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Water use and deprivation potential for sugarcane cultivation in Pakistan

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Abstract: Due to population growth and economic development, the demand for the agricultural production is increasing rapidly leading to an accelerating pressure on the existing water resources. Sugarcane is an important cash crop of Pakistan; it is a water intensive crop and grown in the watershed of the Indus river. In this study, the impact of water use in terms of water deprivation has been estimated by using water stress index of the Indus watershed. The results revealed that a large amount of water ranging between 14,625 to 27,529 m^3/ha has been used in the Faisalabad and Rahim Yar Khan regions of Pakistan. Due to yield gap in these regions, the per tonne water utilization for cane production was found to be higher than the global average of 197 m^3/tonne thus contributing to a higher extent of water deprivation potential in the Indus watershed. The results of the study highlight the need to increase the water use efficiency for cane cultivation to reduce the water deprivation potential in Pakistan. Recommendations are made for increasing the irrigation water efficiency through on-farm water management techniques. The results of the study are helpful for the policy makers to suggest further improvements for sustainable cane production in Pakistan.

Keywords: Water stress, water derivation, sugarcane, Pakistan.

1. Introduction

Sugarcane is an important food and energy crop which is grown in 107 countries worldwide over a wide range of climates from the latitudes of 30ºN to 30ºS. The cultivation of sugarcane generally occurs in tropical to subtropical regions with adequate precipitation and solar radiation. The crop is cultivated on an area of 20.42-million-hectare land with total production of 1,333 million tonne worldwide [1-3]. Pakistan is 5th largest in cane cultivation in the world in terms of production and sugarcane is the 2nd largest cash crop of the country accounting for 17% of the gross value added from all crops [4-5]. According to an estimate by the United Nations (UN), the world population is expected to increase to 9.3 billion by the year 2050 which can cause a threat to the balance between demand and supply chain of food for growing population [6]. The global food production needs to be increased by 60% by the year 2050 to meet the increasing demands for food [7]. Agriculture is one of the highly water consuming activity as 70% of the world's freshwater is withdrawn for irrigation in the agriculture sector and it has been predicted that the demands of freshwater in the agriculture sector especially in the developing countries will increase by 50% as compared to the present situation by the year 2025 [8]. The global freshwater withdrawal has increased 7 times from the past century due to changing diet preferences of the growing population [9]. Moreover, due to the growth of agriculture, industrialization, households and energy consumption, the pressure on freshwater resources is escalating rapidly and the overexploitation of freshwater is causing social, environmental and economic problems. According to an assessment of water management in agriculture, around 1.2 billion people (almost a fifth of the world population) are living in water scarce regions. So, it is a global challenge to use water in a secure way in future. The management of water resources is required not only at the local and national levels, but also at the international level for the sustainability of agricultural production [10-11].

Climate is one of the important factors affecting agricultural production. One of the four top ranking environmental risks is water crisis, occurring due to the failure of climate change mitigation and adaptation [12]. There is a prediction of gradual change in the future climate which could affect the vulnerability of the global food supply system. According to an estimate, the global mean surface temperature could rise by 4.8ºC by the end of 21st century [13]. As a result, the water scarcity is expected to increase rapidly due to intensifying pressure on the existing water resources [14].

In Pakistan, sugarcane is mainly used for sugar production but following the recent industrial advancement, its byproducts have also been used to produce various products such as alcohol, chipboard, and dozens of others industrial chemical compounds which are a big source of revenue to the government [5]. In addition, sugarcane is one of the most water intensive crop; according to one estimate, it requires around 400 m^3 of irrigation water to produce a tonne of sugarcane in the country [15]. In the last few years, the country has been facing severe water shortages as the availability of water is decreasing due to expansion of irrigated areas, growth in population and urbanization [16]. That is why, the information about water usage and its availability for the water resource planning is required to satisfy the increasing demand for food production in future [8].

Several approaches to water footprint have been developed to quantify the impacts of water use [17]. Water footprint (WF) is a term, firstly used by Hoekstra, as an indicator of water use. It is the total volume of freshwater used to produce products, crops or goods throughout the production process [3, 14]. The term WF specifies the total amount of water used to produce a product and the relevant impacts of production systems on water resources, but this term only indicates the volumetric amount of water used which does not provide information in terms of actual impacts of water use because the water use impacts in water abundant areas cannot be compared with water scarce regions [8].

Another approach to evaluate the impacts on freshwater use is the life cycle assessment (LCA) approach which was proposed by the LCA community. In the LCA approach, the impacts related to the water use are determined in terms of water deprivation potential by combining the volumetric freshwater consumption and water stress index of the region where the water has been extracted [7].

The main source of water for the agricultural production in Pakistan is the surface water [18], while groundwater is the second largest source [19]. The Indus River and its tributaries (Chenab, Jhelum, Sutlej and Ravi) are the main sources of surface water in the country. About 80% of the total area in the Punjab province of Pakistan has freshwater availability [18]. In Pakistan, the volumetric water used for the cane cultivation is around 430 m^3 per tonne which is more than double the global average. [15, 20-21]. However, the past studies lack in assessing the environmental impacts related to the irrigation water used at the point of source and location of water used to address water scarcity in a specific region [7-8]. Therefore, the objectives of the study are (1) to assess the amount of irrigation water used for cane cultivation in the province of Punjab in Pakistan; (2) to estimate the water stress situation and deprivation potential in the Indus basin due to cane cultivation in the province of Punjab in Pakistan. The results of the study can be used by the policy makers in sugarcane cultivation planning to enhance the efficiency of water resource use in Pakistan.

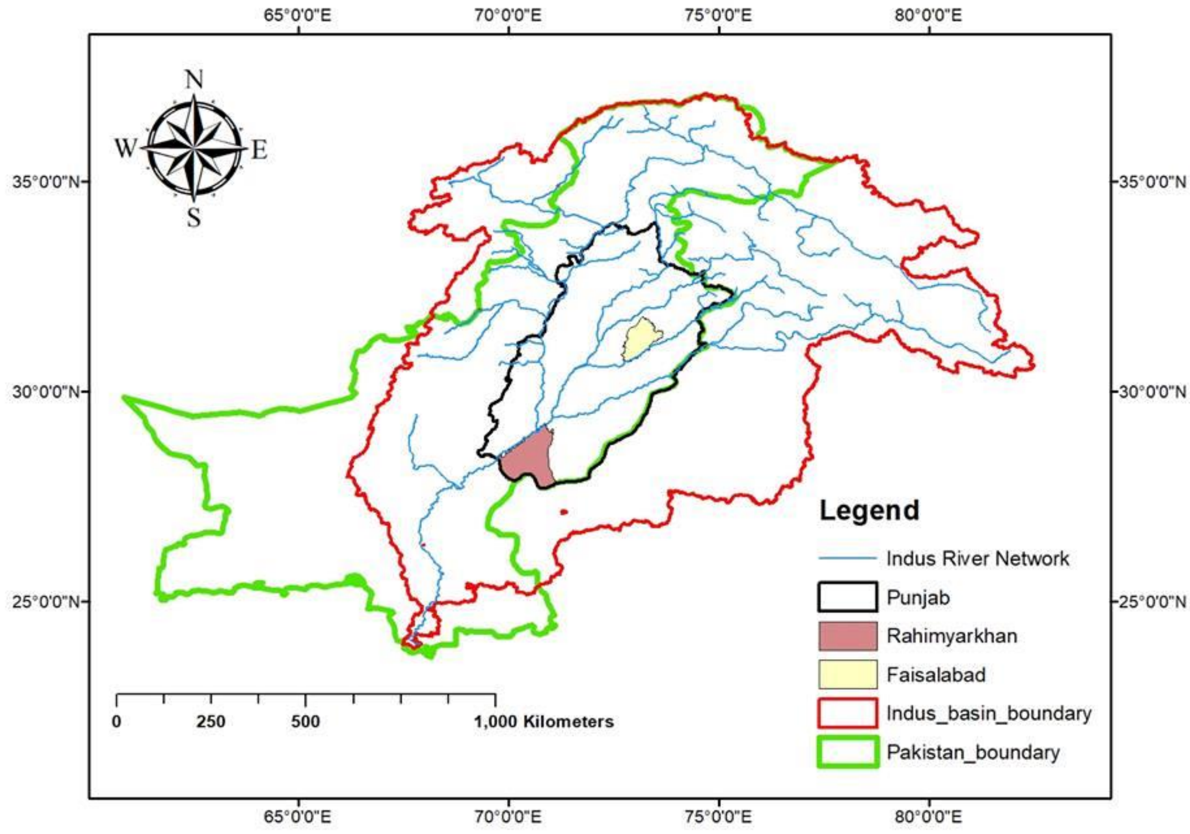
2. Materials and Method

2.1 Sugarcane cultivation in Pakistan and the study area

Pakistan is one of the countries in South Asian with total land area of 796,095 km^2. Around 40% or more of the population in the country is employed in agriculture [22]. Agriculture is the backbone of Pakistan contributing around 21% of the gross domestic product (GDP) and employs 44% of the labor [23-24]. Of the total land area, 27% is reserved for agriculture with more than 8 million farms in the country [25]. Most of the cultivable and irrigated land is in the eastern province of Punjab and Sindh around the Indus river and its tributaries [22]. The sugarcane production in the whole country is about 63.75 million tonnes on an area of 1.1 million hectares [26]. Two regions of Punjab i.e. Faisalabad located at 31.43ºN latitude and 71.10ºE longitude and Rahim Yar Khan at 28.38ºN latitude and 70.38ºE longitude, are the main domains of cane cultivation in Punjab and account for more than 50% of the total cane production in the whole province, or 32% of the whole country [27-28]. The total area under sugarcane is about 705,000 hectares in Punjab. The total cane production in Punjab is around 42000 tonnes with 30% and 29% share of the total production in the regions of Rahim Yar Khan and Faisalabad respectively [29]. The sugarcane area and production in Faisalabad and Rahim Yar Khan as reported by the Crop Reporting Department (CRD) are summarized in Table 1. The study area has been shown in Figure 1.

Table 1. Plantation area, sugarcane production and yield in Faisalabad and Rahim Yar Khan in the year 2016-2017.

Watershed	Region	Plantation area (ha)	Sugarcane production (t)
Indus	Faisalabad	106,430	5,938,900
	Rahim Yar Khan	161,060	12,478,350



Source: Punjab Agricultural Department

Figure 1. Location of Faisalabad and Rahim Yar Khan in the Indus watershed of Pakistan.

The data for the sugarcane cultivation in Faisalabad and Rahim Yar Khan has been collected from the farmers in the Punjab province. Farmers were surveyed separately in each region via questionnaires. For cane cultivation, the direct sowing method is used in the corresponding regions and cane is planted in furrows at a depth of 5-6 cm and covered with 2-3 cm soil. In the Punjab province of Pakistan, cane is usually planted in the mid of February and harvesting takes place in December or January. The planting time of 15 February and harvesting time of 16 December has been taken as a baseline cropping calendar of sugarcane in the province of Punjab for the assessment of crop water requirement (CWR). The data about the timing of surface water utilization was taken directly from the farmers. Moreover, for groundwater calculations, the data about the timing of pumping groundwater, motor horsepower, the depth of bore holes made under the ground and the diameter of the suction pipe was taken from the farmers. For assessing the CWR, CROPWAT model developed by the Food and Agricultural Organization of the United Nations (FAO) has been used [30-32]. For irrigation purpose, surface water (canal water) and groundwater are used in both regions as rainfall is the minor source of water for land cultivation in the study area. The amount of groundwater has been calculated based on the available groundwater data by using Equation 1 [33-36]. The surface water calculations have been performed with the available amount of data (canal surface water) and the Punjab Irrigation Department (PID) has recently made the data available online on their official website (irrigation.punjab.gov.pk/Search.aspx) where each distributary has its fair share of water. In this study, it has been considered according to the total withdrawal of the country that of the total water used for cane cultivation, 66.4% is canal water and 33.6% groundwater [37].

$$Q = \frac{t \times 129574.1 \times BHP}{d + \left[\frac{255.5998 \times BHP^2}{(d^2 \times D^4)}\right]} \quad (1)$$

Where;

Q = Volume of water (litres)
T = Total irrigation time for whole crop cycle (hours)
BHP = Engine power of pump (in hp)
d = Average depth of well (m)
D = Diameter of suction pipe (in inches)

The sugarcane cultivation system for the accounting of water use and deprivation caused due to cane cultivation has been shown in Figure 2. To calculate the water scarcity footprint, the water stress index has been used as a mid-point indicator (characterization factor) for the suggested midpoint category i.e. water deprivation in life cycle impact assessment (LCIA). The water stress index (WSI) indicates the portion of consumptive use of water ($WU_{consumptive}$) that deprives other users of freshwater.

The water stress index (WSI) is defined as the ratio between the freshwater withdrawal to the hydrological availability of water within a watershed [38]. The value of WSI for the watershed of Indus (Pakistan) was about 0.97 [39] which was used to calculate the water scarcity footprint of sugarcane. It should be noted that a WSI (ranges from 0 to 1) of '0' shows no stress while '1' shows the severe level of water stress in the watershed according to the methodology of Pfister et al [38]. It means that the value of water stress index for Pakistan, which has nearly approached '1', shows that the country is under severe level of water stress.

2.2 Assessment of crop water requirement

The crop water requirement (CWR), also denoted as ET_c, is defined as the amount of water lost from the soil through evaporation and the amount of water lost from crop through transpiration for proper crop growth. ET_c can be calculated by using Equation 2 [37-38]. The water accounting (water use) for the sugarcane has been estimated based on the rainfall and irrigation conditions in the cane planted areas. The data relevant to the irrigation practices collected from the farmers is used to calculate water use.

$$ET_c = ET_0 \times K_c \quad (2)$$

Where, ET_0 is the reference evapotranspiration and K_c represents the crop coefficient of Penman-Monteith equation [30-32]. The monthly ET_0 and monthly rainfall values have been calculated separately for the respective regions of cane plantation by using the past 36 years data (1981-2017) provided by the Punjab Meteorological Department (PMD). The monthly rainfall data was used to calculate the effective rainfall which is the rainfall effectively/actually used by plants or crops [40]. The values of K_c at the initial, mid-season and end-season stage of sugarcane have been taken from the Sugarcane Research Institute as shown in Table 2. For an appropriate assessment, the soil properties are also given as an input to the CROPWAT model and the relevant soil properties are shown in Table 3.

Table 2. Crop coefficient for the initial, mid-season and end-season stage in Faisalabad and Rahim Yar Khan

Region	Crop coefficient (K_c)		
	Initial	Mid-season	End-season
Faisalabad	0.45	1.3	0.52
Rahim Yar Khan	0.41	1.25	0.46

Source: Punjab Agricultural Department

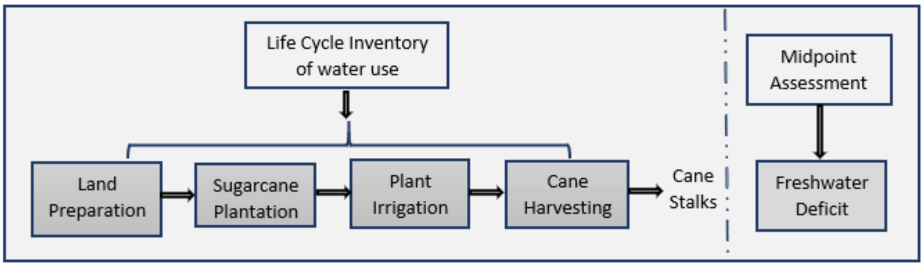


Figure 2. Sugarcane cultivation system and water use.

Table 3. Soil properties of Faisalabad and Rahim Yar Khan.

Soil Parameters \ Regions	Units	Faisalabad	Rahim Yar Khan
Soil type	-	Sandy clayey loam	Clayey loam
Total available soil moisture	mm/m	158.32	183.33
Maximum rain infiltration rate	mm/day	122	40
Initial soil moisture depletion	%	0	0
No. of horizons	-	4	4

Source: National Engineering Services of Pakistan (NESPAK)

Table 4. The amount of water used for sugarcane cultivation in the Indus watershed classified by two main regions of Punjab

Parameter	Unit	Region			
		Faisalabad	**Range**	**Rahim Yar Khan**	**Range**
Yield	t/ha	62.29	48.9-74.96	79.2	65.2-97.8
Total water used	m^3/ha	20,743	14,625-27,195	24,015	21,694-27,529
	m^3/t	333	289-385	303	257-415
Rain water used	m^3/ha	3,130	-	700	-
	m^3/t	51	42-64	9	7.2-10.7
Irrigation water used	m^3/ha	17,613	11,495-24,065	23,315	20,994-26,829
	m^3/t	283	228-341	294	250-404

In Pakistan, the rainfall is a limited source of water and the CWR is fulfilled with the application of additional amount of water through irrigation. In this study, the total amount of water used in the field is considered as the sum of effective rainfall and the irrigation water used to fulfill the CWR in an irrigated agricultural system [7]. To calculate the actual amount of irrigation water used for cane cultivation, the conveyance losses, field application losses and the irrigation efficiency for the furrow irrigation system has also been considered in the study [41]. The irrigation efficiency of 0.6 for the furrow irrigation system has been suggested by the Punjab Irrigation department (PID). To convert the crop water use in millimeters into the volume of water per land surface (m^3/ha), Equation 3 can be used [8].

$$CWU = 10 \times \sum_{d=1}^{lgp} ET_{crop}(m^3/ha) \qquad (3)$$

The factor 10 has been used for the conversion of millimeters in to m^3/ha and *lgp* represents the length of the growth period in days [14]. The crop water use, either rain or irrigation water is then converted to the units of m^3/tonne by using Equation 4.

$$CWU\left(\frac{m^3}{tonne}\right) = CWU(m^3/hectare)/yield(tonne/hectare) \qquad (4)$$

2.3 Water use impact assessment and water stress index

To assess the environmental impact related to water use, both the amount of water consumed, and the water stress situation of a specific region are considered to calculate the water deprivation indicating the amount of water deficient at the downstream for human consumption and maintenance of the ecosystem [38]. The deprivation potential or water scarcity footprint of cane be calculated by multiplying the amount of irrigation water used for the crop and water stress index of a region as shown in the Equation 5.

$$Water\ scarcity\ footprint_{sugarcane,i} = Irrigation\ water\ use_{sugarcane,i} \times WSI_i \qquad (5)$$

Where, $Irrigation\ water\ use_{sugarcane,i}$ represents the amount of irrigation water used for cane cultivation in watershed *i*, and WSI_i, represents the water stress index of the watershed *i*. The deprivation potential or water scarcity footprint is measured in units of "m^3 H_2Oeq". In this study, only the amount of irrigation water used for sugarcane cultivation has been taken into consideration to assess the water scarcity footprint as only the timing of irrigation water use can affect the local water availability in the region. A lower value of water scarcity footprint indicates less impact related to the water use and vice versa [7].

3. Results and Discussion

3.1 Water use for cane cultivation in Punjab

The average yield for sugarcane obtained by interviewing the farmers in Faisalabad for the year 2016-2017 was 62.29 t/ha for Faisalabad and that of Rahim Yar Khan is 79.17 t/ha. Table 4 represents the comparison of fresh water used for sugarcane cultivation in the two main regions of cane production (Faisalabad and Rahim Yar Khan) in Punjab province under the Indus watershed. The results revealed that the total freshwater used for cane cultivation per unit area ranges between 14,625 to 27,529 m^3/ha. Qamar et al. (2018) calculated the average dose of water for sugarcane at around 25,000 m^3/ha in Punjab providing a confirmation of the results of this study [42]. Irrigation water is the main source for cane cultivation in the respective regions as rain water is not enough to meet the crop water requirement. The irrigation water shares around 85-97% of the total freshwater used in the corresponding regions. However, per tonne of cane production, the results have shown a significant difference in the freshwater used in Faisalabad and Rahim Yar khan with the range between 289-385 m^3/t and 257-415 m^3/t of cane, respectively. This could be due to the difference in the cane yields of the regions which depend on several factors such as crop variety, soil characteristics, fertilization, irrigation water applied and other treatment practices. The global average volumetric water use of sugarcane is 210 m^3/t [3]. While the total water consumption (irrigation + rain) for the whole country was reported as 430 m^3/t. It means that water use for cane production in Pakistan is higher than the global average due to low yield reported in Pakistan [15]. The results of this study show that the total amount of water consumption for cane cultivation in Punjab is closer to the reported value (Table 4). The irrigation water used for cane cultivation in Rahim Yar Khan is more than Faisalabad due to very less contribution of rain i.e. 9 m^3/t on average to fulfill the CWR due to which more irrigation water is provided to fulfill the crop water demand. Therefore, the irrigation water, which contributes to affecting the local availability of water, should be considered by the policy makers or water planners to manage and to allocate the right share of water to its users. The graphical presentation of the amount of water use can be seen in Figure 3.

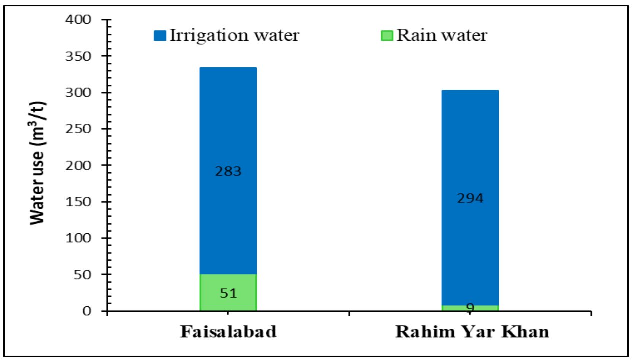


Figure 3. Rain water and the irrigation water use for sugarcane cultivation (2016-2017).

Table 5. Water scarcity footprint of cane production classified by two main regions of Punjab.

Parameter	Unit	Faisalabad	Rahim Yar Khan
Total water use	m^3/t	333	303
Irrigation water use	m^3/t	283	294
Water scarcity footprint	m^3 H_2Oeq/t	274.5	285.2

3.2 Water scarcity footprint of sugarcane

To evaluate and to compare the impact of freshwater used for sugarcane cultivation in the Punjab Province of Pakistan, the volumetric amount of water used is combined with the water stress index of Indus watershed to assess the water scarcity footprint caused due to cane cultivation in each region separately (Equation 5).

The results of the water scarcity footprint are shown in Table 5. The results show that the total water use for cane cultivation in Faisalabad is higher than Rahim Yar Khan but the water scarcity footprint in Rahim Yar Khan is comparatively more i.e. 285 m^3 H_2Oeq/t than Faisalabad. The higher value of water scarcity footprint in Rahim Yar Khan indicates that the water use impacts are relatively higher as compared to Faisalabad. Moreover, the farmers apply more irrigation water to sugarcane crop in Rahim Yar Khan due to less contribution of rainfall to fulfill the crop water requirement, thereby, creating more stress in the Indus watershed. The results of this study match with the real water stress situation in Pakistan. The per unit water consumption for the cane cultivation in both regions is significantly higher than the global average [3] which shows that the irrigation water productivity is not good for sugarcane cultivation and there is a potential for improvements to enhance the water productivity in terms of more yield production per unit of water consumption.

3.3 Recommendations in water resource management for sugarcane cultivation in Pakistan

Pakistan is one of the most water stressed countries in the world [43]. The per capita water availability in Indus-Pakistan was around 1700 m^3/person in the year 1990 which is projected to reduce to about 700 m^3/person by 2025 [44]. The results of the study have showed that there should be some suitable planning for the water resource management in the country to reduce the impacts related to the water used for cane cultivation.

The world's average yield of sugarcane is around 66 tonnes per hectare while average yield of Pakistan is around 51.5 tonnes per hectare which means that the potential yield is not achieved in the country. Many research institutes like Shakarganj Sugar Research Institute at Jhang, Quaid e Azam Agricultural Research Institute at Larkana etc. are very active in working on sugarcane variety development programs. It was observed that the varieties lose their yield potential after they are grown for few years in a specific region [45]. Different clones were tested by the Sugarcane Research Institutes in the Punjab province of Pakistan. From these tested clones, S2006-US-658 followed by S2008-AUS-133, S2008-AUS-138, S2008-AUS-134 and SPF-234 can be recommended to be grown in the Punjab province of Pakistan giving a fair tonnage of yield and promising ratoonability [46]. Moreover, the main reasons for lower yield is due to pest and disease attack and nutritional and droughts problems [47]; so, the development of the site-specific varieties for the respective problem could help to improve the yield not only at country level but also at the regional level. Thereby, the water use efficiency can be increased by improving the yield through improved cane varieties as the water use efficiency mainly depends on the crop yield [8].

The farmers in Pakistan are over irrigating their lands through flood irrigation by wasting around 50-60% of the total irrigation water applied to the field. Therefore, the water efficient technologies like precision land leveling, bed planting and the watercourse improvement can prove valuable in terms of management and the sustainable use of irrigation water is Pakistan [48]. The Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP) is under implementation since 2012 with the assistance of World Bank for the installation of 69 subsidy to the farmers via a cost-sharing arrangement of 60:40. The PIPIP project aims at the improvement of water courses and to install laser land levelers to enhance the efficiency of irrigation water [49-50]. The precision land levelling is a kind of on farm water conservation technology through which the current irrigation application efficiency of 60% can increase up to 80% with the increased crop yield because it can reduce evaporation and percolation losses from the field by faster flow irrigation water through the field as it reduces the water holding into the depressions. Moreover, on precisely levelled fields, bed planting can prove beneficial by saving irrigation water. Through bed planting (on field management technology), the water use efficiency as well as the fertilizer use efficiency can be improved. By using bed planting technique, 30-50% water can be saved with an increase in the yield by 20-25%. In Pakistan, watercourses are used to divert the canal water into the field in which a large amount of water is lost due to poor conveyance efficiency of the system. So, the lining of watercourses can save around 30-45% of irrigation water [48]. By adapting to the above mentioned recommendations, the per unit water consumption of sugarcane can be reduced through increased field efficiencies, thereby increasing the water productivity level for sugarcane production. Hence, the water scarcity footprint can be reduced in the sugarcane cultivation areas through improved water productivity.

The policy reforms are also very important for the improvement of water security in Pakistan. According to the National Sugar Policy Plan 2009-2010, the growers should be provided with the progressive techniques to conserve water [51]. Moreover, sugar beet could be used for instance to produce sugar as it does not have only a short crop cycle (4-5 months) [52], but the sugar recovery from sugar beet is also much higher than sugarcane. In addition, the irrigation management through efficient irrigation techniques (centrally pivoted sprinklers and drip irrigation) could prove a reliable way to conserve water and for its implementation. The low cost irrigation systems are available for the small-holders via a credit on its purchase with enough technical support [51].

4. Conclusion

The demand for the food production is increasing due to population growth, urbanization and economic development which exert a great pressure on the existing freshwater resources. In this study, the amount of water use and the water deprivation potential in Indus watershed due to sugarcane cultivation in the province of Punjab of Pakistan has been evaluated. The results of study revealed that the water use and the deprivation in Rahim Yar Khan was higher than Faisalabad due to very less rainfall in Rahim Yar Khan and almost the whole crop water demand being fulfilled by irrigation water. The water use per tonne of sugarcane production in Pakistan was found to be higher than the global average due to less yield gained by the farmers than the potential yield. The results of the water scarcity footprint are required to be focused by the policy makers to suggest improvements to increase the irrigation water use efficiency. This is because the volumetric water use in the Punjab province of Pakistan was found to be higher than the global average resulting in more water deprivation potential. So, by increasing the water use efficiency to obtain more yield per drop of water use can help in decreasing the volumetric water use, thereby, decreasing the water deprivation potential. Therefore, the policy makers and water planners should identify the appropriate measures to increase the water use efficiency in the Indus watershed to reduce the water scarcity footprint of sugarcane in Pakistan. So, the water scarcity footprint is an important tool to assess the risks associated with the irrigation water use and to assess the deprivation potential of water in a watershed which is hard to assess only by focusing at the volumetric amount of water used for the crop production. To increase the efficiency of water used for cane cultivation in Indus watershed, the specific crop varieties like drought resistant, pest resistant and nutrient resistant varieties are recommended to be used to gain more yield. In addition, on farm field management through precision land leveling and bed planting techniques are also recommended because precision land levelling can increase the water application efficiency to 60-80% and bed planting can save 30-50% water by 20-25% increase in yield. Moreover, by watercourse lining, around 30-45% irrigation water can be saved which is lost in the watercourses due to poor conveyance efficiency of watercourses. Furthermore, the tools like water use and water scarcity footprint can help the policy makers to postulate other measures to increase the water use efficiency for agricultural production.

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Conflict of Interest

The authors state no conflict of interest.

References

[1] Ruan, H., Feng, P., Wang, B., Xing, H., Leary, G.J.O., Huang, Z., Guo, H. and Liu, D.L. 2018. Future climate change projects positive impacts on sugarcane productivity in southern China, *European Journal of Agronomy*, 96, 108-119.
[2] Qureshi, M.A. and Afghan, S. 2005. *Sugarcane cultivation in Pakistan*, Shakarganj Sugar Research Institute, Jhang.
[3] Chaibandit, K., Konyai, S. and Slack, D.C. 2017. Evaluation of the water footprint of sugarcane in Eastern Thailand, *Engineering Journal*, 21(5), 193-201.
[4] Azam, M. and Khan, M. 2010. Significance of the sugarcane crops with special reference to NWFP, *Sarhad Journal of Agriculture*, 26(2), 289-295.
[5] Nazir, A., Jariko, G.A. and Junejo, M.A. 2013. Factors affecting sugarcane production in Pakistan, *Pakistan Journal of Commerce and Social Sciences*, 7(1), 128-140.
[6] United Nations. 2011. *World population prospects: The 2010 Revision*, CD-ROM Edition.
[7] Silalertruksa, T., Gheewala, S.H., Mungkung, R., Nilsalab, P., Lecksiwilai, N. and Sawaengsak, W. 2017. Implication of water use and water scarcity footprint for sustainable rice cultivation, *Sustainability*, 9, 2283-2295.
[8] Gheewala, S.H., Silalertruksa, T., Nilsalab, P., Mungkung, R., Perret, S.R. and Chaiyawannakarn, N. 2014. Water footprint and impact of water consumption for food, feed, fuel crops production in Thailand, *Water*, 6, 1698-1718.
[9] Mekonnen, M.M. and Hoekstra, A.Y. 2011. The green, blue and grey water footprint of crops and derived crop products, *Hydrology and Earth System Sciences*, 15, 1577-1600.
[10] Lovarelli, D., Bacenetti, J. and Fiala, M. 2016. Water footprint of crop productions: A review, *Science of the Total Environment*, 548-549, 236-251.
[11] Gheewala, S.H., Silalertruksa, T., Nilsalab, P., Mungkung, R., Perret, S.R. and Chaiyawannakarn, N. 2013. Implications of the biofuels policy mandate in Thailand on water: The case of bioethanol, *Bioresource Technology*, 150, 457-465.
[12] World Economic Forum. 2017. *The Global Risks Report 2017*, 12th Edition. Geneva, Switzerland.
[13] IPCC. 2014. Climate change 2014: Synthesis Report. In: Pachauri, R.K. and Meyer, L.A. (Eds.), *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team. IPCC, Geneva, Switzerland, p. 151.
[14] Kongboon, R. and Sampattagul, S. 2012. The water footprint of sugarcane and cassava in Northern Thailand, *Social and Behavioral Sciences*, 40, 451-460.
[15] Linstead, D.C., Sayed, A.H. and Naqvi, S.A. 2015. *Water footprint of key industrial sectors in Punjab, Pakistan*. WWF-Pakistan, Cleaner Production Institute.
[16] Khoso, S. and Ansari, A.A. 2015. An overview on emerging water scarcity in Pakistan, its causes, impacts and remedial measures, *Journal of Applied Engineering Science*, 13(1), 35-44.
[17] Gheewala, S.H., Silalertruksa, T., Nilsalab, P., Lecksiwilai, N., Sawaengsak, W., Mungkung, R. and Ganasut, J. 2017. Water stress index and its implication for agricultural land-use policy in Thailand, *International Journal of Environmental Science and Technology*, 15(4), 833-846.
[18] Hayat, A. 2007. *Irrigation sector development in Punjab (Pakistan): Case study of district Sargoda*, Master Thesis, Department of Water and Environmental Studies, Linkopings Universitet, Linkoping, Sweden.
[19] Shakoor, A., Khan, Z.M., Arshad, M., Farid, H.U., Sultan, M., Azmat, M., Shahid, M.A. and Hussain, Z. 2017. Regional groundwater quality management through hydrological modeling in LCC, west Faisalabad, Pakistan, *Journal of Chemistry*, 2017, 1-16, doi.org/10.1155/2017/2041648.
[20] Ercin, A.E., Aldaya, M.M. and Hoekstra, A.Y. 2009. *A pilot in corporate water footprint accounting and impact assessment: The water footprint of a sugar-containing carbonated beverage*, University of Twente, Enschede: The Netherlands.
[21] Ghufran, M.A., Batool, A., Irfan, M.F., Butt, M.A. and Farooqi, A. 2015. Water footprint of major cereals and some selected minor crops of Pakistan, *Journal of Water Resource and Hydraulic Engineering*, 4(4), 358-366.
[22] Library of Congress-Federal Research Division. 2005. Country profile: Pakistan.
[23] Hussain, A. and Bangash, R. 2017. Impact of climate change on crops productivity across selected agro-ecological zones in Pakistan, *The Pakistan Development Review*, 56(2), 163-187.
[24] World Bank. 2017. *Climate-smart agriculture in Pakistan. International Center for Tropical Agriculture (CIAT)*, The World Bank, Washington, D.C. Climate change profile of Pakistan. Asian Development Bank, Mandaluyong, Philippines.

[25] Agricultural census. 2010. *Pakistan Report*, Government of Pakistan Statistics Division: Agricultural Census Organization.

[26] Zhao, D. and Li, Y.R. 2015. Climate change and sugarcane production: Potential impact and mitigation strategies, *International Journal of Agronomy*, 2015, 1-10.

[27] Cheema, M.A., Farooq, M., Ahmad, R. and Munir, H. 2006. Climatic Trends in Faisalabad (Pakistan) Over the Last 60 Years (1945 - 2004), *Journal of Agriculture and Social Sciences*, 2, 42-45.

[28] Farooq, A., Asim, M. and Jan, M.Q. 2001. Groundwater geology of a part of the Indus basin in Rahim Yar Khan district, central Pakistan, *Proceedings of the Pakistan Academy of Science*, 38(2), 111-120.

[29] Planning and Development Department, Government of Punjab. 2017. *Punjab development statistics*.

[30] Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56*, Rome, Italy, Food and Agricultural Organization of the United Nations (FAO).

[31] Lee, S.K. and Dang, T.A. 2018. Predicting future water demand for Long Xuyen Quadrangle under the impact of climate variability, *Acta Geophysica*, 66, 1081-1092.

[32] Bouraima, A.K., Weihua, Z. and Chaofu, Z. 2015. Irrigation water requirements of rice using CropWat model in Northern Benin, *International Journal of Agricultural and Biological Engineering*, 8(2), 58-64.

[33] Eyhorn, F., Mader, P. and Ramakrishnan, M. 2005. *The impact of organic cotton farming on the livelihoods of smallholders. Evidence from the Maikaal bioRe project in central India*, Research Institute of Organic Agriculture (FiBL), Ackerstrasse, P.O. Box, CH-5070 Frick, Switzerland.

[34] Srivastava, S.K., Kumar, R. and Singh, R.P. 2009. Extent of groundwater extraction and irrigation efficiency on farms under different water-market regimes in central Uttar Pradesh, *Agricultural Economics Research Review*, 22, 87-97.

[35] Watto, M. and Mugera, A. 2019. Wheat farming system performance and irrigation efficiency in Pakistan: a bootstrapped metafrontier approach, *International Transactions in Operational Research*, 26, 686-706,.doi:10.1111/itor.12314.

[36] Asghar, S., Sasaki, N., Jourdain, D. and Tsusaka, T. 2018. Levels of Technical, Allocative, and Groundwater Use Efficiency and the Factors Affecting the Allocative Efficiency of Wheat Farmers in Pakistan, *Sustainability*, 10(5), 1619, doi:10.3390/su10051619.

[37] Food and Agricultural Organization (FAO). 2011. *Irrigation in Southern and Eastern Asia in figures – AQUASTAT Survey*, FAO Water Report.

[38] Pfister, S., Kohler, A. and Hellweg, S. 2009. Assessing the environmental impacts of freshwater consumption in LCA, *Environmental Science and Technology*, 43, 4098-4104.

[39] Pfister, S. 2011. *Environmental evaluation of freshwater consumption within the framework of life cycle assessment*, ETH Zurich, Switzerland.

[40] Krishan, R., Singh, P., Upadhyaya, D.A. and Roy, D.L.B., 2015. Irrigation scheduling Patna area "A case study for maize", *International Journal of Research Review in Engineering Science and Technology*, 4, 334-341.

[41] Bandaragoda, D.J. and Rehman, S.U. 1995. *Warabandi in Pakistan's canal irrigation systems: Widening gap between theory and practice*, Colombo, Sri Lanka: International Irrigation Management Institute: 89, (IIMI Country Paper, Pakistan No. 7).

[42] Qamar, M.U., Azmat, M., Abbas, A., Usman, M., Shahid, M.A. and Khan, Z.M. 2018. Water pricing and implementation strategies for the sustainability of an irrigation system: A case study within the command area of the Rakh Branch Canal, *Water*, 10(4), 509, doi:10.3390/w10040509.

[43] Briscoe, J., Qamar, U., Contojoch, M., Amir, P. and Blackmore, D. 2005. *Pakistan's water economy running dry*, The World Bank.

[44] Atlantic Council. 2012. *Water insecurity: A threat for Pakistan and India*, South Asia Center.

[45] Malik, K.B. 2014. *Cane and sugar production. Punjab Agricultural Research Board*, Technologies for the prosperity of Agricultural stakeholders.

[46] Sugarcane Research. 2016. *Government of the Punjab Agricultural Department. Annual Report*, Sugarcane Research Institute, AARI, Faisalabad Punjab, Pakistan.

[47] Ur-Rehman, M.S. 2017. *Sugar annual*, USDA Foreign Agricultural Service. Global Agricultural Information Network, Pakistan.

[48] Rizwan, M., Bakhsh, A., Li, X., Anjum, L., Jamal, K. and Hamid, S. 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), 681-698.

[49] Production sectors (Agricultural production). 2015. *Provision of laser land levelers to farmers/service providers on subsidized cost*, Directorate General Agriculture (water management) Punjab, Lahore, Available online: http://ofwm.agripunjab.gov.pk/info_application_forms

[50] Production sectors (Agricultural production). 2015. *Optimizing watercourse conveyance efficiency through enhancing lining length*, Directorate General Agriculture (water management) Punjab, Lahore Available online: http://ofwm.agripunjab.gov.pk/info_application_forms.

[51] Young, W.J., Anwar, A., Bhatti, t., Borgomeo, E., Davies, S., Garthwaite III, W.R., Gilmont, E.M., Leb, C., Lytton, L., Makin, I. and Saeed, B. 2019. *Pakistan: Getting More from Water, Water Security Diagnostic*, World Bank, Washington, DC.

[52] Khan, I. and Jamil, M. 2004. Sugar crops and sugar policy of Pakistan, *Science Vision* 9 (1-2).

