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Economic valuation of the use of irrigation water in rice production in the Hadejia Valley Irrigation Scheme, Jigawa State, Nigeria

Yasir Adamu [a,*], Abdulazeez Hudu Wudil [b], Martins Olusegun Orifah [c], Umar Mukhtar [b]

[a] Department of Agricultural Science Education, Jigawa State College of Education, Nigeria
[b] Department of Agricultural Economics and Agribusiness, Federal University Dutse, Nigeria
[c] Department of Agricultural Extension and Rural Development, Federal University Dutse, Nigeria

Abstract

Water is a vital resource increasingly threatened by population growth and climate change. As the largest consumer of water, irrigation agriculture often uses this resource inefficiently. Accurate valuation and pricing of irrigation water are essential for promoting its efficient use. This study employed the residual value method (RVM) to assess the economic value of irrigation water for sustainable food production in the Hadejia Valley Irrigation Scheme (HVIS), Jigawa State, Nigeria. A multistage sampling technique was used to select 244 rice farmers, and primary data were collected through structured questionnaires. The economic value of irrigation water was estimated at ₦ 228 ($ 0.76) per cubic meter, while its technical productivity among rice farmers under HVIS was 0.79 kg m^{-3}. Findings revealed that the price currently paid by farmers is significantly lower than the water's economic value. This discrepancy stems from a flat-rate pricing system based on cultivated area, which overlooks actual water usage. The study recommends adopting volumetric pricing, using the residual economic value as a reference point, while ensuring affordability. To support sustainable irrigation practices, pricing should remain below the residual value to preserve farmer profitability.

Keywords: residual value, sustainable, technical productivity, volumetric, water pricing

1 Introduction

Water is critical for agriculture, particularly in arid and semi-arid regions where rainfall is unreliable and insufficient. Uneven water distribution, exacerbated by climate change and population growth, highlights the need for conservation (Yasin *et al.*, 2022). Irrigated agriculture is the largest global water consumer (Kiprop, 2015), and in Nigeria, agriculture is a key economic driver, employing many and contributing to GDP. However, the sector struggles with limited access to reliable irrigation systems, essential for food security and improving livelihoods (Adeyolanu & Okelola, 2024).

According to the Food and Agricultural Organisation [FAO] (2018), rice requires more water than other cereal crops and is a major staple food, with an average annual consumption of 54 kg per person globally. Rice is a vital source of nourishment for billions globally and will continue to play a vital role in ensuring food security and supporting livelihoods worldwide. In Nigeria, rice production and consumption have grown significantly, with an annual consumption rising from less than 1.1 million tons (t) in the 1960s to over 7.61 million t by 2019 (Obayelu *et al.*, 2022). Nigeria is the second-largest rice producer in Africa (Philiph *et al.* 2018; Wudil *et al.* 2023), and the largest in West Africa (Nigatu *et al.*, 2017). Kamai *et al.* (2020) reported that the average paddy yield is 2.21 t ha^{-1} in rain-fed farming and 3.85 t ha^{-1} in irrigated systems. Rice is a dietary staple for most Nigerians, leading to high demand and creating a notable gap between supply and demand, as highlighted by Ugalahi *et al.* (2016).

Getnet *et al.* (2022) point out that the challenges of water availability in sub-Saharan Africa are not only related to freshwater scarcity, climate change, or water quality degradation, but also to the management and efficiency of water use. Water use efficiency is significantly shaped by user behaviour, particularly their willingness to pay for sustainable irrigation systems and effective water resource management.

* Corresponding author: yasiradamu3@gmail.com

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Rice production is typically the largest consumer of water in agriculture. Traditional rice cultivation involves flooding fields during or after planting seedlings, leading farmers in irrigated areas to often use excessive water (Materu *et al*., 2018). A critical concern with flooded rice paddies is the emission of methane gas, which contributes to greenhouse gas emissions and climate change. Rice production is responsible for about 12 % of global methane emissions due to the flooded irrigation method (Mafo, 2022). Therefore, Mafo highlights the increasing need to improve irrigation practices among rice farmers, driven by climate variability, increasing water demand, and declining water resources.

Upadhyaya *et al*. (2022) point out that appropriate pricing and recognising the true value of irrigation water can motivate farmers to reduce consumption, curb wasteful practices, and increase investment in water infrastructure. Treating water as an economic good, with prices reflecting its value, is key to enhancing irrigation efficiency. Irrigation water pricing (IWP) involves the total payment for irrigation services, including fixed fees, volumetric charges, or crop-based valuations, calculated based on the monetary value per unit of water or per area of irrigated land per season. Water use inefficiency and low productivity stem from inefficient irrigation practices (e.g., flood irrigation), poor soil and crop management, and weak institutional frameworks. Policy issues, such as energy subsidies, low water pricing, and mismatches between crops and resource availability, exacerbate these challenges (Meena *et al*., 2024). Under-pricing of irrigation water and inadequate cost recovery mechanisms lead to wasteful use, pollution, inefficient allocation, and unsustainable water systems (Omondi, 2014).

The HVIS in Jigawa State, managed by the Hadejia Jama'are River Basin Development Authority (HJRBDA), is a gravity-based system with a potential to irrigate approximately 25,000 hectares (HJRBDA, 2023). Located in northern Nigeria's semi-arid region, HVIS supports diverse crops and livelihoods. Despite being a beneficiary of the Transforming Irrigation Management in Nigeria (TRIMING) project, which aims to improve irrigation efficiency, sustainability, and equitable water distribution, the scheme faces challenges such as inefficiencies and water wastage, particularly in rice production, threatening food production sustainability. One key issue is the flat-rate pricing system, where farmers are charged based only on farm size, ignoring the true economic value of irrigation water.

The existing literature highlights a lack of information on valuing irrigation water in the study area, as most studies (Umar, 2016; Bashir, *et al*., 2020; Adeleke *et al*., 2023) focused on analysing other aspect of the crop production, thus emphasizing the need for reliable data on its economic value. Understanding this value is crucial for developing effective pricing structures, ensuring cost recovery, and supporting the long-term sustainability of irrigation projects. This study aims to provide information on the valuation and pricing of irrigation water. It seeks to assist policy makers in establishing fair pricing frameworks that balance revenue generation with social equity, avoiding undue burden on vulnerable communities while covering operation and maintenance costs. The study therefore assessed the economic value of irrigation water in the HVIS; and determined the technical productivity of irrigation water among rice farmers under the HVIS in Jigawa State, Nigeria.

2 Materials and methods

2.1 Description of the study area

The study was conducted in the Hadejia Valley Irrigation Scheme (HVIS) in Jigawa State, Nigeria. Jigawa State is located between latitudes 11.00°N and 13.00°N, and longitudes 8.00°E and 10.15°E. The Hadejia Valley Irrigation Scheme (HVIS), managed by the Hadejia Jama'are River Basin Development Authority (HJRBDA), is situated in the Auyo and Kafin Hausa Local Government Areas (LGAs) of Jigawa State. In phase one, only Auyo LGA features developed irrigable areas otherwise known as sectors (Fig. 1). The scheme is located between the Hadejia River and its tributary, the Kafin Hausa River, near the Fadama town of Auyo. It includes a barrage with a storage capacity of 11.4 m^3 of water (Federal Ministry of Water Resources [FMWR], 2017). The region experiences an annual rainfall range of 1,100 mm to 1,600 mm, and the mean monthly temperature varies between 23 °C and 37 °C. The HVIS is comprised of six (6) sectors namely; Zumunta Rahama, Agumari, Afa, New Akubushin, Gamtsaka and Yagasha. The sectors are further divided into 19 sub-sectors as follows; Zumunta Rahama (Gamsarka, Ayama, Zumoni, Adaha sub-sectors),

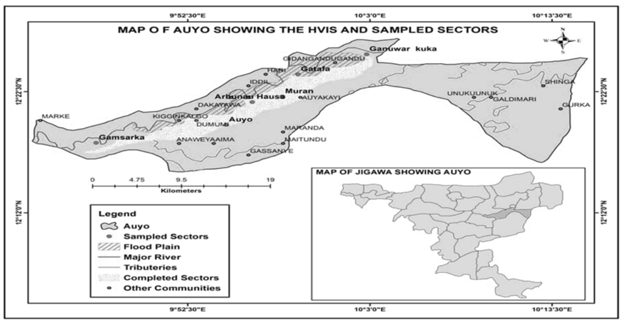

Fig. 1: *Map showing the Hadejia Valley Irrigation Scheme (HVIS) sites (sectors)*
Source: GIS Lab, Federal University, Dutse (2019)

Agumari (Marina, Mado, Auyo, Aguza sub sectors), Afa (Arbunau Hausa, Furawa, Auyakayi), New Akubushin (Akubushin, Muran sub sectors), Gamtsaka (Gatafa, Meshaywa, Tsaka sub-sectors) and Yagasha (Yamidi, Ganuwarkuka, Shawara sub-sectors) (HJRBDA, 2023).

2.2 Sampling procedure and sample size

The study targeted rice farmers within the HVIS in Jigawa State as the study population. A multistage sampling technique was used to select the respondents. In the first stage, Auyo LGA was purposively selected because of its developed irrigable areas, or sectors that are currently being rehabilitated under the TRIMING project. In the second stage, one sub-sector was randomly selected from each of the six sectors: Gamsarka, Auyo, Arbunau-Hausa, Muran, Gatafa, and Ganuwar Kuka. In the third stage, simple random sampling was used in selecting a proportionate sample of 244 rice farmers from the list provided by the HJRBDA. Of these, 230 completed surveys were retrieved and analysed (table 1). The sample size was determined using RAOSOFT sample size determination software, as used in Orifah *et al.* (2021), and subsequently allocated proportionally across the selected sub-sectors using Bowley's proportional allocation formula (Bowley, 1926).

Table 1: *Sampling distribution of the number of rice farmers in Auyo LGA using Bowley's proportional allocation technique.*

Sectors	*Sub-sectors*	*Farmers* (n)	*Sample* (n_b)
Zumunta Rahama	Gamsarka	383	39
Agumari	Auyo	816	83
Afa	Arbunau Hausa	285	29
New–Akubushin	Muran	241	24
Gamtsaka	Gatafa	438	45
Yagasha	Ganuwar Kuka	233	24
Total		2396	244

2.3 Method of data collection and analysis

The study used data from both primary and secondary sources. The primary data used for the study were collected from the selected rice farmers under the irrigation scheme for the 2024 dry season, and was achieved through individual interviews using questionnaires, while the data from secondary sources: total acreage allocated for irrigated rice production, and daily water discharges from barrage to the main canals, were collected from the HJRBDA.

2.3.1 Residual value method

The residual value method (RVM), or residual imputation model, is used to assess the economic value of irrigation water when water acts as an intermediate input in crop production (Upadhyaya *et al.*, 2022). The approach calculates the contribution of water to total crop output by subtracting the costs of all other production inputs from the total value of the crop (Qamar *et al.*, 2018).

Let the crop production function be expressed as:

$$Y = f(Q_1, Q_2, \ldots, Q_n, Q_W) \tag{1}$$

where Y is the crop output per hectare, Q_W is the quantity of irrigation water used, and Q_i represents other input quantities ($i = 1, \ldots, n$) as summarised in Table 2.

Table 2: *Description of input quantities.*

Symbol	*Description*
Q_S	Seed cost
Q_F	Fertiliser cost
Q_M	Manure cost
Q_{Hb}	Herbicide cost
Q_P	Pesticide cost
Q_{Ox}	Other agrochemical cost
Q_{Sb}	Storage bags cost
Q_N	Net (kali) cost
Q_{Is}	Irrigation siphons tubes cost
Q_h	Water hose cost
Q_{Bs}	Bird scarer cost
T	Transportation cost
L	Storage cost
Q_W	Irrigation water cost

Assuming competitive input markets, the total value product (TVP) of the crop is:

$$\text{TVP} = Y \cdot P_Y = \sum_{i=1}^{n} P_i Q_i + P_W Q_W \tag{2}$$

where P_Y is the price of the crop, P_i is the price of input i, and P_W is the price of irrigation water.

The residual value of water (RVW), or economic value of irrigation water, is obtained by isolating the water term and dividing by the quantity of irrigation water (Q_w) used:

$$P_W = \frac{Y \cdot P_Y - \sum_{i=1}^{n} P_i Q_i}{Q_W} \tag{3}$$

This estimated P_W represents the maximum price that farmers are willing to pay for irrigation water, capturing its economic value in the production process.

2.3.2 Estimation of the quantity of irrigation water used

Since there were no precise records of the total volume of irrigation water used for rice during the 2024 dry season, and farmers were unaware of the exact amount of water applied to their fields, it is essential to estimate the quantity of irrigation water used per ha. This estimation was possible due to the availability of data on the daily discharge of water from the barrage to the main canal, the irrigation frequency for each farmer (i.e., how often crops were irrigated), and the total acreage allocated for rice cultivation within the HVIS.

The daily discharge data, recorded at a rate of 2 m^3 per 1.8 m opening of the barrage gate to the main canal from March to June, was obtained from the HJRBDA's daily off-take register. These daily discharge values recorded throughout the entire irrigated rice production season were summed up and then converted into monthly volumes of water released to obtain the total volume of irrigation water used under HVIS (Table 3). The total volume of water released was divided by the total hectares of land under the scheme to calculate the average volume of water used per ha for rice cultivation (assuming water distribution was equitable and proportional to farmland size). Nevertheless, as the irrigation frequency varied between farmers, this difference enabled the estimation of the volume of water used by each farmer for rice production. A similar method was applied by Omondi (2014) to determine per-ha volume of irrigation water for rice cultivation.

Table 3: *Estimation of irrigation water volume used in the Hadejia Valley Irrigation Scheme (HVIS) from March to June 2024.*

Item	*Amount / Quantity*
Total volume of water released, V (m^3)	26,850,240
Number of times water was released, T	31
Total acreage under HVIS, A (ha)	5,814.3
Average volume of water diverted per hectare per release, X (m^3 ha^{-1})	$X = \frac{V}{T \cdot A} = 149$
Total volume of water used by each farmer (m^3 ha^{-1})	$X \times$ irrigation frequency

2.3.3 Technical water productivity analysis

The technical water productivity (TWP) was calculated as total paddy grain yield divided by total volume of water applied to the fields and was expressed in kg m^{-3} as shown in equation 4.

$$\text{TWP (kg m}^{-3}) = \frac{\text{Grain yield (kg)}}{\text{Total water applied (m}^3)} \qquad (4)$$

3 Results

3.1 Landholdings of respondents

Table 4 shows the distribution of farm sizes among respondents. The majority of farmers (74%) operate small plots between 0.2 and 1.3 ha, with only 8% holding more than 2 ha. The mean land size was 1.0 ha (SD = 0.71 ha). Regarding land allocated to rice production, most farmers (81%) devoted 0.2–1.3 ha, with a mean of 0.87 ha. These results indicate that small-scale farming dominates the scheme and that not all irrigable land is exclusively used for rice cultivation.

Table 4: *Distribution of respondents based on their farm size (n=230).*

	Resp.	*Min.*	*Mean*	*Max.*	*Std.*
Variable	*%*	*in ha*			
Land size within the scheme					
0.2 – 0.7	38				
0.8 – 1.3	36	0.2	1.00	4.8	0.71
1.4 – 1.9	18				
2.0 and above	8				
Size of farm devoted to rice production					
0.2 – 0.7	44				
0.8 – 1.3	37	0.2	0.87	4.8	0.62
1.4 – 1.9	16				
2.0 and above	3				

3.2 Costs and returns from irrigated rice production

Table 5 presents the cost and return structure of irrigated rice production. The average total variable cost (TVC) per hectare was ₦ 1,103,266, with labour representing the largest share (41%). Average paddy yield was 5,607 kg ha^{-1}, of which 4,243 kg ha^{-1} was sold. With a unit price of ₦ 640 kg^{-1}, total revenue amounted to ₦ 2,716,960 ha^{-1}, yielding a gross margin of ₦ 1,613,694 ha^{-1}. These figures highlight the profitability of irrigated rice production under the scheme.

3.3 Economic value of irrigation water

The residual value method (Equation 3) was used to estimate the economic value of irrigation water. As shown in Table 6, the residual value of water (RVW) was ₦ 228 m^{-3}, indicating that each cubic metre of irrigation water contributed substantially to farm profitability. Current charges for water, based on flat O&M fees of ₦ 40,770 ha^{-1}, are considerably lower than this economic value, highlighting potential underpricing.

Table 5: *Distribution of respondents based on their farm size (n=230).*

Variable	*Quantity*	*Unit price**	*Total**	*%†*
Costs				
Seed (kg)	53.2	700	37,240	3
NPK fertiliser (kg)	246.8	645	159,186	14
Urea fertiliser (kg)	177.9	756	134,492	12
Manure (kg)	5981.2	11	65,793	6
Herbicide (L)	5.6	4,150	23,240	2
Pesticide (L)	4.7	3,400	15,980	1.4
Other agroch. (kg)	3.7	2,930	10,841	1
Storage bags	62	430	26,660	2.4
Net (Kali) (m)	7.7	8,190	63,063	6
Irrigation Siphons (m)	7.8	3,610	28,158	3
Hose (m)	14.4	4,040	58,176	5
Bird scarer (packet)	5	900	4,500	0.4
Transportation	-	-	21,536	2
Labour (man-days)	71	6,400	454,400	41
TVC			*1,103,266*	100
Returns				
Av. yield of paddy (kg)	5,607	-	-	-
Av. quantity sold (kg)	4,243	-	-	-
Rev. from paddy (₦)	4,243	640	2,715,520	-
Rev. from by-prod. (₦)	8	180	1,440	-
Total revenue (TR)			*2,716,960*	-
Gross margin (₦)			*1,613,694*	-

*in ₦ (1000 ₦ corresponded to USD 0.625 in 2024, the year of the survey); †in percentage of total cost; TVC = Total variable cost.

3.4 Technical water productivity of irrigation water

Technical water productivity (TWP) measures the efficiency of water use in crop production (Kijne *et al.*, 2003). Table 6 shows that an average of 7,079 $m^3\ ha^{-1}$ of water was applied, resulting in 5,607 $kg\ ha^{-1}$ of paddy. The TWP was 0.79 $kg\ m^{-3}$, indicating moderate water productivity under HVIS. These results underscore the importance of irrigation in enhancing rice yields compared to traditional rain-fed systems and suggest potential for further efficiency improvements.

Table 6: *Technical water productivity and economic value of irrigation water per hectare.*

Item	*Amount/ Quantity*
Average yield of paddy ($kg\ ha^{-1}$)	5,607
Gross margin (₦ ha^{-1})	1,613,694
Av. volume of irrigation water applied ($m^3\ ha^{-1}$)	7,079
Technical water productivity ($kg\ m^{-3}$)	0.79
Economic value of irrigation water (₦ m^{-3})	228

4 Discussion

The calculated gross margin per hectare (₦ 1,613,694) demonstrated that irrigated rice production was highly profitable in the study area. This was consistent with the findings of Bashir *et al.* (2020), who reported a gross margin of ₦ 9,670,400 and a net farm income of ₦ 9,619,450 per hectare, confirming profitability in rice farming under irrigation. Beyond profitability, the gross margin together with the volume of water used were critical in evaluating the economic value of irrigation water and in informing efficient water pricing strategies. The estimated economic value of irrigation water in this study (₦ 228 m^{-3}) was higher than values reported elsewhere. For example, Wudil *et al.* (2023) estimated 0.11 USD m^{-3} (₦ 41.22 m^{-3}, at an exchange rate of ₦ 380 per USD in 2023) for rice production in the Kano River Irrigation Project. The difference between these studies was likely not due to differences in actual water use efficiency, but rather to macroeconomic conditions. By 2025, the exchange rate had risen to ₦ 1,599.55 per USD, almost four times the 2023 level, reflecting a significant depreciation of the Naira. Consequently, differences in economic water values across studies should be interpreted in light of exchange rate fluctuations, which heavily influence monetary valuations. A similar pattern was observed when comparing the present result with that of Upadhyaya & Roy (2020), who reported INR 4.73 m^{-3} for rice in India (₦ 22.79 m^{-3} at the 2020 exchange rate). These cross-country comparisons highlighted how both economic conditions and irrigation contexts shape water valuation.

The residual value of ₦ 228 m^{-3} obtained here could serve as a benchmark for potential irrigation water pricing, representing the maximum price farmers should theoretically pay while still covering production costs. However, for long-term sustainability and farmer welfare, prices should be set below this benchmark. Moderately higher water charges could promote more efficient use, generate funds for infrastructure operation and maintenance, and strengthen the financial viability of irrigation schemes, provided that service quality and reliability are simultaneously improved. This perspective aligned with Yasin *et al.* (2022), who recommended that increases in canal water charges be tied to improved delivery and transparent collection. By contrast, setting charges close to or above full cost recovery could erode farm profitability and discourage water use. Rodgers (2004) similarly argued that volumetric tariffs approaching full cost recovery would disproportionately burden farmers while producing only modest water savings. These findings suggest that careful calibration of water pricing is required to balance efficiency, equity, and sustainability.

In terms of technical water productivity (TWP), the study found that 0.79 kg of paddy was produced per cubic meter of water applied. This exceeded the 0.514 kg m^{-3} reported by Wudil *et al*. (2023) for rice under the Kano River Irrigation Project and fell within the global average range of 0.6–1.6 kg m^{-3} identified by Zwart & Bastiaanssen (2004). Although this value indicated reasonable water use efficiency, there remains considerable room for improvement. Modern irrigation technologies, such as soil moisture sensors and drip systems, alongside precision agriculture practices, could increase TWP further. In addition, farmer training and better water management strategies would help minimise water losses. Mdemu & Francis (2012) argued that aligning irrigation with periods of high-water availability and optimising field operations are effective strategies to improve water productivity in large-scale rice schemes. Enhancing TWP would not only raise output per unit of water but also increase the economic value derived from irrigation, as greater gross margins could be realised per cubic meter of water applied.

5 Conclusion

Irrigated rice production was shown to substantially enhance farmers' profitability, as indicated by gross margin, yield, and water use efficiency. However, the current area-based pricing system in HVIS undervalues irrigation water, charging well below its estimated economic value. The residual value calculated in this study offers a useful benchmark for designing fairer and more sustainable pricing strategies that recognise the true value of water while remaining affordable for farmers. Linking water charges to economic value is therefore essential for improving productivity and safeguarding long-term food security. Based on these findings, the following recommendations are proposed:

1. If volumetric pricing is adopted by HJRBDA, the economic value of irrigation water estimated in this study should serve as a benchmark, while ensuring prices remain affordable for farmers.

2. To maintain profitability and scheme sustainability, water charges should be set below the residual value and adjusted in line with farmers' economic returns.

3. Promote public–private partnerships to leverage investment and expertise for the development of irrigation infrastructure, facilitating access to advanced technologies and efficient services.

4. Install water meters at both scheme and farm levels under volumetric pricing, in order to monitor usage, prevent unauthorised diversions, and enable accurate billing.

5. Encourage farmers to adopt efficient irrigation techniques and modern water-saving technologies (e.g. alternate wetting and drying, direct seeded rice, drip irrigation, soil moisture sensors) to reduce wastage and secure sustainable water and food supplies.

Conflict of interest

The authors declare that they have no conflict of interest.

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