J. Qual. Assur. in Agri. Sci. Vol. 1(1), 14-21, 2021 https://doi.org/10.52862/jqaas.2021.1.1.3
www.jqaas.org

IRRIGATION WATER STATUS IN PAKISTAN, CHALLENGES AND MANAGEMENT STRATEGIES: A MINI REVIEW

*Wajiha Anum[1], Liaquat Ali[1], Syed Ali Zulqadar[2]

[1]*Regional Agricultural Research Institute Bahawalpur-6300, Agriculture Department, Government of Punjab, Pakistan,*

[2]*Soil and Water Testing Laboratory for Research, Bahawalpur-63100, Agriculture Department, Government of Punjab, Pakistan*

***Correspondence**: wajiha_anum@live.com.

Article Received: 04-06-2021, Revised 18-08-2021, Accepted 20-08-2021

ABSTRACT

The upsurge in population and scarceness in resources is leading the world towards deprivation of natural resources. Among them, water in either form, is the critical resource for sustaining life on earth. The conditions are more challenging in countries like Pakistan, where rainfall is less and semi-arid conditions prevail throughout the year. Pakistan agriculture produce is dependant mostly on the irrigation water and requires a well-chosen and sustainable water management strategic plan. However, certain aspects like water salinity, water logging, water sodicity, metal toxicity and surface water recharge are among the most crucial issues threatening the agriculture sector. This review will focus on the basic irrigation system of Pakistan, how the water is distributed among farmers, policies and their implementations and specific emphasis is made on the advanced irrigation methods being applied in the country. A complete prognosis is the utmost need under the current scenario of irrigation water needs and for future strategies. Moreover, the recent literature relevant to the factors that impedes the sustainable use of water and how it can be managed more efficiently under the available resources. Future prospects are suggested as up scaling of modern technology, improved agriculture-education and trainings, better-quality inputs for improved irrigation, reclamation of saline/water logged soils, more focus on credit and support prices for water inputs as well as improved water conservation techniques. Recommendations include upgrading of extension services, liberation of varieties which tolerates heat and drought, improvement in irrigation water management as well as advancement in reclamation and drainage practices.

Keywords: Irrigation scheduling, Sprinkler irrigation, Water resources, Indus Basin, water war, crises,

INTRODUCTION

Irrigation plays a dynamic role in endurance of humankind specifically in arid and semi-arid regions worldwide (Latif et al., 2016). Pakistan is listed as third amongst the water starving countries in the world (Nabi et al., 2019), owing to water deprivation with the passing time. A drastic reduction has been observed in water availability in Pakistan during the last six decades i.e., it is reduced from 5,260 m^3 in 1951 to 1040 m^3 in 2010 (Mustafa et al., 2013). In Pakistan, the per head water availability was 5650 cubic meter that has been fallen down to level of 908 cubic metres/ annum giving rise to an alarming situation (Business recorder, 2021) whereas the scarcity threshold level is 1000 cubic meters thus marking the country in the water famine zone. Irrigation agriculture provides livelihood and food security to almost about 220 million people of Pakistan. The two provinces of Punjab and Sindh are irrigated ones and without the adequate and timely availability of irrigation water the country can face an economic collapse (Faizan-ul- Hasan et al., 2021). Currently, various crop lands facing converted into degraded lands in terms of salinity and sodicty due to high temperature in these areas.

Irrigation water issues in Pakistan

Pakistan is at a risk of diminishing irrigation water resources required for sustaining the agriculture sector. The two crucial factors for affecting efficient use of current water resources are identified as the decrease in water resources and low agriculture water productivity (Watto and Mugera, 2015). Pakistan is among the countries with world largest integrated irrigation system but regardless of this, the agriculture is facing a downfall due to a number of social, economic and administrative factors like in-equitable distribution of resources, over exploitation of ground water, water logging and salinity (Anjum et al., 2010). Under such circumstances, the farmers are shifting from water intensive but economically important crops like rice, cotton, sugarcane and wheat towards less water demanding crops like vegetables, however, this shift has instigated market pressure and economic downfall in the country (Asif, 2013). It is projected that till 2025, there will be~32%, shortfall in water requirement thus giving rise

to shortage of food about 70 million tons (Qureshi, 2011). Moreover, combined factors like siltation of main reservoirs and climate changes effects can result in 30 % reduction in water storage capacity by 2025. Likewise, the situation is exacerbated due to water thefts by influential farmers because of which a significant proportion of tail reach the farmers stipulating that the water theft occurs at head and middle areas, as a result, water turns are not received regularly (Hussain, 2005). Similarly, groundwater is withdrawn extensively on regular basis. A number of farmers are not aware of the water shortage issues in the country and sometimes apply surplus water/no. of irrigations to their fields under hot climates, which leads to groundwater depletion. The situation is aggravated as Pakistan being a semi-arid country, is not receiving enough rainfalls to maintain the ground water levels making ways for water famine (Khan et al., 2017). On the other hand, due to high pumping of ground water in many areas causing deterioration of ground water quality and causing reduction in crop yields (Riaz et al., 2018). In this regard, social issues like lack of education, less awareness of water conservation strategies and less awareness about importance of water prevails in the country. Small land holders are uneducated and have limited access to the current situations of irrigation water and limited resources. In addition, community reluctant to adopt the advanced water saving techniques and irrigation methods especially non-progressive farmers.

Irrigation pattern in Pakistan

Pakistan depends solely on Indus basin and its major tributaries of Jhelum, Beas, Chenab, Sutlej, Ravi and the surface water resources solely and is the basic source of surface water resource. The Indus River covers a length 3180km and basin area is 1.165 million km². The flow of the rivers is dependent on the ice melted from glaciers, snowfall and rain in the catchment area. Apart from the Indus River, there are ephemeral streams which only flow during the rainy season and do not fulfil the water requirement in Indus basin system as compared to the main tributaries (Qureshi, 2011). Irrigation network of Pakistan comprising barrages and link canals is depicted in figure 1. The Pakistan irrigation system comprises of three major storage reservoirs (Tarbela, Mangla and Chashman), nineteen barrages, eighty-two small dams and about forty-eight major command canals. The Tarbela dam is second largest dam in the world and largest in Pakistan having 240 square km area and generates electricity about 3500 megawatts (Arshad and Oad, 2017). The average annual inflows from the eastern and western rivers in kharif season is 134.4 while for rabi season it is 30.9 making total annual river inflow of 165.3 during 2001-2018 (Habib, 2021).

Irrigation use Management

In order to fulfil the criteria for achieving food security, a careful and well managed system is required to utilize the scarce water resources (Rosegrant and Cai, 2002). The advanced irrigation methods like drip and sprinkler irrigations can reduce the water quantity as water is maximum available at the root zone of the crop. However, in cases where farmers are poor, the government should provide subsides on installation of such systems. A considerable water use efficiency and proper management of irrigation water is a pre requisite.

Management strategies opted by Government

The government plays its part in framing the laws and regulations on the current irrigation water conditions. Recently, Pakistan government formulated a water policy which works on more crops per drop. The policy will work on developing the action plans and management practices in order to overcome the water scarcity (Ministry of Water Resources, 2018). Many management practices are proposed in this policy which includes cultivation of drought resistant crops (Hu and Xiong, 2014), soil mulching for preserving soil moisture (Kader et al., 2019), technologies that reduce field irrigation losses (Evans and Sadler, 2008), replacement of water intensive crop with less water demanding crops (Davis et al., 2017), improved water productivity through deficit irrigation (Galindo et al., 2018), and conservation tillage practices to enhance the water use efficiency in the crops (Ali et al., 2017). The use of untreated wastewater on crops on long terms give rise to soil contamination and pollutes shallow aquifers (Khattak et al., 2012). These conditions pose threats to human health as heavy metals are transferred via food chain (Powell et al., 2003).

An insight to challenges and issues for irrigation water

Water pollution

Pakistan's agriculture is affected largely due to water pollution, that is resulted from excessive use of fertilizers and pesticides. As they dissolve in water and seep towards the underground water bodies. As a result, they water bodies get saline and the subsequent water causes waterlogging, soil salinity and decrease soil fertility. Jabeen et al (2015) stated that water pollution costs Pakistan 0.9 per cent of the GDP. Agricultural drainage contributes to impurity of water resources but it is marginal to the pollution that results from domestic

J. Qual. Assur. in Agri. Sci. Vol. 1(1), 14-21, 2021
www.jqaas.org

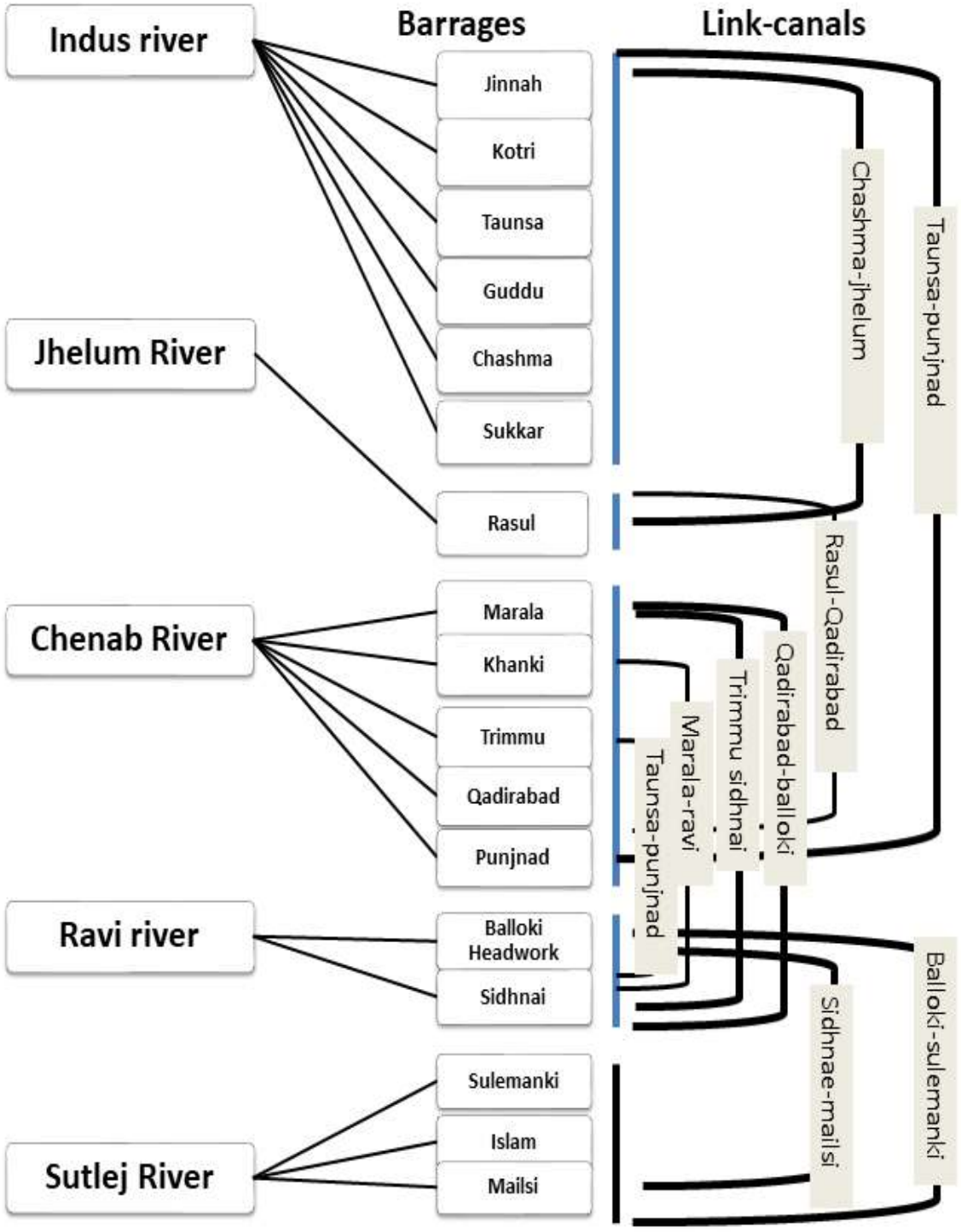

Figure 1. Schematic diagram of Indus-Basin System of Pakistan

and industrial pollution. For instance, in Sindh, the pollution of water due to irrigation is only 3.21% of the total Pollution. Ground water pollution mostly occurs with the continuous and non-judious use of unfit water for irrigation purposes. Saline water and brackish water results in development of soil Sodicity, salinity and ion toxicity results in development of soil Sodicity, salinity and ion toxicity.

J. Qual. Assur. in Agri. Sci. Vol. 1(1), 14-21, 2021
www.jqaas.org

All of these factors are crucial for better understanding of unfit irrigation water and how it influence crop and soil health especially in arid and semi-arid regions. Under the arid climatic conditions there is no sufficient rainfall and as a result, the accumulated salts in the soils do not leach down properly and get accumulated in the crop root zone (Soomro et al., 2021). Sodicity occurs with the presence of excess sodium in the soil that deteriorates soil structure and reduces water infiltration into the soil. Concentration of some salts like sodium, boron, chloride along with some trace elements when becomes high enough to affect the plant growth negatively leads to toxicity (Zaman et al., 2018). Indus basin comprise of varying quality of water that range from fresh to hazardous. In various areas the water creates sodicity when applied to crops because it contains high amounts of carbonates, bicarbonates and ph. The total groundwater abstraction from tube wells is 6.05 Mham, the public and private tube wells contribute about 1.23 Mham and 4.81 MAF respectively (Naqushband et al., 2017). According to Qureshi (2020) Pakistan has 1.2 million private tube wells operating in the country and total groundwater extraction is about 60 billion m^3. Farmers are able to irrigate their fields, but non-renewal of groundwater has led to low quality water causing salinization problems.

Strategies to comb back water scarcity

Crop productivity is dependent on many factors among which plant soil atmosphere interaction is of core importance (Byrne et al., 1982). A well-managed irrigation system based on new technologies can reduce the negative impacts of water losses, ground water table and economic impacts (Khan et al., 2007). Irrigation scheduling is of prime importance and is known to significantly improve water use efficiency if applied at right time and water demanding crop growth stages (Fang et al., 2010). An efficient Irrigation scheduling that fulfils the required soil water contents gives rise to high grain yield along with water use efficiency, (Kang et al., 2002). irrigation application methods like furrow irrigated raised beds, sprinkler irrigation and furrow irrigated raised bed with plastic mulch were tested and significantly reduce the cost of cultivation, enhance crop yield and water use efficiency. Sprinkler irrigation is popular advanced water application methods that have higher application efficiency as compared to flood irrigation (Jay et al., 2005). About 80% of irrigation efficiency has been achieved in Indian subcontinent

Groundwater irrigation is crucial in maintaining the agricultural productivity and it is vital for maintaining the food security as drought and heat spans are becoming more frequent (Qureshi et al., 2010). In Punjab province, about 70% of the farmers are dependent on the groundwater for achieving a successful crop production (Qureshi et al., 2003). However, unpolluted irrigation water is a pre requisite for maintaining soil health and health of crops and human beings.

Brackishness of Water in Pakistan

climatic conditions under sprinkler irrigation (Sharma, 1884). Haq (1990), revealed 30% water saving of sprinkler irrigation when compared to flatbed sowing. Apart from the irrigation water quality, the management practices for application of water plays a vital role, for instance two irrigation supplies i.e., canal irrigation and water course irrigation are differently managed in the country (Faizan-ul Hasan et al., 2021). Both differ in their efficiency, more efficiency has been observed in canal irrigation supply (76%) while the efficiency observed in watercourse system in Punjab is 52% and in Sindh it is 54% (Yu et al., 2013). Hence, a better infrastructure and management is required for improving water productivity (Davies et al., 2017). In this regard, Provisional the government is playing its role by improving watercourses and capacity building of water users' association along with better management practices in the provinces (GoS, 2017; GoP, 2018). Punjab irrigation department is also working on water issues under Punjab water act 2019. On farm water management and water user association ordinance 1981 and Punjab soil reclamation act 1952. Sindh province is mostly managing groundwater for supplementary irrigation (SID, 2020), and regulates canal water to farm gate. Sindh irrigation act (revised 1996) governs the management practices like water distribution, revenue collection and dispute resolution. Punjab irrigation and drainage authority (GOP, 1997) deals with canal water system to make it more effective and economical. In Sindh, 14 canal commands are looked by 1200 farmer organisations (FOs) along with Sindh irrigation drainage and authority (SIDA established in 1998) and area of water boards (AWBs) (Azad, 2003). Problem arises due to water scheduling as water in canal and watercourses run particularly in kharif season when farmers does not require water in such quantities as in rabi season (Faizan-ul-Hasan et al., 2021).

Table 1. Different irrigation systems and their comparative efficacy in Pakistan

Irrigation System	Crop	Results	Reference
Sprinkler vs. surface irrigation	Rice and wheat	Sprinkler was better (Rice produced 18% more yield)	Kahlown et al., (2007)
Rain gun sprinkler vs. surface irrigation	Corn fodder	Rain gun was better (34.52% of water saving)	Iqbal (1994)
Furrow vs. sprinkler vs. drip irrigation	Cotton	Cotton yields, Drip (4380 kg/ha) furrow (3630 kg/ha) sprinkler (3380 kg/ha) Drip irrigation produced 21% more seed-cotton than the furrow method and 30% more than the sprinkler method.	Cetin (2002)
Furrow (conventional) vs. Drip.	Corn	Water used for irrigation Furrow irrigation (547- 629 mm/ year) Drip irrigation (371- 428 mm/ year)	Nazirbay et al., (2005)
Drip and furrow irrigation.	Tomato	Water savings Drip irrigation (56.4%) 22% more yield than furrow irrigation	Tagar et al., (2012)
Drip irrigation vs. furrow irrigation	Cotton	Increased seed cotton yield, yield components, water saving (53.3%) and water use efficiency (7.9 kg ha^{-1} mm^{-1}) was obtained under drip irrigation system as compared to furrow irrigation system.	Muhammad et al., (2010)
Under plastic tunnel drip and furrow systems.	Tomato, cucumber and bell pepper	The average water use efficiency in drip irrigation was Tomato (250%) Cucumber (274%) Bell pepper (245%)	Musa et al., (2014)
Line planting under basin irrigation, Ridge planting and planting under furrow irrigation.	Maize	Ridge planting was superior to furrow irrigation and basin irrigation with regard to average water use efficiency.	Kori et al., (2017)
Comparison between Trickle irrigation, Rain gun sprinkler, Border irrigation and Furrow irrigation were made.	Cotton	Water saved under furrow. Rain gun sprinkler (14.26%) and trickle irrigation (34%) compared with border irrigation method.	Waheed-uz-Zaman et al., (2000)
Basin, furrow and rain gun sprinkler systems.	Sunflower	Using rain gun sprinkler irrigation system, 30.8% and 28.3% higher water use efficiency and 21.1% and 9.0% more water application efficiency was achieved as compared to basin and furrow irrigation system, respectively	Rana et al., (2006)
• Precision land levelling • Bed planting • Drip irrigation	Wheat, rice and cotton	Crop sown on precisely levelled land resulted in saving of 2768.1 million m^3 and 3699.3 million m^3 of irrigation water Drip irrigation enhanced the yields by 30-40%.	Rizwan et al., (2018)
Furrow irrigation system vs. flood irrigation system.	Kinnow mandarin	Furrow irrigation average water saving (46.14%) and water use efficiency (4.58 kg m^{-3}) flood irrigation WUE (2.34 kg m^{-3})	Raza et al., (2021)

CONCLUSION

Irrigation system of a country is of due importance as without proper management system and polices the adequate water supply is un-attainable. Irrigation water issues in Pakistan are hyping regardless of the available resources, due to over exploitation and non-judious irrigation water usage. The advanced irrigation methods like drip irrigation, sprinkler irrigation and furrow irrigations are now widely adopted and increase in crop production is observed. In order to diminish the threats of water famine in Pakistan, a fast implementation of rules and regulations are required which focus on the appropriate use of water, planting of crops with less water requirement, identification of crop stages that are critical for irrigation and selection and growing of those crops which can be adapted to semi-arid conditions of country. In this regard, researchers of Pakistan have devoted their time in breeding crop varieties that are heat and drought tolerant. Plantation of trees/crops that reduces the water logging/salinity and sodicity issues. Owing to the current water situation in Pakistan more education programmes must be introduced for farmers in which detailed water consumption and current water situation is described to the farmers along with installation and operating of advanced irrigation systems. Apart from these, seasonal and Annual River flows and their monitoring is continuously required for obtaining maximum output.

REFERENCES:

Anjum, S. A., L.C. Wang, L. Xue, M.F. Saleem, G.X. Wang and C.M Zou. 2010. Desertification in Pakistan: causes, impacts and management. J. Food Agric. Environ. 8: 1203-1208

Arshad, M., and R.N. Oad. 2017. Water Resources and Irrigation Network of Pakistan. Applied Irrigation Engineering. University of Agriculture, Faisalabad, 5-7

Asif, M. 2013. Climatic change, irrigation water crisis and food security in Pakistan.

Azad, A., A. Rasheed and Y. Memon. 2003. Sindh water resources management–issues and options. FAO investment centre occasional paper series. (15)

Bhutta, M. N. 1999. Vision on Water for Food and Agriculture: Pakistan Perspective: Regional South Asia Meeting on Water for Food and Rural Development. New Delhi.

Business recorder. 2021. Retrieved from https://www.brecorder.com/news/40064309/per-capita-water-availability-pushes-country-to-alarming-level-wapda

Byrne, J., G. Quinn, J. Mpitsos, I. Lederhendler, F. Belardetti and C. Biondi. C. 1982. Plant Productivity and Environment. Science. 218: 443–448

Cetin, O., and L. Bilgel. 2002. Effects of different irrigation methods on shedding and yield of cotton. Agric. Water. Manag. 54(1): 1-15

Davies, S., A. Gueneau, D. Mekonnen, C. Ringler and S. Robinson. 2017. Irrigation and water management in the Indus Basin: infrastructure and management strategies to improve agricultural productivity. Agric. Rural Econ. Pak. 117–169

Davis, K. F., A. Seveso, M.C. Rulli, and P. D'Odorico. (2017). Water savings of crop redistribution in the United States. Water. 9(2): 83

Dinar, A., and J. Mody. 2004. Irrigation water management policies: allocation and pricing principles and implementation experience. P. 112-122. In Natural Resources Forum. Volume 28. No. 2: Oxford, UK: Blackwell Publishing Ltd.

Evans, R. G., and E.J. Sadler. 2008. Methods and technologies to improve efficiency of water use. Water Resour.Res. 44(7)

Faizan–ul-Hasan, F., B. Fatima, and S. Heaney-Mustafa. 2021. A critique of successful elements of existing on-farm irrigation water management initiatives in Pakistan. Agric. Water. Manag. 244, 106598.

Fang, Q., L. Ma, Q. Yu, L.R. Ahuja, R.W. Malone and G. Hoogenboom. 2010. Irrigation strategies to improve the water use efficiency of wheat–maize double cropping systems in North China Plain. Agric. Water Manag. 97: 1165–1174

Galindo, A., J. Collado-González, I. Griñán, M. Corell, A. Centeno, M.J. Martín-Palomo, and D. Pérez-López. 2018. Deficit irrigation and emerging fruit crops as a strategy to save water in Mediterranean semiarid agrosystems. Agric. Water. Manag. 202: 311-324

GoP., 1997. Punjab Irrigation and Drainage Act. Government of Punjab, Lahore. Retrieved from: https://www.iucn.org/sites/dev/files/import/downloads/the_punjab_irrigation_and_drainage_authority_act_1997.pdf

GoP. 2018. On Farm Water Management: Directorate of Agriculture. Government of Punjab. Retrieved from: http://ofwm.agripunjab.gov.pk /services.

Habib, Z. 2021. Water availability, use and challenges in Pakistan-Water sector challenges in the Indus Basin and impact of climate change. Food & Agriculture Org.

Haq, N. 1990. Evaluation of modern irrigation techniques for sandy loam soil having low slopes. Department of Irrigation and Drainage, University of Agriculture, Faisalabad.

Hu, H., and L. Xiong. 2014. Genetic engineering and breeding of drought-resistant crops. Annu. Rev. Plant. Biol. 65: 715-741

Hussain, I. 2005. Pro-poor intervention strategies in irrigated agriculture in Asia. International Water Management Institute, Colombo, Sri Lanka.

Iqbal, A. 1994. Feasibility of Raingun Sprinkler Irrigation System for Corn (fodder) under Farmer's Conditions (Doctoral dissertation, M. Sc Thesis, Dept. of Irrigation and Drainage, University of Agriculture, Faisalabad).

Jabeen, A., X.Huang and M. Aamir. 2015. The challenges of water pollution, threat to public health, flaws of water laws and policies in Pakistan. J. Water. Resour. Prot. 7(17): 1516

Jay, L., K. Jack, K.L. Janet and B.K. Thomas. 2005. Surface and Agricultural Water; John Wiley & Sons, Inc.: Hoboken, NJ, USA.

Kader, M. A., A. Singha, M.A. Begum, A. Jewel, F.H. Khan and N.I. Khan. 2019. Mulching as water-saving technique in dryland agriculture. Bull. Natl. Res. Cent. 43(1): 1-6

Kahlown, M. A., A. Raoof, M. Zubair, and W.D. Kemper. 2007. Water use efficiency and economic feasibility of growing rice and wheat with sprinkler irrigation in the Indus Basin of Pakistan. Agric. Water. Manag. 87(3): 292-298

Kang, S.Z., L. Zhang, Y.l. Liang, X.T. Hu, H.J. Cai, and B.J. Gu. 2002. Effects of limited irrigation on yield and water use efficiency of winter wheat in the Loess Plateau of China. Agric. Water Manag. 55: 203–216.

Khan, S., and A. Abbas. 2007. A. Upscaling water savings from farm to irrigation system level using gis-based agro-hydrological modelling. Irrig. Drain. J. Int. Comm. Irrig. Drain. 42: 29–42.

Khan, H. F., Y.E. Yang, C. Ringler, S. Wi, M.J.M. Cheema and M. Basharat. 2017. Guiding groundwater policy in the Indus Basin of Pakistan using a physically based groundwater model. J. Water Resour. Plan. Manag. 143(3): 05016014.

Khattak, M. A., N. Ahmed, M.A. Qazi, A. Izhar, M.N. Chaudhary, S. Ilyas, ... and N Iqbal. 2012. Evaluation of ground water quality for irrigation and drinking purposes of the areas adjacent to Hudiara industrial drain, Lahore, Pakistan.

Kori, S. M., C. Soothar, A.L. Qureshi and S.H. Ashrafani. 2017. Effect of different irrigation methods on water use efficiency and yield of maize crop. Pak. J. Agric. Agricul. Eng. Vet. Sci. 33(1): 54-65.

Latif, M., S.S. Haider, and M.U. Rashid. 2016. Adoption of high efficiency irrigation systems to overcome scarcity of irrigation water in Pakistan. Proc. Pak. Acad. Sci. B Life Environ. Sci. 53(4): 243-252

Ministry of Water Resources. 2018. Pakistan-National Water Policy; Government of Pakistan: Islamabad, Pakistan, 2018. Retrieved from: https://ffc.gov.pk/wp-content/uploads/2018/12/National-Water-Policy-April-2018-FINAL_3.pdf

Muhammad, D., I. Raza, S. Ahmad, M.N. Afzal, and M.A. Mian. 2010. Efficiency of drip vs furrow irrigation system with variable plant density on cotton under southern Punjab climatic conditions. Furrow. 30(126): 2-55

Musa, M., M. Iqbal, M. Tariq, F.H. Sahi, N.M. Cheema, and F.N. Jahan. 2014. Comparative water use efficiency of drip and furrow irrigation systems for off-season vegetables under plastic tunnel. SAARC J. Agric. 12(1): 62-71

Mustafa, D., M. Akhter and N. Nasrallah. 2013. Understanding Pakistan's water-security nexus. Washington, DC: United States Institute of Peace.

Nabi, G., M. Ali, S. Khan, and S. Kumar. 2019. The crisis of water shortage and pollution in Pakistan: Risk to public health, biodiversity, and ecosystem. Environ. Sci. Pollut. Res. 26(11): 10443-10445

Naqushband, M., M.T. Niazi, K. Mehmood, and A. Dogar. 2017. Tackling of problematic soil and brackish water in Pakistan and improvement in the efficiency of urea and can fertilizers. NFC IEFR J. Engineer. Scientific. Res. 2

Nazirbay, I., S. Evett, Y. Esanbekov and B. Kamilov. 2005. Water use of maize for two irrigation methods and two scheduling methods. In Asa-Cssa-Sssa Annual Meeting, Salt Lake City, Utah.

Powell, K.L., R.G. Taylor, A.A. Cronin, M.H. Barrette, S. Pedley, J. Sellwood, S. Trowsdale and D.N. Lerner. 2003. Microbial contamination of two urban sandstone aquifers in the UK. Water Res. 37:339-352.

Qureshi, A. S. 2011. Water management in the Indus Basin in Pakistan: challenges and opportunities. Mt. Res. Dev. 31(3): 252-260.

Qureshi, A. S., M.A. Gill, and A. Sarwar. 2010. Sustainable groundwater management in Pakistan: challenges and opportunities. Irrig. Drain: ICID. 59(2): 107-116

Qureshi, A.S., T. Shah and M. Akhtar. 2003. The groundwater economy of Pakistan. IWMI

Working Paper No. 64. International Water Management Institute: Colombo, Sri Lanka; 23 pp.

Qureshi, A. S. 2020. Groundwater governance in Pakistan: From colossal development to neglected management. Water. 12(11): 3017.

Raza, A., I.A. Warraich, M.A. Nawaz, M. Asim, A. Aziz, F. Shireen and M.A. Rahman. 2021. Does furrow irrigation system improve yield and water use efficiency of Kinnow mandarin (citrus reticulata blanco)? Int. J. Agric. Ext. 8(3): 199-206.

Riaz, U., Z. Abbas, Q. Zaman, M. Mubashir, M. Jabeen, S.A. Zulqadar, Z. Javeid, S. Rehman, M. Ashraf and J. Qamar 2018. Evaluation of Ground Water Quality for Irrigation Purposes and Effect on Crop Yields: A GIS Based Study of Bahawalpur. Pak J Agric Res, 31(1): 29-36

Rizwan, M., A. Bakhsh, X. Li, L. Anjum, K. Jamal and S. Hamid. 2018. Evaluation of the impact of water management technologies on water savings in the lower chenab canal command area, Indus River Basin. Water. 10(6): 681

Rosegrant, M.W., and X. Cai. 2002. Alternative policies for global irrigation and water: Impacts on food supply, demand and trade. Retrieved from: http://www.worldbank.org/agadirconference

Sharma, S.K. 1984. Principles and Practices of Irrigation Engineering; Oxford and IBH Publication Co.: New York. NY. USA.

Sindh Irrigation Department (SID). 2020. Functions of Sindh Irrigation Department. Government of Sindh, (Retrived from). https://irrigation.sindh.gov.pk/.

Soomro, K. B., S. Alaghmand, M.M. Shaikh, S. Andriyas and A. Talei. 2021. Response of Salts in Saline Soil Using Different Irrigation Scheduling in Semi-Arid Zone of Pakistan. Pak. J. Sci. & Indus. Res.Series A: Physical Sciences. 64(2): 110-118

Tagar, A., F.A. Chandio, I.A. Mari and B. Wagan. 2012. Comparative study of drip and furrow irrigation methods at farmer's field in Umarkot. World. Acad. Sci. Eng. Technol. 69: 863-867

Van Steenbergen, F., M. Basharat and B.K. Lashari. 2015. Key challenges and opportunities for conjunctive management of surface and groundwater in mega-irrigation systems: Lower Indus, Pakistan. Resources. 4(4): 831-856

Waheed-uz-Zaman, M. A., M.A. Rana and M.S. Sabir. 2000. Water saving and crop yield potential of modern irrigation methods in the semi-arid area. Pak. J. Agri. S. ci. Lb. 3(7): 3-4

Watto, M. A., and A.W. Mugera. 2015. Efficiency of irrigation water application in sugarcane cultivation in Pakistan. J. Sci. Food Agric. 95(9): 1860-1867

Zaman, M., S.A. Shahid and L. Heng. 2018. Irrigation water quality. P. 113-131.In: Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques, Springer, Cham.

Publisher's note: JQAAS remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.