# Valuation of Irrigation Water Quality in Punjab, Pakistan

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**Abstract**

The study evaluates the irrigation water quality in different regions of Punjab, Pakistan, focusing on Sharaqpur, Lahore, Faisalabad, and Multan. These regions, with varying geographical and socio-economic characteristics, were selected to assess the impact of irrigation water quality on agricultural productivity. Primary data were collected through a questionnaire survey completed by 400 farmers, capturing information on crop types, sources of irrigation, water usage, economic viability, and challenges faced. Secondary data were obtained from FAO CLIMWAT and CROPWAT software. Descriptive statistics were used to analyze the socioeconomic characteristics of the farmers. The residual imputation model was employed to estimate the economic value of irrigation water for major crops by calculating the residual value of water per acre and per hectare. Geographic Information System (GIS) mapping techniques visualized the distribution of water quality parameters across Punjab. The results indicate that cotton and wheat have the highest residual value of irrigation water, while vegetables have the lowest. The findings suggest that optimizing water usage for high-value crops can enhance agricultural profitability and support sustainable water resource management. The study underscores the need for policies that encourage efficient water use and provide financial incentives for adopting water-saving technologies.

**Keywords:** Irrigation water quality, Residual imputation model, GIS mapping

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## 1. Introduction

Water is very important for our life and for all the activities we do in our daily life. Determining how much it is actually worth and how to use it in an efficient way it is important to have knowledge for making good decisions about things like pricing the water systems, designing different water systems, removal of subsidies and estimation of opportunity costs to industrial and domestic water uses are some reasons for the necessity for valuing irrigation water. Different microeconomic techniques used for estimating water value includes net-back analysis, hedonic models and optimizing models. In Jordan Residual imputation method is used to determine the average economic value of irrigation water for agriculture purposes. And irrigation is seen as a very important factor for rural development and they created different employment opportunities for generating income and enhancing food security [1].

Water scarcity is increasing at global level especially in developing countries. Mainly water is used for the purpose of irrigation worldwide. Globally water scarcity issues are the reason for 20% climate change globally. So, in order to protect water resources, it is important to produce and then allocate water for production purposes that use less water and yield more crops. Measuring water consumption per cubic metre of crop yield helps us understand how we can produce crops using the available quantity of water and it is a very good initiative in areas where water is present in limited amounts [2].

Groundwater resource of natural water systems is very crucial as it is used for drinking purposes, for agriculture purposes and in industrialisation as well. Because surface water is not enough for survival. But having more clean water then only water which is not enough for drinking and agricultural purposes is more important. Scientists use tools like Geographic Information System to study water. Using this technique, they found out that only a few areas have good water quality but not all of them are safe for drinking. Economists found out that groundwater resources are worth its quality of water because people are willing to pay for it [3].

Pakistan with 149 million population relies so badly on water for their agricultural needs. Because of inadequate funding for irrigation maintenance and water shortages which are common issues they are causing water logging, salinity, inequitable distribution and overexploitation. So, a water pricing initiative is very important to ensure a well-organized allocation of water for irrigation purposes. This study aimed to estimate the marginal value product of irrigation water and measure water use efficiency on farms [4].

Scarcity issues are increasing worldwide. Developing countries are the major target of it because they don't have enough resources for saving water and other reasons which are contributing to it include population growth, urbanization and industrialization. Experts think that lack of efficient water pricing systems is another less hyped reason for water scarcity issues. So, if we want to meet the needs of a growing population then proper estimation of water systems must be conducted. Groundwater irrigation through tube wells is an effective alternative but for providing water a proper water pricing system should be maintained. So basically, experts elaborate the importance of economic valuation of groundwater for irrigation purposes. And with this economic analysis should also monitor the percentage of net income per crop used to pay for water purchase expenditures [5].

In arid regions water scarcity issues are causing great challenges in building up institutions that balance both beneficial use of water with increasing demands of people. So, by doing this expert can make choices regarding water development, conservation and allocation by considering water's economic value especially at the times of heightened scarcity. For taking precise estimation for economic valuation of irrigation water it is important to work on some important factors which includes establishing denominators for water values, identifying perspectives from which values will be measured. These values for agriculture purposes illustrated after a recent drought policy of the Rio Grande Basin [6].

In Punjab Pakistan economic valuation of irrigation water is one of the major governance issues. Punjab which is known for its agriculture values due to its low irrigation water pricing is leading to idol use of irrigation water causing water scarcity and climate change risks. So, it is important to do economic valuation of irrigation water in Punjab. Here in Punjab, the residual valuation method is used to assess the economic value of canal irrigation water systems for crops including rice, cotton, wheat and sugarcane. 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. So, results showed that sustainable management is still needed for efficient output. And one more thing which is important to do is to increase irrigation water prices while considering the economic benefits of farmers and make sure consistent water supply and sustainable water use [7].A research conducted through surveys in an area having 120 farms in central Punjab. Then collected data analysed using residual imputation method and net income approach. The results showed that delivery cost for irrigation water was found to be higher than estimated delivery expense. This research could be valuable in future for determining economic valuation of different approaches to increase water resources and improving efficiency in water delivery and applications on farms (8).

Groundwater quality near Hudiara drain in Lahore analysed for irrigation and drinking purposes for different parameters including Electrical Conductivity (EC), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC) and Chloride levels. Results showed that mostly heavy metals were absent but manganese, zinc and nitrate were present within permissible limits but fluoride level was higher. Results then compared with the standard of World Health Organization (WHO) and Agriculture Department of Punjab for irrigation. Overall results show that mostly water samples were safe for drinking purpose but for irrigation purposes some water samples need to be adjusted and managed then they can be used but most samples are unsuitable for the purpose of irrigation (9).

Linear programming models used to determine the value of irrigation water for a farm located in a district of Pakistan. These models allow determination of different irrigation levels for different crops which calculate marginal value, total value under varied water supply conditions. Speciality of this model is that it considers both financial and economic situations. Analysis revealed that the economic value of water is higher than the cost of implementing water saving technologies (10).

Modern drip irrigation technology is best in the town nowadays because it is very helpful for farmers to use water efficiently by delivering it directly to plant roots. It is very efficient technology for areas with shortage of water. It is not common in Pakistan but farmers in Punjab are very interested in knowing this technology and for seeing the difference in crop growth with this technology (11).

 

In an industrial area of Pakistan a study was conducted using a mapping tool called GIS. With the help of GIS researchers looked at the areas having different water qualities. Results reveal that many parameters like pH, SAR, RSC, Sodium and phosphate levels are exceeding World Health Organization (WHO) and National Environmental Standards (NEQS) which indicates that water near industrial area is not safe for drinking as well as for irrigation purposes (12).

Arsenic is a harmful substance found naturally in groundwater. In Sheikhupura district, Pakistan, researchers studied water from 58 sources used for drinking and agriculture. They found that most elements in the water are within safe limits according to World Health Organization (WHO) guidelines, except for arsenic. Arsenic levels in the water ranged from 0.46 to 92.3 micrograms per liter (µg/L), with an average of 39.4 µg/L. Alarmingly, 87% of samples exceeded the WHO's recommended limit of 10 µg/L for safe drinking water. The type of rocks in the area and evaporation were found to be major factors affecting water quality. A map showed high arsenic levels across the district, with some areas having nearly all samples exceeding safe limits. Groundwater contamination is also a major concern in Sheikhupura. Arsenic exposure causes severe health risk to people living there. Different measures were taken to assess the quality of groundwater in Sheikhupura which includes Average Daily Dose (ADD), Hazard quotient (HQ) and Carcinogenic risk (CR). Results showed that 87$ of samples had a hazard quotient greater than 1 which indicates significant health risk in between 0.043 to 8.546 which means people are at high risk from arsenic in their water which indicates that strict monitoring and management must be done in groundwater areas (13).

Groundwater is the major demand for drinking, industry and farming in countries like Pakistan, India and Bangladesh. In Punjab Pakistan water especially for irrigation comes from groundwater. From the past few years, the demand for groundwater has increased for irrigation purposes. So groundwater should be use wisely in order to ensure future needs for irrigation purposes (14).

Water shortage for irrigation purposes is concerning nowadays. In a study different ways were used for pricing water for its efficient use. One way includes charging farmers for the water they use. Results reveal that the main problem is not about how much water costs but more about how water is given out. Farmers use the amount of water that they think is sufficient and increase or decrease in cost does not affect it. So it means farmers are not using water efficiently (15).

Groundwater plays a crucial role for growing crops worldwide because surface water is not enough for growing crops. In the study a specific area known as Lower chenab canal east was tested for changes in groundwater quality over time and space. 289 samples were tested for Electrical Conductivity (EC), For Sodium adsorption ratio (SAR), and for Residual sodium carbonate (RSC). A Kriging method was used to make maps to verify the groundwater quality. Results revealed that 40% of the area has good water quality and 49% is just okay and the remaining 10% is not good for growing crops. This information plays a valuable role in determining which part of land is best for growing crops (16).

Tube well water was investigated using statistical tools in rural and urban areas of Tehsil Mailsi in Punjab specially for checking arsenic contamination levels. Results showed that arsenic levels in tube well water are exceeding World Health Organization which is 10 (µg/L) and tube well water arsenic level is between 12 to 448.5 micrograms per litre (µg/L) which means that this water is unsafe for irrigation purpose (17).

### 1.1 Literature Review

Shakoor et al. in a study highlighted the need for the testing of the water quality before use. Significant amounts of harmful substances in solution that can reduce crop yields and impair soil fertility. Main characteristics for quality assessment irrigation water is total dissolved solids, sodium absorption ratio (SAR), Electrical conductivity and residual sodium carbonate (RSC). Unfortunately, in Pakistan, the quality of surface and groundwater is not routinely monitored for domestic use and irrigation. The water quality has worsened due to the disposal of untreated industrial wastewater and agricultural wastewater directly into groundwater and canal water. Salt water invasion into fresh groundwater areas from the saline water zone have also caused groundwater quality to deteriorate. Because of continuous circulation and replenishment of fresh water from rivers into the aquifer, groundwater, near the water bodies is suitable for use. Using untreated water for irrigation can cause soil issues such as salinity, alkalinity, and toxicity. There is a need for proper management of poor-quality water and removing the salinity from the water bodies.[18]

Mekennon et al lays stress on the issues related to water scarcity, salinity, waterlogging and water transport. 75% of the flow of the Indus river basin is diverted to Pakistan's canal irrigation system.. However, 25% of this surface water, which is 26 million acre feet (32 $km^3$), is lost due to transport losses in the canal system. Additionally, of the 78 million acre-feet (96 $km^3$) that reach headwaters, 45% is lost to transportation losses in tertiary channels. Groundwater is increasingly overexploited as the surface system can only meet 30% of the total irrigation demand. Groundwater pumping is also high maintenance, requiring significant investments in pipes and pumps and ongoing diesel expenses. Half of the total direct energy consumption in Punjab's agricultural is involved in groundwater extraction.[19]

Hossain et al explain the significance of reducing consumption and improving resource management. He highlighted that over the past few decades; over-irrigation has led to severe water shortages and reduced water quality. This study determined the irrigation requirements of cotton, rice and wheat using the CROPWAT model in southern Punjab (Multan). In the study area, evapotranspiration ranged from 1.8 to 10.24 mm/day, while effective precipitation ranged from 2 to 31.3 mm. Rice, cotton and wheat required 996.4, 623.3 and 209.5 mm of irrigation, respectively. Among rice, cotton and wheat, the total net irrigation of rice, cotton and wheat was calculated to be 72.4, 67.8 and 44.1 mm, and the total gross irrigation being 103.5, 99.8 and 63 mm, respectively. The CROPWAT model showed a moderately useful result for identifying irrigation needs in southern Punjab. The study emphasizes the need to use groundwater extraction technologies and water management technologies to implement a water management system that reduces water scarcity.[20]

Watto et al in this study uses a Positive Mathematical Programming (PMP) approach to estimate groundwater-derived irrigation demand with the help of a data set of 200 predominantly groundwater-irrigated farms from the Punjab province of Pakistan. He found that the optimal PMP solution uses less water than is available. Second, when water supply is limited, farmers allocate land to different crops based on their total yields rather than in irrigation. The results of the study suggest that restrictions on groundwater perception would force farmers to revaluate their irrigation water demand and the introduction of Rs. 0.04/$m^3$ of groundwater. It would prove to be beneficial for the farmers as it would make them aware of the economic and environmental value of water.[21]

Ghuman et al uses the concept of performance indicators to check the efficiency of the agricultural sector. The performance of a participatory irrigation management system is compared with that of a conventional centrally controlled irrigation system. The study is conducted in the Lower Chenab and Jhelum canal irrigation systems (Punjab, Pakistan). The performance indicators used included: establishment, operation/maintenance costs, collected water charges and water distribution. Data was collected from various sources i.e. field measurements, interviews from the farmers and with irrigation department officers, previous studies and data from the Punjab Irrigation Department. The analysis shows that the costs of establishing an administration and a controlled irrigation system are higher as compared to the costs of operation and maintenance. Essential changes in the governance system and capacity building work are needed to earn the benefits. [22]

Basharat et al.evaluated the growing issues of waterlogging ,groundwater depletion and the canal water supply. In Punjab, canal water supply does not solve the problem of high irrigation demand. This is due to waterlogging and exhaustion of groundwater in the Bari Doab. After the Indus Waters Agreement of 1960, the gradual reduction in flows and the eventual drying up of the rivers played a major role in lowering the groundwater levels. In this study, water allocations in the 1991 water sharing agreement, annual average canal water alteration and canal irrigation demand in Punjab were compared. It was concluded that the efficiency of existing irrigation systems can be improved by adopting the concept of Integrated Water Resources Management (IWRM). To prevent waterlogging and groundwater depletion, redistribution of canal water among irrigation parts of Punjab relative to the water demand and crop concentration is recommended.[23]

Usman et al suggests that Population growth and resource scarcity are leading depletion of natural resources. Water which is critical resource for sustaining life on Earth, however is the most scarce. Pakistan faces this issue on a larger scale due to less rainfall. Pakistan's agricultural production is largely dependent on irrigation water and requires a sustainable water management plan. However, some aspects such as water salinity, water extraction, metal toxicity and surface water restoration are among the most important issues threatening the agricultural sector of Pakistan. This review focuses on Pakistan's irrigation system, how water is distributed to farmers, policies and their implementation, with emphasis on the advanced irrigation methods in the country. Future predictions are suggested on expansion of modern technologies, improvement of agricultural education, reclamation of saline/waterlogged land, as well as better water conservation techniques.[24]

Berger et al. in this study calculated the The Water Scarcity Footprint (WSF) , which serves as a method to estimate the local impacts associated with water consumption in a certain region, with the help of high

spatiotemporal resolution for various locations in Punjab, Pakistan ,using the monetary data given by the SWAT hydrologic model and the Fe-flow hydraulic model. The calculated “water scarcity indices” (WDI) are used for two purposes such as to calculate the WSF of cotton and wheat (in the study area) and then compare it with the WSF data obtained by using the lower spatial and temporal resolution WDI. The result calculated based on the high-resolution WDI is more than 60% higher than the WSF calculated with the basin-level WDI. The study highlights the need for water scarcity factors at high spatial (e.g. partial irrigation) and temporal (monthly) resolution to obtain robust WSF results.[25]
Van et al. in This article reviews groundwater management policies in four provinces of Pakistan over the past 50 years. He illustrated the timeline of investments throughout different periods of time. Until the 1990s, the focus was almost exclusively on aids and public investment in sewage infrastructure. However, in the recent years, the development of tunnel borings has taken off, especially in the rural areas of Punjab and Baluchistan. Intensive use of groundwater has enabled significant increases in agricultural production, however there is need to address significant overuse of groundwater and its quality. In the mountainous province of Baluchistan, there is a need to promote local groundwater management and build on a number of promising examples.[26]
Hassan et al. explains the institutional arrangements for on-farm water supply and its management. Decades of effort regarding this sector were also studied. He also highlighted the issues related to the less effectiveness of agricultural sector. This study outlines investments in expanding irrigation systems, on-farm water management, and conservation technologies. This paints a clear picture of up-to-date agricultural practices and systems and has also helped identify problems in the implementation of these practices. Despite these attempts, agriculture is no longer a profitable business for most farmers, while water productivity remains the lowest in the region. The difference between on-farm water management and the irrigation department requires the formation of a new management model based on past experience to make agriculture profitable.[27]
Brar et al in this study justifies the government’s comprehensive Irrigation Management Reform Program in Punjab Province by the fact that it can improve the management of Punjab's irrigation system. Irrigation sector reforms include: i) policy for the improvement of the management irrigation system , ii) water resource management reforms, iii) reforms to improve quality of water for irrigation services, and iv) on-farm water management reforms to increase sustainability of irrigated agriculture. This article provides an overview of the main issues related to irrigation and water resources management. The paper also highlights major initiatives of the Punjab government to realize irrigation sector management reforms.[28]
Kumar et al in this article provides an overview of the current state of groundwater abstraction and strategies needed for sustainable groundwater use. He states that the Introduction of canal irrigation coupled with other management practices over the past 45 years have helped strengthen agricultural production. According to the researcher, total water bodies available for irrigation is able to meet less than 75 percent of the total water needs. The introduction of a network of canals in the south-west Punjab and not using its groundwater has resulted in the rising of the groundwater table, waterlogging and salinity problems. On the contrary, in the central Punjab area , the groundwater level has fallen to a critical level (more than 10 m) due to excessive use. An effective water management strategy of the state would be reduction in groundwater abstraction and increased groundwater recharge in an overused area. [29]
Kumar et al conducted this study in 2005-06, in two districts, Amritsar and Faridkot in Punjab (the former having a predominantly tube well irrigated area and the latter having canal and tube irrigation facilities) and assessed the extent of water depletion and measured the efficiency of irrigation at the farm level. Due to the availability of water at shallow depths, crops such as maize, groundnut and pulses replaced paddy fields and wheat throughout the state during the 1970s. The area under these two crops increased from 7.22% to 32.92% for paddy and from 37.12% to 43.53% for wheat. As a result, the problem of groundwater depletion has become serious in Amritsar district, with a drop in the level of 77 cm/year. In Faridkot district, that year's decrease was 33 cm/year. There is an urgent need to eliminate the rice and wheat cultivation where groundwater depletion is serious, regulation for groundwater use and spread improved agronomic procedures for increases efficiency of the use of water.[30]
Ijaz et al conducted a study in which data from a cross-sectional survey of 120 farms, located along the Mithaluck irrigation canal in central Punjab, was collected. The collected data were analysed using residual imputation method and changing the net income method and applying it to a linear model for estimating the productivity value of irrigation. The results of this study could prove useful in determining economic viability of various sources for water recharge and improving application efficiency.[31]
Muhammad et al formulated Linear programming models of a representative farm in a district of Punjab province, Pakistan for irrigation water value estimation. The models allow a choice between several irrigation levels for each potential crop. Model provide basis for approximating total, average, and threshold irrigation

water values. Models formulated were specified for both financial and economic scenarios. As of now, the returns from added water, estimated from the economic model, would justify investment in technologies to save water, While current government pricing policies may serve to protect low-income members of the population, they also hinder agricultural investment in increasing the productivity of scarce irrigation water.[32]

Rizwan et al shows the potential of water management technologies to save water as well as increase crop yields. Traditional irrigation practices, low crop productivity as well as low irrigation efficiency are the major problems of ordinary farmers in Pakistan. These problems are more evident in the Lower Chenab Canal Command (LCC) area, which is a major part of the Indus Basin Project in Pakistan. To overcome these challenges, various water management technologies such as precision land levelling (PLL), planting beds, drip irrigation systems and streamlining have been introduced to farmers to increase water savings and crop yields in five distribution areas – Khurrianwala, Shahkot, Mungi, Khikhi , Killianwala and Dijkot. The use of drip irrigation resulted in water conservation and increased crop yields by 30–40%, resulting in a 15-20% improvement in transport efficiency. About 2768.1 million $m^3$ and 3699.3 million $m^3$ of irrigation water can be saved if wheat, rice and cotton in the LCC command area are sown in precisely aligned fields and beds.[33]

Kaur et al used a linear programming model to suggest an optimal cropping pattern in order to increases net returns and ensure significant groundwater savings for sustainability in Punjab. The dominance of paddy wheat crop rotation has led to overexploitation and scarcity of ground water. The modification of agriculture with respect to crops with lower water consumption and the use of conservation technologies is of utmost importance. This study attempts to design a diversification plan to achieve water sustainability. The results showed that the shift in maize and basmati cultivation in Plan –I resulted in significant water saving of 8 percent. Water savings reached 16.16 percent when new cropping activities such as direct seeded rice i.e. DSR technology and conventionally seeded paddy but strain gauge scheduled irrigation were introduced without adverse impact on productivity.[34]

### 1.1.2 **Methodology**

***<u>Study Area:</u>***

The study area is Punjab’s different regions that are conducted to valuate the irrigation water quality in Punjab's different regions. The study area consists of different cities of Pakistan including Sharaqpur, Lahore, Faisalabad, and Multan. Each of these regions has a different geographical area within Punjab. Sharaqpur is a town that is located in the Sheikhupura District of Punjab, Pakistan. It is known for its agricultural significance and is situated near the Ravi River. The irrigation water quality in this area is valuated to determine its irrigation water quality for agriculture. Lahore is one of the most populous cities in Punjab which is an urbanized area where irrigation water quality might be affected by industrial activities, urban runoff, and other sources of contamination. Faisalabad is one of the major industrial and commercial centres in Punjab. It is also an important agricultural hub, known for its textile industry and agricultural production. The valuation of irrigation water quality in Faisalabad is important to determine the irrigation water quality that might be affected by both agricultural productivity and industrial development. Multan is an important agricultural region, particularly known for its production of crops such as cotton, wheat, sugarcane, and mango. The valuation of irrigation water quality in Multan is important to determine the region's agricultural economy and to ensure the health of its agricultural lands.

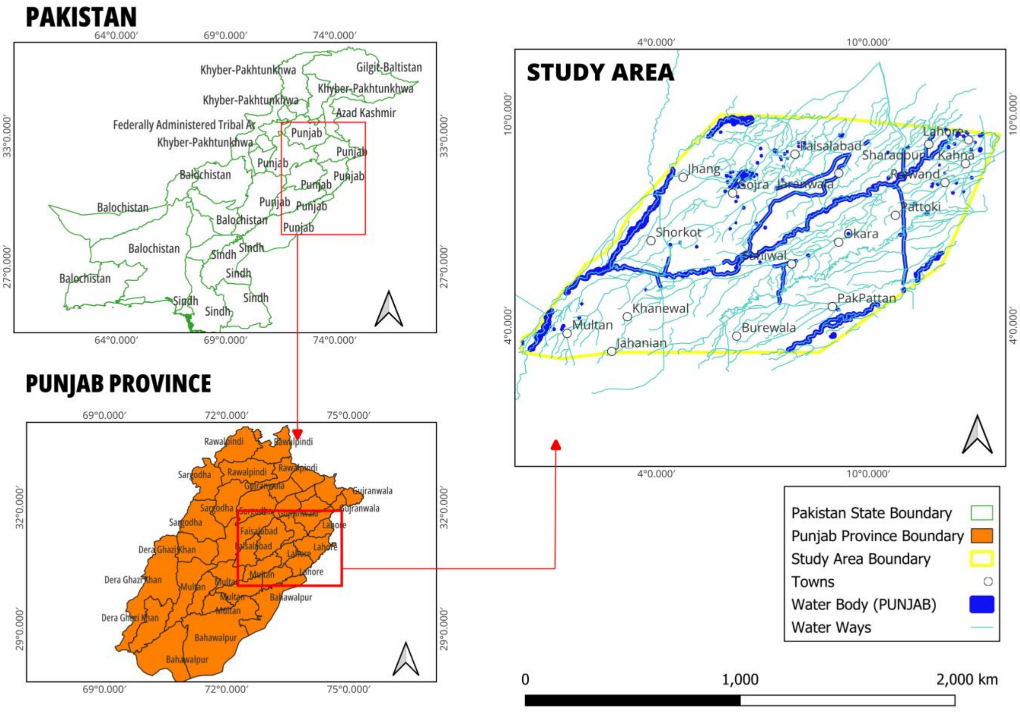


**Figure 1: Study Area Map of Punjab**

Data Collection:

Primary data was collected through a questionnaire survey that is distributed to the farmers of different regions of Punjab. The questionnaire survey was filled out by 400 farmers of different Punjab areas. The questionnaire find out the various aspects of agricultural practices related to irrigation water in a Punjab specific area. It provided information on the types of crops commonly grown with irrigation water, the main source of irrigation water, the duration of daily water supply, and the frequency of irrigation. Additionally, it find out about the economic viability of different crop types, revenue generation from crops per hectare, farmers' willingness to pay for irrigated water, and challenges faced in obtaining irrigation water. The questionnaire also investigated if any changes have been made to crop selection based on water productivity assessments, any reduction in irrigation water in recent years, and the use of water-saving technologies or practices for irrigation. Furthermore, it provided suggestions on how policymakers can support smallholder irrigation farmers in optimizing water usage and crop selection, such as by providing subsidies for water-efficient technologies, offering training on water management practices, improving access to irrigation infrastructure, and providing financial incentives for crop diversification. Secondary data on irrigation, crop-water use, and requirements can be collected from FAO CLIMWAT and CROPWAT software (2009).

***Data Analysis:***

Descriptive statistics is used to describe the socioeconomic characteristics of the farmers such as frequencies, percentages, and means. The residual imputation model can be used to determine the average economic value of irrigation water used in production across major crops grown.

***Economic valuation:***

The residual imputation model is a common method used to find the shadow pricing of irrigation water and other goods produced. The residual imputation model is used to understand how input like capital, labour, land, and irrigation water can contribute to the final output, which can be cropped. Therefore, the residual imputation model is used to determine the residual value of water for major crops grown in the different Punjab areas such as Multan, Lahore, Faisalabad, and Sharaqpur. Different crops are selected to estimate the value of water for these crops then can help to develop the farm budgets for each crop and to calculate the gross margins. It is helpful to convert all the costs and returns to per-hectare values to standardize the analysis and it can be done by deducting the production costs from gross returns and dividing by the amount of water applied (irrigation crop water requirement), and it helps to determine the price of water and its impact on crop profitability from gross returns to determine the price of water.

**Formula:**

There is an agricultural production function, where Y is the final output (e.g., crops) produced by capital (K), labour (L), land (R), and irrigation water (W):

$$\mathbf{Y = f\,(K, L, R, W)} \quad [35]$$

The total value of the output can be expressed in the following way if the technology remains constant but everything else can be changed:

$$\mathbf{TVP_Y = (VMP_k Q_k) + (VMP_L Q_L) + (VMP_R Q_R) + (VMP_w Q_w)} \quad [35]$$

Where VMP is the value of the marginal product of each resource (K, L, R, W), and Q is the quantity of each resource.

It can assume the competitive markets and known prices for factors (capital, labour, land), therefore rearrangement in the equation is helpful to find the shadow price of water ($P_W^*$):

$$\mathbf{P_W^* = (TVP_Y - P_K Q_K + P_L Q_L + P_R Q_R)/Q_W} \quad [35]$$

This formula can be used to estimate the value of irrigation water in the production process.

***GIS Mapping*:**

Geographic mapping techniques are used to visualize the distribution of water quality parameters across the different regions of Punjab. Mapping is done to determine how much area is there for irrigation how many sources of irrigation are present in the area and what kind of crops farmers are growing and what is its overall production rate.

### 1.1.3 Valuation Based On Residual Imputation Model:

**Table 1: Residual Value of Irrigation Water (m3/Acre)**

| **CROPS** | Average Total Sale **TVP** (Rs/Acre) | Average Total Cost (Rs/ Acre) | Average Gross Margin (Rs/Acre) | Average Water Consumption (m3/Acre) | Sales/ Water consumption | Residual value (Rs/$m^3$) |
|---|---|---|---|---|---|---|
| Fruits | 160000 | 90000 | 70000 | 9864 | 16.22 | 7.10 |
| Vegetables | 1000000 | 180000 | 80000 | 19728 | 50.69 | 4.06 |
| Wheat | 156000 | 80000 | 76000 | 4932 | 31.63 | 15.41 |
| Rice | 210000 | 140000 | 70000 | 96174 | 2.18 | 0.73 |
| Maize | 150000 | 60000 | 90000 | 7398 | 20.28 | 12.17 |
| Cotton | 150000 | 50000 | 100000 | 4932 | 30.41 | 20.28 |
| Sugarcane | 240000 | 95000 | 145000 | 19728 | 12.17 | 7.35 |

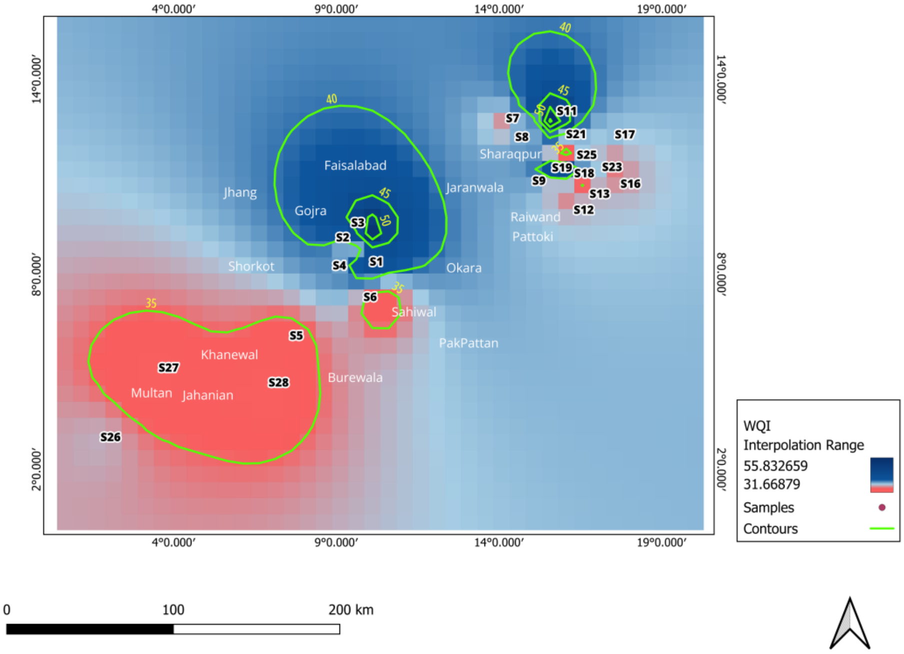


**Figure 2: Irrigation water quality index**

**Table2: Residual Value of Irrigation Water ($m^3$/Ha)**

| **CROPS** | Average Total sale **TVP** (Rs/ Ha) | Average Total Cost (Rs/ Ha) | Average gross margin (Rs/Ha) | Average Water Consumption ($m^3$/Ha) | Sales/ Water consumption | Residual value (Rs/$m^3$) |
|---|---|---|---|---|---|---|
| Fruits | 395368 | 222394.5 | 172973.5 | 24350 | 16.23 | 7.10 |
| Vegetables | 2471050 | 444789 | 2026261 | 487000 | 50.74 | 4.16 |
| Wheat | 385483.8 | 197684 | 187799.8 | 12175 | 31.66 | 15.43 |
| Rice | 518920.5 | 345947 | 172973.5 | 231325 | 2.24 | 0.75 |
| Maize | 370657.5 | 148263 | 222394.5 | 18222.6 | 203.37 | 12.20 |
| Cotton | 370657.5 | 123552.5 | 247105 | 12175 | 30.44 | 20.30 |
| Sugar cane | 593052 | 234749.75 | 358302.25 | 48700 | 12.18 | 7.36 |

 

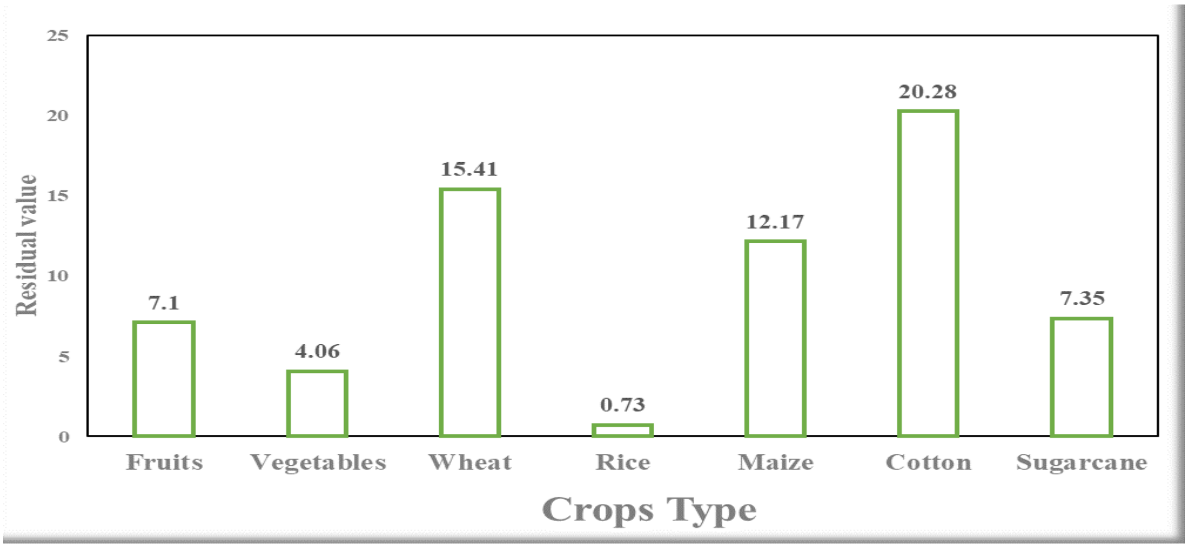


**Figure 3: RVM Value of Different Crops.**

## 2. Results:

Table 1 and Table 2 shows the average gross margins and residual value of water for the different crops; Fruits, Vegetables, Wheat, Rice, Maize, Cotton and Sugarcane. Table 1 shows the gross margin for one acre of the area for each crop and table 2 shows the gross margin and residual value for one-hectare area for each crop. From the results the highest gross margin is of sugarcane (1,45,000), followed by Cotton ( 1,00,000 ), followed by maize ( 90,000 ), Vegetables ( 80,000 ), Wheat ( 76,000 ), Fruit ( 70,000 ) and Rice ( 70,000) respectively in decreasing order. These crop budgets were used to determine the price of water (Rs/$m^3$) through Residual Valuation Method (RVM). The costs of production for each crop was determined from gross returns of each individual crop. These returns were further divided by the amount of water applied ($m^3$). Through residual valuation method the economic values of irrigation water for the seven crops were Cotton, Wheat, Maize, Sugarcane, Fruits, Vegetables and Rice were estimated on per Hectare per cubic meter and per acre per cubic meter basis. The economic value of irrigation water for different crops for one-acre land of cotton, wheat, maize, Sugarcane, Fruit, vegetables and rice are Rs. 20.28, 15.41, 12.17, 7.35, 7.10, 4.06 and 7.35 respectively. Whereas, the economic value of irrigation water for different crops for one Hectare land of cotton, wheat, maize, Sugarcane, Fruit, vegetables and rice are Rs. 20.30, 15.43, 12.20, 7.36, 7.10, 4.16 and 7.36 respectively. The highest residual value was of Cotton and wheat and lowest was that of vegetables. There was a study conducted to analyzed the groundwater from selected locations along the River Ravi, estimating its economic value and mapping threat zones. The water quality was average, with chemical and bacteriological parameters within acceptable limits. However, pH and chemical parameters exceeded WHO limits. The willingness to pay for drinking water quality was low due to low-literacy levels. The economic value of water for irrigation was found to be higher for wheat than rice and sugarcane. Farmers should be encouraged to grow wheat crops [36]. Residual value technique used to determine the economic value of irrigation water used across crops in the Kerio valley in Kenya. A sample of 216 smallholder farmers was selected, and data was collected from various sources. Field food crops, such as green grams and maize, had higher economic values than fruit trees, indicating greater potential in field crops [37]. The economic value of irrigation in Jordan was determined using the Residual Imputation Method (RIM). The results show that the average water value used in agriculture is JD 0.51 m. Cucumbers have the highest water value, followed by string beans and sweet pepper. Fruit trees have the lowest water value, with bananas having the highest. The paper suggests that low water prices may lead to excessive use, and that water prices should recover the real cost of water supply to ensure financial sustainability of water utilities [38]

## 3. Conclusion

The Residual Imputation Model for Residual Value of Irrigation Water (m3/Acre and m3/Ha) suggests that Fruits and Vegetables production provide the highest economic benefit from water use, while Rice production provides the lowest. When considering the Residual Value of Irrigation Water (m3/Ha), Vegetables provide the highest economic benefit, followed by Fruits. Other crops like Wheat, Cotton, Maize, and Sugarcane provide a lower economic benefit from water use compared to Fruits and Vegetables. These data can helps in decisions making regarding the allocation of water resources for irrigation, that have the aim of maximizing economic benefits while considering environmental sustainability.

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