Research Article

A Critical Analysis of the Economic Valuation of Canal Irrigation Water in Punjab, Pakistan

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Abstract | Economic valuation of irrigation water is one of most critical water governance issues in Pakistan. In the agriculture-dominant province of Punjab, low irrigation water charging rates lead to its inefficient use by farmers. Under the rapidly increasing water scarcity and climate change issues, it is inevitable to assess the actual economic value of canal irrigation water in Punjab. This study applied the Residual Valuation Method to assess the real economic value of canal irrigation water of four major crops (wheat, rice, cotton and sugarcane) in Punjab. The study found that the average economic values of wheat, rice, cotton, and sugarcane crops are PKR 2.6/m^3, PKR 2.4/m^3, PKR 2.4/m^3, and PKR 3.0/m^3, respectively. These values are substantially higher than the current flat-rate canal irrigation water charging rates in Punjab. The research further indicated the need to enhance canal water charging rates to ensure its efficient use and sustainable management. The study also observed that any increase in irrigation water charge rate by the government has to be linked with farmers' overall economic returns from crop production along with ensured irrigation supply and reliable service delivery.

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Introduction

Water is one of the most demanding but poorly valued natural resources in the world. Despite its vital importance for sustainable development, water has historically been cherished as a God-gifted free and infinite resource (Rios *et al.*, 2018; WWAP, 2020). Poorly managed extraction and inefficient use of water across the globe have resulted in the scarcity and degradation of this valuable natural resource. Currently, water scarcity, declining quality and associated problems are among the most significant global risks due to their internal significance and impact on social, economic, ecological and cultural development (WEF, 2020; WWAP, 2020). Unsustainable and wasteful use of water is widespread in developing countries, including Pakistan, because of its low value – rather a freely available resource to everyone (GoP, 2012; Young *et al.*, 2019). The low price of water mostly leads to its inefficient and uneconomical use, mainly in the agriculture sector.

Globally, the agriculture sector uses almost 70% of the global freshwater resources (FAO, 2016). In agriculture-led economies, such as Pakistan, this usage is over 90% of the total water supplies, mainly used for irrigating crops (GoP, 2018; Young *et al*., 2019). Given the arid to semi-arid climate, irrigation plays a pivotal role in crop production in Pakistan. The Punjab province, with a population of about 110 million, is the main irrigation and farming hub in Pakistan (FODP-WSTF, 2012; PBS, 2017). Over 36 million acres (14.5 million hectares) of cultivated lands are irrigated in Punjab to harvest almost 80% of the total crops grown in Pakistan (PBS, 2017). These irrigated lands contribute to about 26% of the provincial gross domestic product (GDP) and cater for about 40% of the workforce in Punjab (GoP, 2017). However, the growth of irrigated agriculture has suffered badly during the last few years, mainly because of diminishing crop yields (PES, 2019; Young *et al*., 2019). Among many challenges, one of the critical issues leading to this dwindling performance is the inefficient use of irrigation water, mostly due to the low economic value of surface or canal irrigation water (GoP, 2012; Young *et al*., 2019).

At present, the annual surface or canal water supply fee – also called *abiana* in the local language – is flat and minimal, irrespective of the volume of water consumed (GoP, 2012; Young *et al*., 2019). On average, the annual irrigation water fee in Pakistan is about PKR 350 per acre (about two US dollars) with values ranging from PKR 126-214, PKR 185-428, PKR 125-210, PKR 69-136, and PKR 75-131 per acre for cotton, sugarcane, rice, maize, and wheat crops, respectively in different provinces (FODP-WSTF, 2012; GoP, 2012; Qamar *et al*., 2018). This fee does not properly reflect the actual value of irrigation water. Notably, in Punjab, the *abiana* is PKR 135 per acre (less than one US dollar) – PKR 85 in Kharif or autumn, and PKR 50 in Rabi (GoP, 2012). Particularly, Punjab occupies over 76% of the irrigated area in Pakistan and, accordingly, has the most significant impact of this low rate of canal water price (GoP, 2012). In 2003, because of various challenges in the *abiana* collection system, Punjab introduced a flat rate irrigation pricing (GoP, 2012). Although this political decision helped was made to support the farming community; it logically ignored the fact that sugarcane consumes four times more water than wheat and almost two times more than cotton. Hence, there is need for a proper understanding of the economic value of water in agriculture.

The economic valuation of water is a complex phenomenon because of its social, economic, ecological, hydrological, institutional, legal, and notably, political dimensions (Young and Loomis, 2014). Perhaps, no other commodity requires such multidimensional considerations in its economic valuation, especially in the absence of proper water markets. The economic value (EV) of water has mostly been assessed by considering it as an input in the production function (Young and Loomis, 2014). During the last two decades, different economic valuation methods have been applied by various researchers to assess the EV of irrigation water. Chandrasekaran *et al*. (2009) in India and Jaghdani *et al*. (2012) in Iran have used the Contingent Valuation Method (CVM) for assessing EV of irrigation water. Other techniques, such as Willingness to Pay (WTP) was applied by Leyva and Sayadi (2005) in Spain and Biswas and Venkatachalam (2015) in India. Likewise, the Hedonic Pricing method was used in Greece (Latinopoulos *et al*., 2004) and USA (Buck *et al*., 2014). In European countries, the EU Water Framework Directive (WFD) is the most established guiding document for estimating the real EV of water (Carvalho *et al*., 2019).

From an irrigation water pricing standpoint, Linear Programming (LP), Multi-Criteria Decision Making (MCDM), Residual Valuation Method (RVM)/ Residual Imputation Method (RIM), and Production Function Analysis (PFA) techniques are mainly found in the literature (Qamar *et al*., 2018). In recent years, the RVM is a commonly used technique employed by researchers to assess the EV of irrigation water in developing countries with numerous examples across the world. For example, Kiprop *et al*. (2015) applied the RVM to assess the EV of water for different fruits (mangoes, bananas, and lemons) and grain crops (grams, sorghum, millet, maize, cowpeas, and cassava) in Kenya. Al-Karablieh *et al*. (2012) assessed the actual EV of water for grains, vegetables, and fruit crops in Jordan by applying the RVM. In Iran, Jaghdani *et al*. (2012) compared RVM and CVM to measure the EV of water in the Qazvin Irrigation Network. Speelman *et al*. (2008) used the RVM/RIM to calculate the EV of water in an irrigation scheme in South Africa. Similarly, Bongole (2014) applied RVM to compute the net value of irrigation water in Tanzania.

In Pakistan, Qamar *et al.* (2018) used the RVM for calculating the EV of surface/canal irrigation water for rice, wheat, and sugarcane crops in the Lower Chenab Canal system in Punjab. This study pointed out that results generated by the RVM provided an insight into the actual value of irrigation water and suggested its application in other irrigation channels in Pakistan to measure the EV of irrigation water (Qamar *et al.*, 2018). Ashfaq *et al.* (2005) have also applied the RVM to assess the EV of water in Pakistan. In general, the reviewed studies argued that the RVM could provide reasonably justifiable estimates under data, funds, and time constraints. Therefore, in the context of this particular analysis, the RVM is considered to be the most appropriate technique to be applied for the valuation of canal irrigation water. Using the RVM, this article assessed the actual EV of canal irrigation water for four major crops (wheat, rice, cotton and sugarcane) in Punjab. This economic appraisal is then critically examined to evaluate the optimization of the canal irrigation water price (*abiana)* in Punjab. The section to follow explains the methodology used, which is followed by a discussion of the results and concluding comments emphasizing the findings from this study.

Materials and Methods

Study area

The study area is Punjab province – a hub of agriculture and irrigation in Pakistan. Punjab produces almost 77% of wheat, 51% of rice, 65% of cotton and 66% of total sugarcane production in the country (GoP, 2018). All these crops require irrigation, and according to an estimate, those consume about 80% of the total water resources in Pakistan (Young *et al.*, 2019), which is a disproportionately high share. Furthermore, nearly 90% of the total crop production in Punjab is dependent on irrigation provided through a vast network of irrigation canals for transporting water to the fields (FODP-WSTF, 2012). Almost 70% (over 27 million acres) of the total cropped area in Punjab is under cultivation with these major crops (GoP, 2018) and their economic significance for the province is high. Hence, an EV of canal irrigation water for the four major crops, namely wheat, rice, cotton and sugarcane, could provide a reasonable estimate of the actual price of canal irrigation water in Punjab.

Residual Valuation Method (RVM)

To estimate the EV of canal irrigation water, the present study used the RVM which evaluates the shadow price of irrigation water, considering it as an intermediate input in the production function. In this technique, the contribution of each crop production input to output is considered to measure the residual value of irrigation water (Kiprop *et al.*, 2015; Qamar *et al.*, 2018). This method is based on crop input and output costs analysis, using farm budgets. The EV of water is the difference between the crop output and the inputs costs of all non-water crop production functions (Young and Loomis, 2014). In fact, many researchers (Al-Karablieh *et al.*, 2012; Ashfaq *et al.*, 2005; Bongole, 2014; Jaghdani *et al.*, 2012; Kiprop *et al.*, 2015; Qamar *et al.*, 2018; Speelman *et al.*, 2008) have suggested the RVM for assessing the EV of irrigation water in countries where generally no water markets exist.

Conceptually, the RVM considers crop production as a function of input parameters, including irrigation water (Young and Loomis, 2014). Statistically, the crop production function in the RVM is written as:

$$Y = f(X_L, X_S, X_F, X_H, X_W, F_C) \text{.....(1)}$$

Where;

Y: Output per unit area; X_L: Land preparation cost; Xs: Seed and sowing operation cost; X_F : Fertilizer and weedicide cost; X_H: Harvesting Cost; X_W: Canal irrigation water cost; F_C: Fixed cost.

Mathematically, the production function shown in equation (1) is rearranged and simplified into equation (2), to calculate the EV of surface irrigation water. Equation (2) is similar to the equation developed by Qamar *et al.* (2018) to assess the EV or residual value of canal irrigation water in Punjab.

$$P_W = \frac{Y - X_L - X_S - X_F - X_H - F_C}{X_W} \quad (2)$$

Where;

P_w is the EV/residual value of water, and X_w is the volume of surface irrigation water consumed by crops. Assuming all parameters in equation (2) are known except P_w, the EV value of irrigation water can be assessed per unit of area. In simple terms, the EV/residual value of irrigation water is equivalent to all the non-water crop production expenses, subtracted from the total outcome, and divided by the volume of irrigation water consumed.

Table 1: *Input costs, output prices, and calculation of gross margins of selected crops, Punjab, Pakistan, 2018-19.*

Crop	Land Preparation Cost	Seed and Sowing Cost	Fertilizer and Weedicide Cost	Harvesting Cost	Land Rent/ Fixed Cost	Total Input Cost	Total Output/ Sale Price	Gross Margin
	PKR per Hectare							
Wheat	5,289	11,510	18,592	17,791	30,888	84,078	116,485	32,407
Rice	12,560	8,431	19,808	20,361	37,065	98,225	158,144	59,919
Cotton	10,603	8,918	50,085	16,828	49,420	135,853	191,008	55,155
Sugarcane	15,814	36,297	33,922	36,455	74,130	196,617	294,049	97,432

Note: *Input and output cost values are retrieved from crop budgets of PAD (2018).*

Table 2: *Estimated economic/residual value of canal irrigation water, Punjab, Pakistan 2018-19.*

Crop	Financial Returns (PKR/ hectare)		*Irrigation Water (m^3/hectare)	Water Productivity (PKR/ m^3)		Economic/ Residual Value (PKR/m^3)
	Total Output/ Sale Price	Gross Margin	Average Volume Consumed	Total Output / Irrigation Water	Gross Margin / Irrigation Water	Gross Margin Excluding Fixed Cost / Irrigation Water
Wheat	116,485	32,407	3,954	29.5	8.2	2.6
Rice	158,144	59,919	14,826	10.7	4.0	2.4
Cotton	191,008	55,155	7,660	24.9	7.2	2.4
Sugarcane	294,049	97,432	16,309	18.0	6.0	3.0

** values retrieved from OFWM Crop Water Requirement Manual (2018)*

Data used

Secondary data of crop inputs and outputs were used in this study to estimate equation (2). The average crop input and output prices for the 2018-19 financial year were collected from the Agriculture Marketing Information System (AMIS) of the Punjab Agriculture Department (PAD, whereas the average crop water requirement/volume of irrigation water consumed by the selected crops is accessed from the On-Farm Water Management (OFWM) manual of irrigation and crop water requirement. For this analysis, it is assumed that only canal water is applied for irrigating crops.

Results and Discussion

The application of the RVM has produced reasonable estimates of irrigation water price for Pakistan and elsewhere. Young and Loomis (2014) reported that RVM is the most practical method for calculating the EV of non-market commodities, including irrigation water. Similarly, Birol *et al*. (2006) suggested that RVM is a relatively simple method based on crop inputs and output data, either primary or secondary. With its foundations in microeconomic theory, the RVM technique is comparatively inexpensive (Birol *et al*., 2006; Young and Loomis, 2014). However, it does not consider the non-use values of water (Young and Loomis, 2014).

For the calculation of the gross margin, the average crop input costs and the output values of the selected crops (wheat, rice, cotton and sugarcane) were retrieved from the crop budgets of PAD. Table 1 sums up the total input costs, outputs, and gross profits for the selected crops. As shown in Table 1, the total input cost is subtracted from the output/sale price of each crop to compute the gross margin. This gross profit is the actual economic price earned by the farmers from the harvested crops. There is a significant variation in input cost, revenue earned, and consequent gross margin between the selected crops (Table 1). Generally, wheat has the lowest gross margin, whereas sugarcane has the highest economic profit. A possible reason for this variation is that sugarcane is an annual crop, whereas wheat is bi-annual. The sale price of sugarcane is also higher than that of wheat.

To estimate water productivity (PKR/m^3), the sale price and gross margins calculated in Table 1 are divided by the average volume of irrigation water consumed by each crop. Table 2 summarises the calculated water productivity and EV/residual values of canal irrigation water. The water productivity of wheat is the highest at PKR 8.2/m^3, followed by cotton PKR 7.2/m^3, sugarcane PKR 6.0/m^3, and rice PKR 4.0/ m^3. This variation in water productivity is possibly due to significantly less irrigation required for wheat compared to rice and sugarcane crops. Kiprop *et al*. (2015) and Qamar *et al*. (2018) assessed the EV or residual value of irrigation water by excluding the fixed cost/land rent from equation (2). Accordingly, the EV of canal irrigation water is calculated by dividing the gross margin (excluding the fixed cost) to the volume of water consumed by the selected crops. As shown in Table 2, the average EV or residual values of wheat, rice, cotton, and sugarcane crops are PKR 2.6/m^3, PKR 2.4/m^3, PKR 2.4/m^3, and PKR 3.0/m^3, respectively. By comparison, the EV/residual values of surface irrigation water assessed in this case study are substantially higher than the current irrigation water price in Punjab (Figure 1). Comparatively, the current water values are PKR 0.034/m^3 for wheat, PKR 0.009/m^3 for rice, PKR 0.017/m^3 for cotton, and PKR 0.008/m^3 for sugarcane when converted into per unit of volume of water consumed.

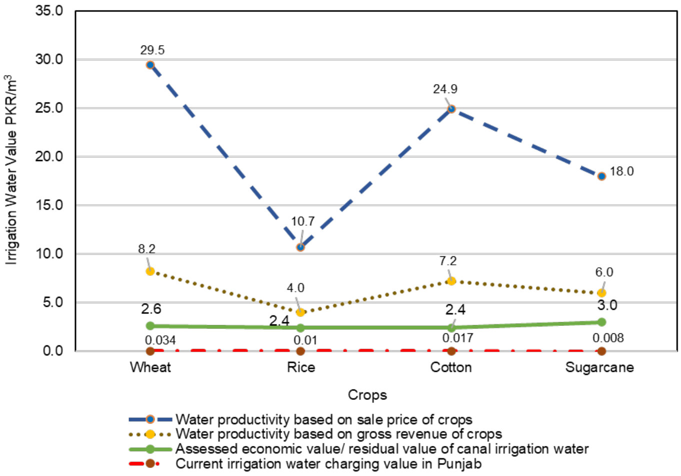

Figure 1: *Assessed water productivity, economic value, and current irrigation water values of selected crops.*

The estimated EV/residual values of canal irrigation water for the selected crops are likewise to the EV calculated by Ashfaq *et al.* (2005), Hussain *et al.* (2009), and Qamar *et al.* (2018) using the RVM technique. For example, Hussain *et al.* (2009) found that the EVs of cotton and wheat crops were respectively PKR 2.9/m^3 and PKR 1.2/m^3 in Mithaluck distributary canal in Punjab. Similarly, Qamar *et al.* (2018) found that the EV/residual value of sugarcane was PKR 4.8/m^3, and rice was PKR 4.6/m^3, in Rakh branch canal in Punjab. Most likely, the difference in the economic/residual values assessed in this case study and those calculated by Hussain *et al.* (2009) and Qamar *et al.* (2018) are most probably be due to difference in the data sources. This case study used secondary data (average values/prices), whereas Hussain *et al.* (2009) and Qamar *et al.* (2018) used primary data for the EV of irrigation water. Crop input and output prices, crop variety, agronomic practices, and soil type might also be the contributing factors to the variation in EVs or residual values. Generally, primary data give better results; nevertheless, this economic valuation provided ample understanding of the status quo and actual EV of the canal irrigation water in Punjab.

This analysis shows that the actual EV of canal irrigation water is substantially higher than the current price. Even the recovery of the existing irrigation water price is less than 50% in Punjab (FODP-WSTF, 2012). Instead of recovering the full or significant amount of the annual operation and maintenance (O&M) cost, the Punjab government provides massive subsidy on canal irrigation water. In fact, the recovery of *abiana* in Punjab is only 20% of the total O&M cost (Qamar *et al*., 2018), as shown in Figure 2. At present, the government is subsidizing about PKR 7 billion (US$ 44 million) yearly for the O&M of the irrigation sector (Qamar *et al*., 2018). This significant amount can otherwise be used to address other water governance issues. The low value of canal irrigation water and its low-cost recovery have made the irrigation system operationally inefficient and financially unsustainable. For financial sustainability and good governance of the irrigation system, it should be able to recover the full cost (capital and O&M) of the irrigation water supplies from the consumers (Bell *et al*., 2014), which is not in the case of Punjab.

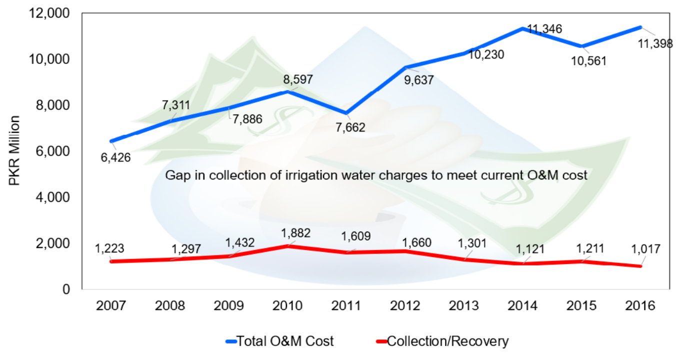

Figure 2: *Total operation and management (O&M) cost and collection of canal irrigation price in Punjab, Pakistan.*

Since the recognition of water as a scarce, vulnerable, and valuable economic commodity by the United Nations (UN) in the 1990s, many countries have introduced various water pricing instruments. In 1992, the famous Dublin Principles set the foundation for considering water as an economic good (Rogers *et al*., 2002). Dublin Principle (1) recognizes water as a vulnerable and finite resource, whereas Dublin Principle (4) defines water as a public commodity, which has social and economic value (GWP, 1999).

The primary objective of this historical declaration is to encourage efficient and sustainable use of water as a valuable resource. In response to the landmark Dublin declaration, many countries had introduced water pricing for different economic sectors. Developed countries spearheaded this transformation from valuing water as a free product to it being a priced commodity. However, non-existence of water markets is a major hurdle in assessing its real EV. In many countries like Pakistan, water is not traded as an economic good in the markets (Biswas and Venkatachalam, 2015). This makes it extremely difficult for policymakers to assess the market price and the opportunity cost of water. Over the years, the researchers have, however, developed various pricing structures for charging a price on water, especially irrigation water.

Water charging rates significantly vary across different economic sectors. Even within a particular sector, different water pricing structures exist in various parts of the world. Generally, five types of water pricing structures exist in the irrigation sector (Qamar *et al*., 2018; Rios *et al*., 2018). These are (Figure 3): (i) flat rate or area-based system, which levies a fixed water price per unit of area, regardless of the volume of water consumed; (ii) volumetric rate method, which is generally based on a variable pricing structure, wherein the volume of water used and prices are proportional; (iii) crop-based pricing system, which defines the water charges based on a variable rate per unit of irrigated area, depending on the crop type; (iv) block or tier system, which implies a multi-rate pricing, depending on threshold values of water consumed; and (v) complex rate system, as the name suggests, based on different parameters, and mostly mapped with behavioural patterns.

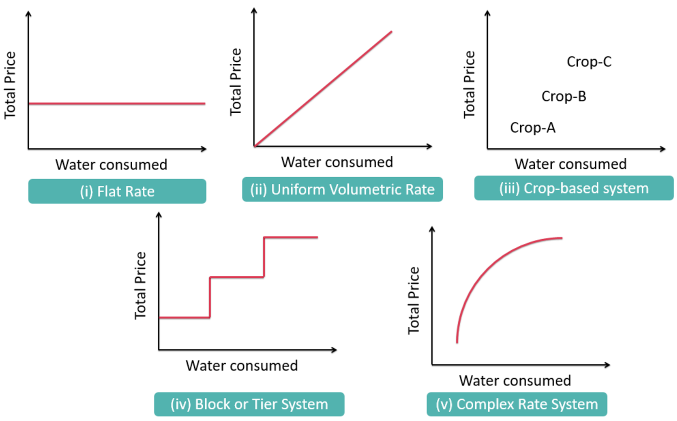

Figure 3: *Common water pricing structures.*
Adapted from Rios *et al.* (2018) *and* Qamar *et al.* (2018)

From the water pricing structures shown in Figure 3, the flat-rate system is most prevalent in developing countries like Pakistan, because it is the easiest to implement and requires insignificant monitoring. However, this system generally gains less support from researchers and policymakers as it leads to wasteful and unsustainable water consumption (Bell *et al*., 2016; Rios *et al*., 2018). Arguably, all of these water pricing instruments require the real EV of water to be assessed for better planning and implementation of any prices.

The economic valuation conducted in this study demonstrates that canal irrigation water price should be enhanced to ensure efficient use and sustainable management of irrigation water in Punjab. An increase in the actual price of surface irrigation water is probably inevitable because of a significant difference between the current minimal flat rate and its assessed price. Many researchers (Bongole, 2014; Karthikeyan, 2010; Qamar *et al*., 2018) have already proposed an increase in canal irrigation water's price, based on economic valuations. However, the primary question is, how much such an increase should be, considering the current dismal socio-economic conditions of farmers, who are still struggling to achieve food security for their households (Pervaiz *et al*., 2017), the efficiency of O&M and *abiana* collection arrangements in Punjab. Bell *et al*. (2014) noticed that farmers are generally willing to pay the irrigation price if water reliability and better irrigation service delivery are ensured. For example, farmers are paying energy/diesel costs even higher than the assessed EV of surface irrigation water for abstracting groundwater, due to its ensured availability and reliability.

Reforms in status quo-oriented systems, such as water pricing, are challenging because of multifaceted social and economic implications. Such policy changes generally need a structural approach, stakeholder involvement, ensured availability and reliability of water, improved service delivery, and a transparent and accountable mechanism for collection of irrigation water charges (FODP-WSTF, 2012; GoP, 2012; Qamar *et al*., 2018; Young *et al*., 2019). Arguably, countries like Pakistan are reluctant to opt for such sustainable transitions, due to weak institutions and the lack of implementation and monitoring strategies. However, under the current water challenges, such difficult decisions need to be made to ensure sustainable future water and food security.

Moreover, such a policy intervention would result in multiple benefits. Firstly, it would encourage the efficient use of water; secondly, it may contribute to the adoption of water-saving and climate-resilient technologies by the farmers; and thirdly, it would reduce the burden on the government budget, and help the Punjab Irrigation Department to orient itself towards a self-sustaining irrigation service delivery institution. Many researchers (Al-Karablieh *et al*., 2012; Kiprop *et al*., 2015; Qamar *et al*., 2018) have proposed such a type of policy intervention for sustainable management of canal irrigation water. However, any increase in the irrigation water price will need to be linked with the farmers' overall economic returns from the produce and with ensured irrigation supply and accountable service delivery. Under the snowballing climate change impacts on water resources, Pakistan needs to make such difficult water governance decisions to optimize water price for ensuring sustainable water and food in the future.

Conclusions and Recommendations

This study applied RVM to assess the EV of canal irrigation water for wheat, rice, cotton, and sugarcane crops in Punjab using 2018-19 data. The assessed EV/residual values of canal irrigation water for wheat, rice, cotton, and sugarcane crops are PKR 2.6/m^3, PKR 2.4/m^3, PKR 2.4/m^3, and PKR 3.0/m^3, respectively. These values are much higher than the current flat *abiana* rate, which translates to a price as low as PKR 0.008/m^3 for sugarcane. Based on this economic valuation, the enhancement of the canal irrigation water charges is proposed subject to improvements in service delivery and transparency in the *abiana* collection system. Any increase in the canal irrigation water charges, however, needs to be linked with ensured availability and reliability of irrigation water to achieve the desired outcomes, given the fact that Punjab is particularly vulnerable to climate change with long periods of drought followed by floods (Young *et al*., 2019; UNDP 2017).

Such policy interventions are always challenging. While low water charges may appear to currently protect farmers' incomes, it has long been known that they inhibit investments in securing the availability of irrigation water (Chaudhry and Young, 1989). Under the current water and climate change scenario, Punjab needs to make challenging decisions to ensure sustainable water and food security for todays and future generations. There is also a role for research in evaluating sustainable irrigation water pricing policies in Punjab, other provinces of Pakistan and across the world to help rationalize the current price and recommend feasible strategies. Moreover, the involvement of Farmer Organizations (FOs)/Water Users Associations (WUAs) is essential in promulgating any irrigation water pricing policy.

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Novelty Statement

This piece of research is original and will significantly contribute to a better understanding of canal irrigation pricing archetype in Punjab, given the imperatives of climate change. The article is a much-needed addition to the limited research on water pricing and its governance in Pakistan.

Author's Contribution

HafIz Qaisar Yasin: Comprehended the concept, carried out the data analysis, and wrote the article.
Dora Marinova: Helped in concept improvement and selection of economic valuation method.
Muhammad Naveed Tahir: Assisted in data collection and literature review.

Conflict of Interests
The author(s) pledged no potential conflicts of interest concerning the research, authorship, and publication of this article.

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