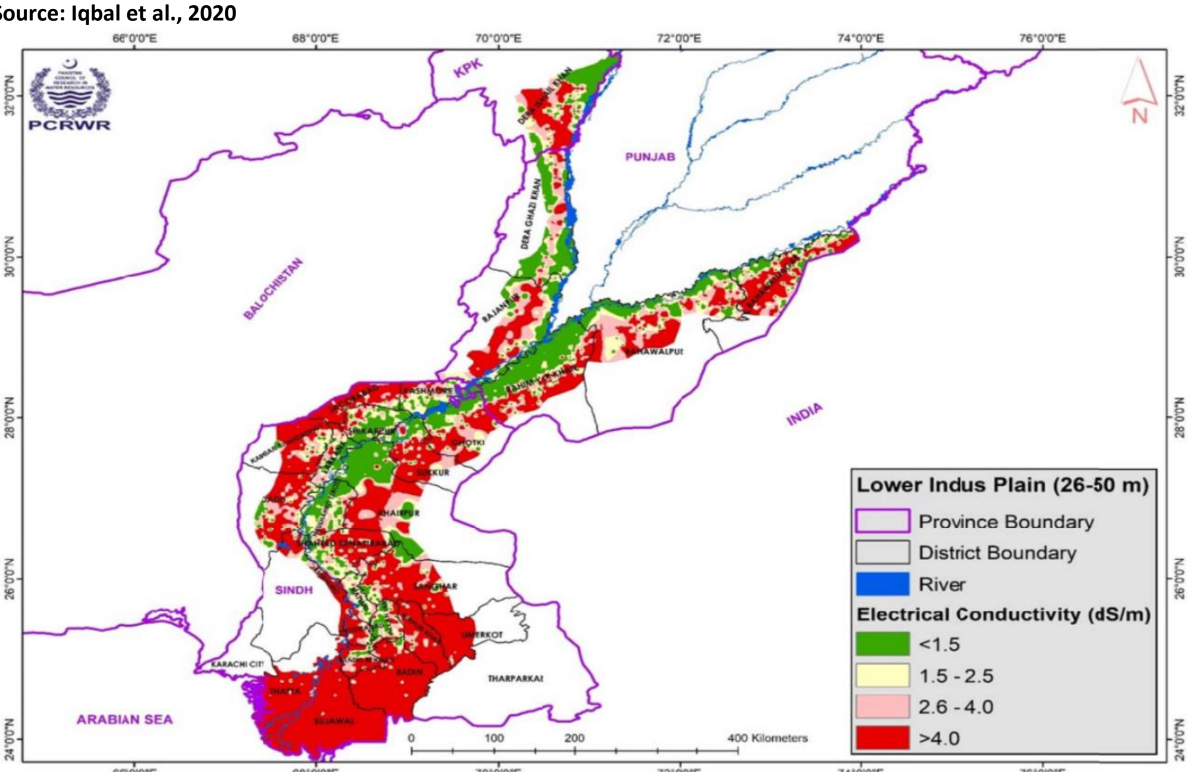

Figure 16: Groundwater Quality at 26-50 m; Lower Indus Plain
Source: Iqbal et al., 2020

2.3 Groundwater Pumps: Electric and Diesel

Pakistan has one of the 'world's largest groundwater aquifers (4th after China, India and the USA). Figure 17 below shows the spread of groundwater irrigation in Pakistan. The tube well numbers increased from less than 200,000 in 1980 to 1.1 million in 2015 (Verma et al., 2018). This is mainly due to increased cropping intensity which rose from 67% to around 150% during a similar time period (WB, 2019). There has been no embargo from the government to install agricultural tubewells, and farmers have utilized this provision to cultivate as much area as was possible.

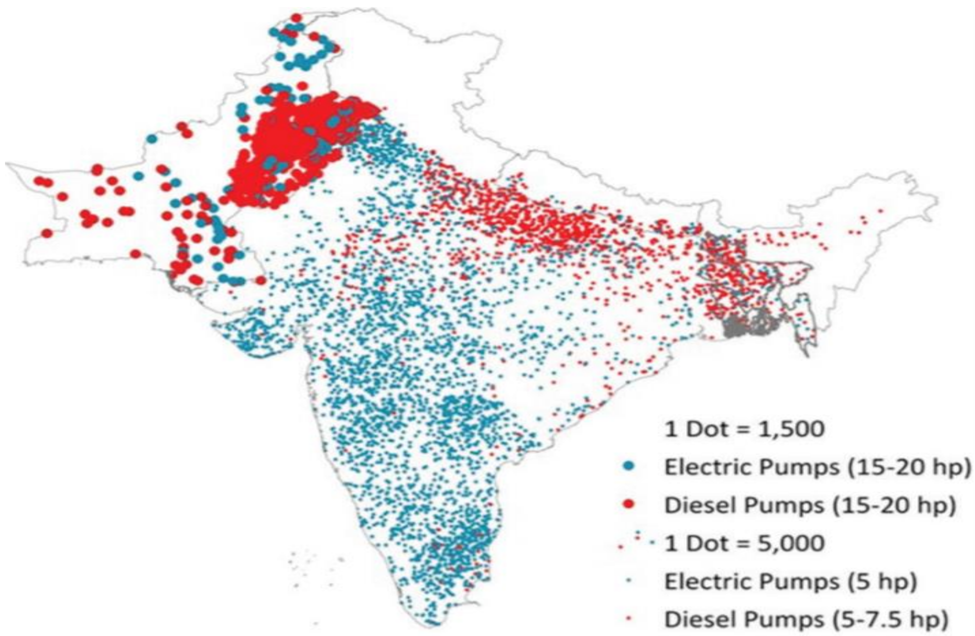

Figure 17: The spread of groundwater irrigation in Pakistan
Source: https://www.researchgate.net/figure/The-spread-of-groundwater-irrigation-in-South-Asia_fig1_331907288

Figure 18 shows that the number of tube wells has increased from 0.2 million to over 1.2 million over the last two and a half decades (Qureshi & Ashraf, 2019).

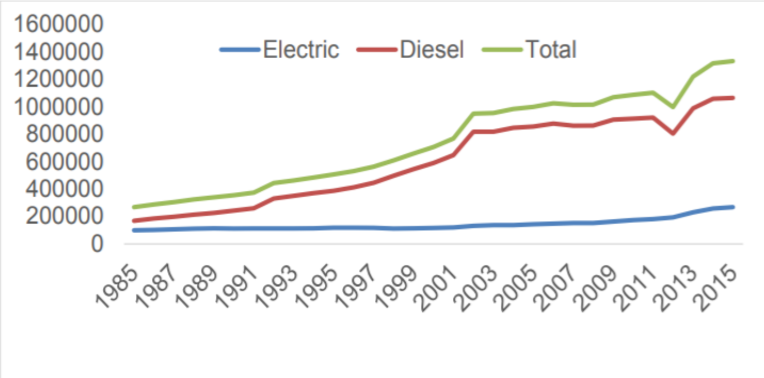

Figure 18: Growth of tube wells in Pakistan

Source: GoP, 2016-17

Diesel pumps are mostly installed at shallow depths that range from 20 – 40 feet. The average farm size where diesel-powered tube wells are installed is less than 12.5 acres and constitute almost 85% of the total. Current estimates state that diesel-powered tube wells contribute nearly 5.025 million metric tons of CO_2 emissions annually (FAO, 2019). Solar-powered irrigation systems provide a promising alternative to diesel-powered tube wells, but their adoption at scale has faced many problems in Pakistan.

Punjab will be the main focus of the SoLAR project in Pakistan. Some preliminary details of the pre-survey conducted with SIP farmers in Punjab are given in section 6. In addition to this, Punjab is also the most populated Province of Pakistan, so it will be worthwhile to look into the spread of diesel and electric pump tube wells across the province. 87% of the total tubewells are diesel-powered, whereas the rest of 13% are electrically powered (Agricultural Department, Punjab, 2014).

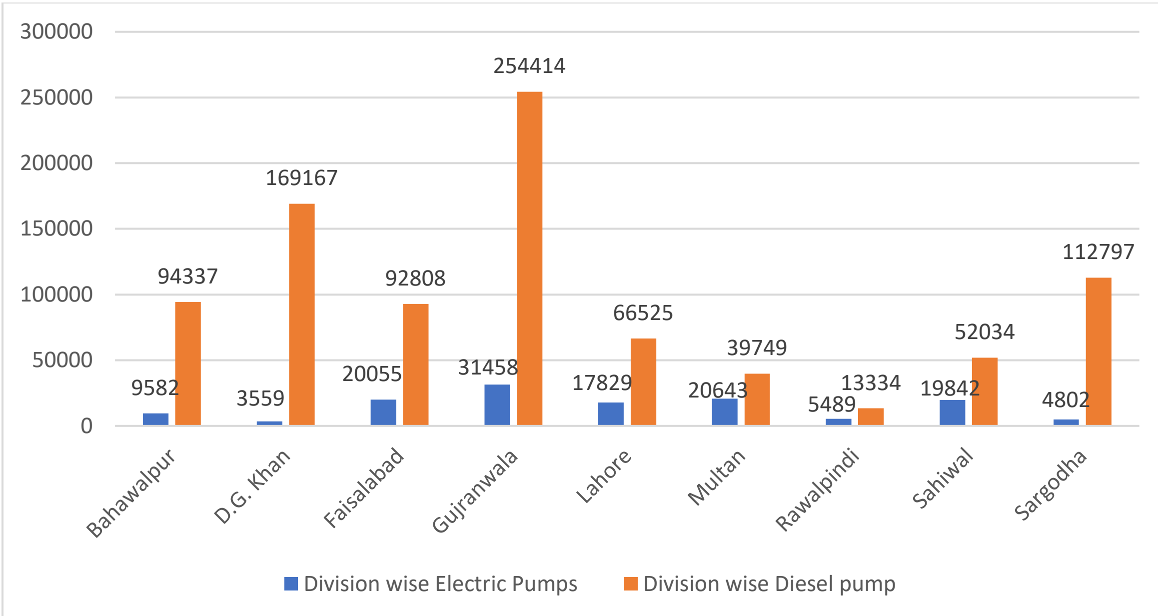

Figure 19: Division-wise Electric/ Diesel Pump Tube-wells in Punjab
Source: http://crs.agripunjab.gov.pk/system/files/Tubewell%202013-14.pdf

In Punjab, the highest number of diesel and electric pump tubewells are in the Gujranwala division. On the other hand, the lowest number of diesel pump tubewells are in the Rawalpindi division and Sargodha division, respectively (Figure 19). The historical trend of tube wells growth in Sindh shows a significant increase during 1998-1999 and 2012-2013 (Figure 20). This results from the prevalence of drought events and an increase in cropping intensity (Iqbal et al., 2020).

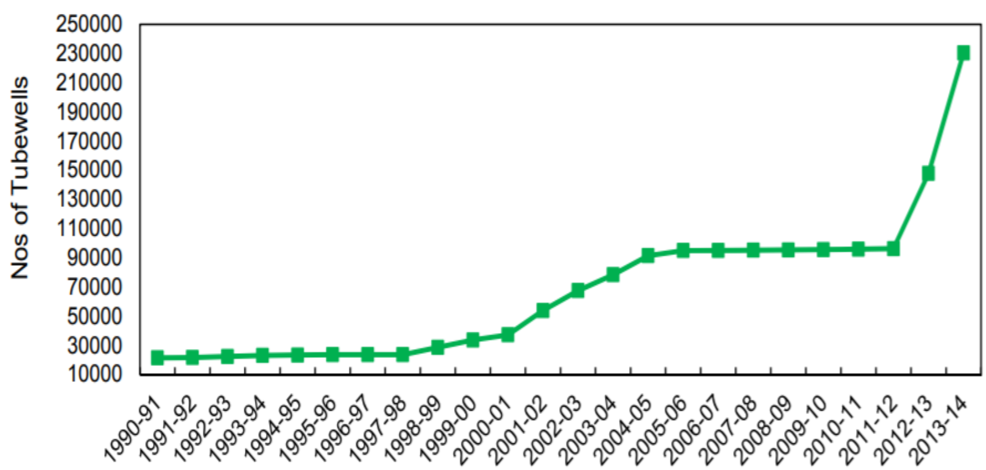

Figure 20:Temporal trend in tubewells growth from 1990-2014 in Sindh

Source: GOP (2018)

The number of tubewells was about 5,000 in 1980 in Baluchistan and has increased to over 40,000 by 2015 (Figure 21). In addition to this, the area under fruit cultivation increased from 660 km^2 in 1992-93 to 2,310 km^2 in 2012-13 (MNFSR, 2014). Hence, the water requirement for raising orchards increased to 1.920 BCM, and most of it comes from groundwater (Ashraf and Sheikh, 2017). Improved communication network and introduction of electricity with subsidized flat rates in Baluchistan after the 1980s has resulted in a tremendous increase in the drilling of tube wells. All these developments have also affected the sustainability of groundwater resources. Despite the importance of groundwater in Baluchistan, no proper groundwater monitoring system exists to regulate its utilization.

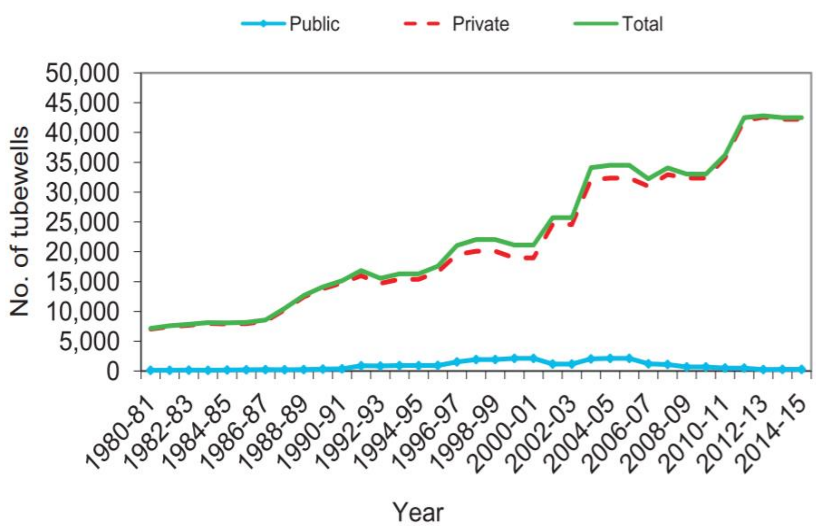

Figure 21:Increasing trend of tubewells in Baluchistan

Source: PCRWR (2016)

Figure 22 shows the historical trend of tube wells growth in Khyber Pakhtunkhwa. It offers a slight increase during the period 2001-02 and 2013-14 (Pakistan Bureau of Statistics, 2015)

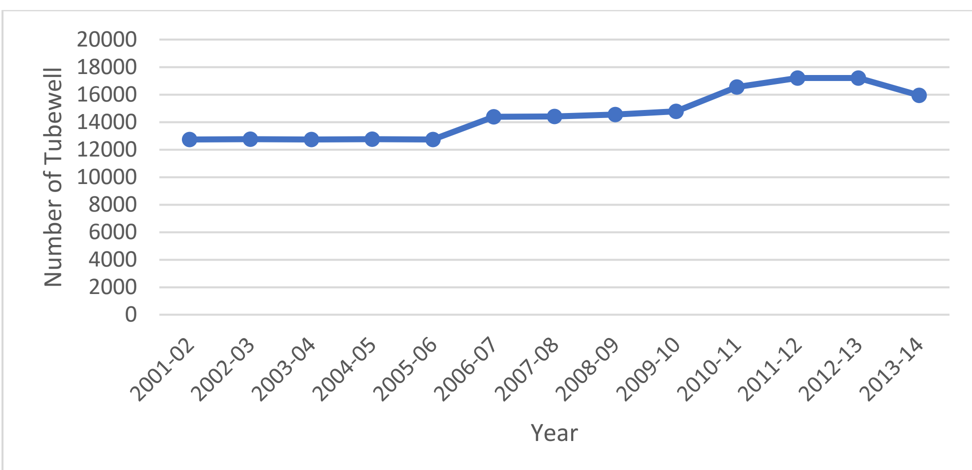

Figure 22:Slight increase in the number of tube wells in Khyber Pakhtunkhwa

Source: Pakistan Bureau of Statistics. (2015)

2.4 Groundwater governance in Pakistan

In the 1980s, high groundwater table led to problems of soil salinization. This problem was addressed through energy subsidies and the import of Chinese-made pumps that promoted groundwater abstraction. Later with time, farmers started to observe a decline in quantity and quality of groundwater, especially in areas located in the tail end of canal command areas. Mostly in river basins, farmers preferred to use surface water due to quality and cost associated. With time as farmland for water-thirsty crops like sugarcane and rice increased, the shortfall between supply and water demand increased. Consequently, groundwater abstraction kept on growing.

Groundwater rights ordinance was introduced in 1978, and a permit system was launched in 1980. Still, direct management of a large number of tube wells proved to be difficult due to an immense number of groundwater users spread over a huge area (Qureshi, 2020). The government also tried to control groundwater extraction through electricity prices by moving from a flat tariff system to an actual billing system and then to a combined flat and billing system. This failed to affect groundwater abstraction as only 15% of total tube wells are powered by electricity (Zoumides & Zachariadis, 2009). Many farmers shifted from using electric pumps to diesel pumps (Qureshi, 2020).

In 1997, the government of Pakistan established Provincial Irrigation and Drainage Authorities (PIDA). PIDA aimed to empower farmers, improve efficiency and sustainability in agriculture. Along with the establishment of PIDA, PIDA Acts were enacted to define groundwater extraction rights, empower Water User Association (WUAs), advocate demarcation of critical groundwater zones, licenses for tube well installation in water distressed areas, and regular monitoring of pumping for all tube wells (Qureshi, 2020). Water User Association (WUAs) were empowered to monitor groundwater in canal command areas.

In addition to this, the provincial governments were made responsible for evaluating the conditions of aquifers and ensuring their sustainable management. Limited institutional capacity impeded the effectiveness of the bodies mentioned above and legislation. Governments allowed farmers to extract groundwater unchecked to ensure food security. Meanwhile, institutional capacity did not improve.

3. Policies and legislations related to use of solar technology in agriculture

Pakistan does not have a specific policy on solar technology for groundwater pumping in agriculture. However, Pakistan does have several policies that have a bearing on the same. The National Water Policy makes some references to groundwater pumping. Water use efficiency, conservation, and renewable energy are among the strategic priorities and planning principles embedded in the National Water Policy. According to the Annual Plan (2020/21), the Pakistan Council for Renewable Energy Technologies (PCRET) will promote low-cost and sustainable energy solutions with renewable resources. Moreover, a Testing Facility is planned to be established for Solar & Allied Equipment with the collaboration of Korea to ensure quality standards in renewable energy products available in the market.

There is also the Policy for Development of Renewable Energy for Power Generation. Given that Pakistan is a federation of four provinces and three administrative units (Gilgit-Baltistan, Azad Jammu and Kashmir, Islamabad Capital Territories), much of the governance and management of water resources devolved are to provinces, wherein each province has embarked on different trajectories to deliver on the National Water Policy. For example, the Province of Khyber Pakhtunkhwa is developing an integrated water resources management plan. In the Agricultural Policy of Khyber Pakhtunkhwa (2015-2025), the importance of adopting alternative energy sources such as solar energy for utilizing at the farm level to improve 'farmers' access to irrigation water has been mentioned. On the other hand, Punjab has passed a Water Act (2019), which explicitly mentions, *"An Act to comprehensively manage and regulate water resources in Punjab in the interest of conservation and sustainability*". Baluchistan, which has the Baluchistan Ground Water Rights Administration Ordinance 1978, is looking to update this Ordinance.

3.1 National Water Policy

The main objective of this policy is given as under:

Lay down a broad policy framework and set of principles for water security. The Provincial Governments can formulate their respective Master Plans and projects for water conservation, water development, and water management (GOP, 2018).

The objectives of this national policy in terms of groundwater aim to regulate groundwater withdrawals for curbing over-abstraction and promote aquifer recharge. It also aims to develop hydropower to increase the share of renewable energy. National water policy sets its strategic priorities for renewable energy by recognizing the importance of the large, medium, and small dams generating energy and storing water for agriculture and domestic purposes. It also highlights that with appropriate policies and subsidies, additional water at a lower cost can be provided in areas with shallow groundwater by converting a large number of tube wells into solar energy.

3.2 Schemes to promote SIPs

The Government of Pakistan has introduced various schemes at the federal and provincial levels to promote the use of SIPs to bring down carbon emissions and reduce the oil import bill. A majority of these schemes have been initiated in the last five years. An overview of these schemes is presented in the following sub-sections.

At the federal level, an interest-free Solar Tube well Financing Scheme was announced in 2015 but not actualized mainly due to a lack of evidence on the impact of SIPs on the sustainability of the groundwater aquifer. The Government of Pakistan has recently commissioned consultants to prove the effects of SIPs on groundwater sustainability. Under the scheme, the federal government would concur to cover mark-up costs on behalf of farmers. The interest-free loan scheme for small farmers (having landholding of up to 12.5 acres) for the installation of 30,000 solar-powered tube wells over a period of three years. Modalities of the scheme were finalized by the Ministry of National Food Security and Research, the State Bank of Pakistan, and the Ministry of Finance. To simplify the lending process for agriculture financing, the banks also introduced a revised loan application as per directions of the State Bank of Pakistan, which is the regulator of Banks in Pakistan. Once finalized, the scheme will be implemented nationwide.

At the provincial level, there are several development investments in solar technology for groundwater pumping in agriculture.

The largest investment is in the Punjab Irrigated Agriculture Productivity Improvement Project (PIAPIP), which stimulates a High-Efficiency Irrigation System (HEIS) coupled with SIP through capital cost subsidies. The Agriculture Department of Punjab province sponsors this project through the World Bank (OFWM, 2020). Departments responsible for executing this project are the Punjab Irrigation Department, divisional and deputy directors of On-Farm Water Management, supply and service companies, project implementation supervision consultants, and participating farmers/water user associations. One of the 'project's main aims is to install High-Efficiency Irrigation System (HEIS) coupled with solar irrigation pumps on 120,000 acres by 2021. This project defined HEIS as a drip and/or sprinkler irrigation system. By 2016/17, installation of HEIS has been completed on 20,000 acres. The primary incentive to farmers considering this conversion was a 60% subsidy on total system cost for installation of HEIS. The responsibility of installing HEIS is to supply and service companies (SSCs) pre-qualified by the Agriculture Department. The same SSCs are responsible for carrying out surveys, preparing designs and cost estimates, installing HEIS, and providing post-installation backup support services. The district/ tehsil OFWM staff mobilizes the farmers to adopt HEIS as the first step in the implementation activities of HEIS. Then interested farmers have to submit their application for HEIS installation to the Deputy Director or Director Agriculture (OFWM) at any time of the year. After scrutinizing the application, eligible applicants are advised to approach pre-qualified SSC of their own choice for a survey, design, and cost estimation of the selected system. Then the selected SSC has to submit the report on the on-site survey, after approval from Deputy Director Agriculture (OFWM), accepting an offer from the farmer and providing proof of submission of the 40% total cost. Under this program, district- wise spread of SIPs across Punjab is shown in figure 23. The highest number of SIPs are installed in the Rawalpindi division, and the least number of SIPs installed are in the Bahawalpur division.

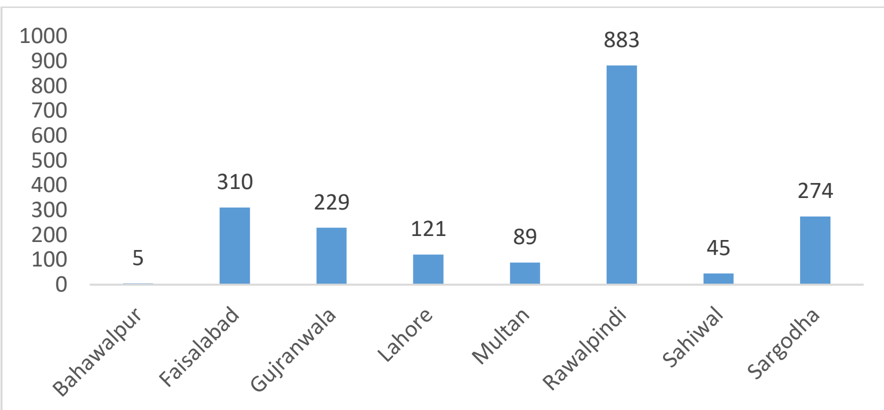

Figure 23:District-wise SIPs in Punjab
Source: Pakistan Agricultural Research Council (PARC)

Agency for Barani Areas Development (ABAD) has launched a project titled Promotion of Alternate Energy for Command Area development of Mini dams/Ponds in the Potohar region of Punjab province, covering Rawalpindi, Attock, Chakwal & Jhelum (OFWM, 2018). The s objectives included utilizing the available water resources for profitable agriculture (high-value crops) and maximizing the benefits of farmers by reducing the operational cost of pumping water through the provision of alternative sources of energy in a sustainable manner. The government has approved a program for installing 200 solar pumps in the Potohar region in 2016. Out of these, a total of 83 solar pumps have been installed by a government institution in different areas of Soan Basin, as shown in Table 2. Most of these solar pumps (70) have been installed by Agency for Barani Areas Development (ABAD).

Over 70 per cent of the command area around mini-dams and ponds is undeveloped in Punjab's Potohar region. To resolve the issue of command area development, PARC has taken the lead and began solar pump installations in this area. Specifically, PARC has demonstrated the development of a command area adjacent to the selected dam in the area around Fatehganj by installing solar pumps integrated with High-Efficiency Irrigation Systems (HEIS), i.e., drip. This demonstration has shown command area development with diversified high-value agriculture; thus, enhancing farm income and livelihood. This has been achieved with negligible operational costs in terms of diesel or electricity expenses. As a result of 'PARC's activities, agriculture has diversified by introducing horticulture in the command areas. By carrying out demonstrated development of command area, PARC has developed a model for the Potohar region.

Govt. Institutions / Agencies	No. Of Installed Pumps
ABAD	70
PARC	07
PCRWR	03
PCRET	02
BARI	01
Total Installed Pumps	**83**

Table 2: Total solar pumps installed by the Govt. agency/institutions
Source: Pakistan Agricultural Research Council (PARC)

Different companies and their authorized dealers have installed 374 solar pumps in the private sector at various places of Soan Basin. Table 3 presents the list of companies and the number of solar pumps they have installed in the area. Pak Agro Tech has installed 100 solar pumps, by far the most solar pumps installed by any other private company active in the Soan Basin.

Private Companies / Authorized Dealers	No. Of Installed Pumps
Pak Agro. Tech.	100
Nizam Energy.	52
Green Line Technologies.	38
MAK Pumps.	25
ATS Engineering.	25
Catkin Engg. Sales & Services.	13
Authorized dealers of Catkin.	50
Mansha Brother	20
Solar Well.	08
ZEUS Energy Pvt. Limited.	06
A.R. Brother.	05
Sharif International.	04

Solar Sigma Ltd.	03
Miscellaneous.	25
Total Installed Pumps	**374**

Table 3: Total solar pumps installed by the Private companies & their authorized dealers
Source: Pakistan Agricultural Research Council (PARC)

The Sindh government has launched 11 schemes to install solar-powered tube wells and pumping stations as part of efforts to improve and strengthen the province's agriculture sector in 2017. Pakistan Rs. 802 million schemes for providing solar water pumps and tube wells on subsidized rates to farmers have been initiated, but the progress on this scheme is still unknown. Water Resources Development Sector Project (2018), which includes pilot testing of about 130 ha of high-value agriculture in the command area of Zhob and Mula rivers in Baluchistan, has been planned. It will involve the installation of approximately 160 cost-effective solar-powered drip irrigation systems, along with other initiatives.

Several pilots have also been undertaken, mainly by the Pakistan Council of Research in Water Resources (PCRWR). However, these have primarily been as technology demonstration pilots, i.e., to show that the technology of PV, submersible DC pumps can work reliably and are suitable for applications in agriculture. In 2017, the Federal and Provincial governments agreed to replace the 30,000 grid-connected tube wells with solar-powered tube wells to decrease the recurring burden of subsidies on electricity on the government, but this project has still not materialized.

The Directorate of Agricultural Engineering, Government of Khyber Pakhtunkhwa from 2015-16 is also giving incentives in the form of sharing 50% cost with farmers for the pumping machinery/solar pumps procurement and using them for irrigation purposes in rain-fed /water scarcity areas of the Province under the project Provision of Pumping Machinery for Productivity Enhancement in Khyber Pakhtunkhwa The project is ongoing and aims to help in increasing the water access with an increase of per acre yield of crops. Irrigation Department, Government of Khyber Pakhtunkhwa in 2016-17 started installing solar systems coupled with pumping systems at ten selected sites as a pilot project, and the Federally Administered Tribal Areas (FATA) and Directorate of Irrigation & Hydel Power are also implementing a project in converting all tube wells to solar technology.

4. Public and Private Stakeholders

The primary stakeholder in the public domain is the Government of Pakistan (GoP), which has taken many incentives in its energy strategy to overcome the energy deficit. The introduction of the net metering scheme in September 2015 has been an encouraging sign. Net metering is a billing system that connects the solar system to the grid system. Excessive energy produced by the solar system during daylight hours can be fed to the grid above and beyond consumer demand. This will encourage consumers to install the solar system as net metering will provide additional income to the consumers and encourage consumers to save energy. Further steps have been taken to reduce bureaucratic procedures (i.e., red tape) in processing applications for the issuance of net metering licenses.

Currently, the PV market is dominated by Chinese products. The dominance of Chinese products is attributed to price competitiveness with similar products from other countries, extensive customer outreach through dealership networks, and the large variation in product quality/pricing that caters to different economic classes of customers. The Federal Board of Revenue's (FBR) role is vital in ensuring that all imported solar equipment into the country complies with the recently approved quality import standards for Solar PV equipment.

Multiple departments have developed and enlisted the Solar PV providers as per their criteria. The Alternative Energy Development Board (AEDB) was established as an autonomous body to promote and facilitate the exploitation of renewable energy projects in Pakistan. AEDB has provisionally approved 52 companies so far under AEDB Certification Regulation 2017 for Certification of Vendors/Installers/Service Providers to install Wind and Solar PV systems for net metering. Similarly, Zarai Taraqiati Bank Limited (ZTBL) is the premier financial institution to develop the agriculture sector by providing financial services and technical know-how. ZTBL has also enlisted 56 companies, including PV solution providers and irrigation appliance providers. Pakistan Engineering Council (PEC) has also registered 262 Solar PV solution providers and 162 solar pump providers. Registration with PEC is one of the primary conditions for solar solution provider companies to participate in the respective irrigation department tenders. However, for net-metering cases on solar-powered irrigation systems, which are available only for 3 phase connection holders, registration with the Alternative Energy Development Board (AEDB) is the main prerequisite.

PCRWR is an apex body with a mandate to conduct, organize, coordinate and promote research on all aspects of water resources, including irrigation (surface and groundwater), drainage, soil reclamation, drinking water, wastewater management, etc. PCRWR has employed solar power harnessing technology in all its vital research areas in various projects. In all its projects, the main focus has remained on using SPIS in integration with other water conservation techniques rather than applying only SPIS techniques.

Pakistan Agricultural Research Council (PARC) is the apex national organization working in close collaboration with other federal and provincial institutions in the country to provide science-based solutions to the agriculture of Pakistan through its statutory functions. PARC has demonstrated a solar-powered irrigation system on pilot scales at Fatehjang, Chakwal, Faisalabad, and Karachi. These solar-pumping systems have been designed to potentially utilize the pumped water through different high-efficiency irrigation systems (HEIS) to develop high-value agriculture. At Provincial levels, the On-Farm Water Management (OFWM) program of the Agriculture Department of Punjab aims to maximize crop and water productivity by ensuring efficient conveyance, application, and irrigation water viz-a-viz promoting improved water management interventions through user participation.

5. SIP related Challenges and Opportunities

5.1 SIP related Opportunities

Pakistan has a vast PV potential, and all the necessary conditions for its implementation are- high radiation yield, a regulatory framework, and financing instruments that support its development. In terms of solar irradiation, it has been estimated that, on average, about 3000 sunlight hours are available in Pakistan each year, which can produce 5-7 kWh/m^2 of solar energy. The monthly average solar irradiation of capital cities of four provinces of Pakistan is given in table 4 below.

Capital of Provinces	**Irradiation (Am) KWb/m^2**	**Irradiation (Max) KWh/mV**
Lahore	2.8	6.27
Peshawar	2.4	6.35
Karachi	3.4	6.31
Quetta	3.6	7.65

Table 4: Irradiation of four provinces of Pakistan
Source: Muhammad et al., (2017)

Exploiting available solar energy for the agriculture sector will increase the country's productivity and food security and help in cleaner and sustainable food production.

Farmers owning smallholdings suffer from reduced profit margins, partially due to rising fuel prices and high pumping costs. Even in electricity-powered tube wells, farmers face great difficulty due to load-shedding and the rapidly increasing cost of electricity. Given the much lower operating cost of solar-powered tube wells, a scheme for replacing diesel or electric tube wells with solar tube wells or installing new solar tube wells can therefore be financially attractive for farmers if the initial high capital cost can be subsidized appropriately.

Most of the arid parts of Pakistan have no access to electricity and have the deepest water tables. The villagers and communities use expensive and dirty fuels such as diesel to pump water from depths of up to 400 feet. The per person and per animal consumption of water is alarmingly lower than the WHO prescribed levels, resulting in poor health and hygiene and lower quality of life, particularly for women responsible for water collection. The SPIS in such regions, apart from energy and water conservation, will also provide further benefits like increased health & hygiene through daily access to water (up to 7 hours a day).

5.2 SIP related challenges

There are demand-side challenges to the adoption of SIPs. Solar-powered irrigation systems provide a promising alternative to diesel-powered tube wells, but their adoption at scale has faced many problems in Pakistan. Farmers cannot invest in solar due to high initial costs and low discharge capacities than diesel-powered pumps. More than 90% of the irrigation is carried out through flood irrigation, and so far, all the provincial governments have tried to promote solar through High-Efficiency Irrigation Techniques. This is one of the primary reasons for the slow adoption rate as the farmers are not ready to shift from flood irrigation to HEIS techniques. As SIPs can only operate during sunlight hours, their operating hours are limited per day. This is also another reason farmers are a bit reluctant to use solar as this may potentially not irrigate their field through flood irrigation.

There are supply-side challenges as well the primary concern amongst water professionals in Pakistan is that any conversion of diesel pumping to PV solar will result in indiscriminate pumping leading to further groundwater depletion. The apprehension is that with PVs, there are no financial (electricity costs) to constrain farmers from pumping, and hence the assumption is that farmers will increase their pumping. PCRWR has undertaken some studies and analysed daylight hours/solar irradiation to conclude that the actual solar energy available will constrain pumping. However, this knowledge has not been widely acknowledged/accepted. There is some criticism that pumping depends not only on energy availability but also on the installed capacity and farmer behaviour that has not been studied in any detail.

Additional challenges include the lack of awareness about the quality of PV and the benefits of high-quality products. The implementation and dissemination of quality standards for PV are expected to reduce price sensitivity and increase the procurement of high-quality PV products.

The possibility of groundwater over-extraction by deploying stand-alone off-grid SIPs with zero marginal costs remains a real challenge. Concern about groundwater over-exploitation is also preventing Pakistan from scaling up its solar irrigation program. The PCRWR used NASA's Gravity Recovery and Climate Experiment (GRACE) satellites data to produce a map of monthly groundwater changes in the Indus River Basin. Based on the analysis conducted from January to March 2016, a depletion trend (drawdown) in groundwater storage appeared. Most parts of Bari, Rechna, Chaz, and Central Thal doab were under stress in March 2016 and need careful water management and planning (regulation of groundwater pumping). Users in this region can expect the reduction in Ground Water Storage (GWS) to decline further and deeper to pump groundwater. Costs of solar-powered pumping systems increase rapidly with an increase in pumping depth and discharge. For depths greater than 100 feet, the cost of solar tube wells increases significantly and becomes uneconomical. Almost 66 per cent of farmers have farm sizes under 25 acres (GOP, 2010). Moreover, many solar panels required for large-size and high discharge tube wells occupy more land area, which small farmers especially find difficult to spare. In addition, several maintenance issues may also emerge.

6. Conclusion

There is potential for solar irrigation in all four provinces and other administrative units of Pakistan. Scaling up SIPs can also meet clean energy targets and provide assured irrigation to the farmers, yet the threat of groundwater over-exploitation remains. The use of groundwater increases rapidly in the irrigation sector, and it has already surpassed surface water use. There is no legislation in Pakistan to restrict overexploitation of groundwater. Groundwater quality is also deteriorating due to the lateral movement of brackish water to the sweet water aquifers, threatening to make existing sweet water aquifers unusable. There is no licensing mechanism to restrict farmers and other groundwater users to dig tube wells. Farmers located at the tails of many distributaries and canals are exclusively dependent on groundwater for irrigation due to the non-availability of surface water.

It is a big challenge to manage groundwater overexploitation in Pakistan and bring down the CO_2 emissions due to the use of diesel pumps. Solar pumps provide an excellent opportunity to control the CO_2 emissions problems but at the same time may end up further exacerbating the problem of groundwater exploitation. The Federal and Provincial Governments need to immediately develop proper plans to convert existing diesel-powered pumps to solar and restrict overexploitation of groundwater through systems that do not enable the farmers to increase the abstraction of groundwater. The government also needs to declare zones where they want to promote solar pumps and see the possibility of decoupling the solar pumps from the HEIS systems, which have not gained much traction in the past many years.

The SDC-SoLAR project aims to generate rigorous evidence on the groundwater extraction behaviour of SIP farmers and feed that evidence into the ongoing discourse on SIPs and the risk of groundwater over-exploitation. In addition, through an experiment with heat sinks and differential tariffs, the project aims to demonstrate changes in farmers pumping behaviour in response to potential incomes earned from selling electricity to the grid. Currently, solar pumps are only promoted in conjunction with HEIS, and farmers are often reluctant to implement HEIS due to its high costs. Therefore, the SDC-SoLAR project will train farmers through research partners to implement surface precision irrigation techniques at the farm level.

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