Analysis and Calculation of Agricultural Irrigation Water Consumption in Southern Lift Irrigated Area

Rongxiang Hu[1,*], Hongwei Jia[1], Yu Wang[2], and Yujie Wang[1]

[1]Zhejiang Institute of Hydraulics & Estuary (Zhejiang Institute of Marine Planning and Design), Hangzhou, Zhejiang Province, 310000, China
[2]Haining Shangtang River Basin Water Resources Management Service Center, Haining, Zhejiang Province, 314400, China

*E-mail: 364601233@qq.com

Abstract. The imperative task of calculating agricultural water consumption (AWC) in southern lift irrigated areas relies on pump station machinery, making it a crucial aspect of statistical analysis. Based on pump station calibration data, this study used different statistical methods to calculate the irrigation water consumption of typical irrigation areas in southern China, and analyzed the rationality of the results of different methods. In this study, a statistical method of irrigation water consumption based on the calibrated total pump station electricity consumption is proposed. The results are more consistent with the actual results and have the value of popularization, which can be used as a reference for the relevant water consumption statistics in lift irrigated areas.

Keywords: agricultural water consumption; lift irrigated areas; pump station calibration.

1 Introduction

Agricultural water consumption (AWC) constitutes a significant portion of industrial water consumption, surpassing 40% and ranking as the primary consumer of water resources. Clearly understanding agricultural water consumption is crucial for more efficient water resource management. However, it possesses distinctive characteristics compared to other industries. Currently, the measurement of agricultural water consumption faces limitations, mainly due to the absence of water charges in agriculture, leading to inadequate measurement efficiency [1]. Compared to the gravity irrigation district, the irrigation area controlled by a single port is smaller in the lift irrigated areas. However, in certain southern irrigation areas, dozens or even hundreds of stations are bundled into large and medium-sized irrigation areas. Due to the abundance of water sources in these irrigation areas, the comprehensive metering of all outlets presents a substantial installation workload. This gives rise to financial challenges, making it challenging to bear the associated capital pressure. Additionally, substantial human and

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material resources are required for the subsequent operation and maintenance of equipment in the following years [2] . In this context, there is a need to find a convenient and feasible measurement and statistical method. The intrinsic link between electricity consumption and water consumption allows for the calculation of water consumption through the conversion of electricity into water [3]. In recent years, the study of electricity-to-water conversion (EWC) has gained significant attention and widespread recognition, leading to the successive introduction of multiple standards and specifications. This progress has notably advanced and standardized the calibration work of pump stations, resulting in more accurate and convenient water consumption results based on electricity statistics. Traditional methods of water meter measurement had high maintenance costs [4], and data collection required a lot of manpower and resources [5]. Although remote water meters could collect data in real time, the costs of maintenance, theft prevention, and management were relatively high. In 2017, Hebei Province issued relevant documents, explicitly proposing the use of EWC to determine the water consumption for agricultural irrigation [6]. In 2019, Shanghai comprehensively promoted the method of measuring agricultural water consumption primarily through "electricity-based measurement and electricity-to-water conversion". This method employs individual electricity meters to measure water pump consumption and converting it to water volume through an "electricity-to-water" conversion factor. Li et al. [7] conducted an analysis of the influencing factors of the EWC factor for groundwater in the Hebei Plain. They found that increasing groundwater depth reduced the EWC factor, suggesting the need to consider the impact of seasonal variations in groundwater in practical applications. Liang et al. [8] conducted experimental observations on different irrigation methods, proposing a negative correlation between the EWC factor and irrigation system pressure. Peng et al. [9] selected typical blocks and used a method combining the EWC or actual water metering with water quotas and planting areas to estimate agricultural water consumption in Tianjin. They considered this method effective in obtaining the annual actual water consumption. Wang et al. [10] utilized remote sensing techniques to acquire a broad range of spatial and temporal distribution of planting structures, obtaining the AWC in the research area.

Zhejiang Province has placed significant emphasis on the EWC measurement. In 2019, it formally specified EWC as a method [11] for measuring water and proposed a requirement for recalibration every two years. Practical experience has demonstrated the clear advantages of EWC compared to installing water level gauges downstream of pump stations. With the implementation of water consumption statistics systems in recent years, bolstering agricultural water management, improving water metering, and strengthening water consumption statistics have appeared more and more frequently in various guiding opinions and methods. Establishing the calculation process and ledger for water consumption is foundational for water management, especially in large and medium-sized irrigation areas, which are key focus areas for national and local authorities. At present, the comprehensive reform of agricultural water prices and the calculation and analysis of the effective utilization factor of farmland irrigation water often rely on typical stations. However, the representativeness of these stations is frequently insufficiently analyzed, leading to potentially significant errors. Given these requirements, conducting measurement work based on the electricity consumption of all pump stations emerges as a promising research direction.

2 Methods

Water consumption statistics methods often fall into two main categories: comprehensive statistics and sampling statistics. Sampling statistics involve using samples to represent the entire population, making it an incomplete statistical method. In lift irrigated areas, where pump stations primarily serve as the water source, and the water source type is singular, sampling methods have a certain foundation. This study categorizes the sampling statistics of irrigation water consumption in lift irrigated areas into two methods based on different approaches: the per-mu estimation method based on typical pump stations and the electricity-based estimation method also based on typical pump stations.

The per-mu estimation method, applicable when numerous pump stations make individual measurements impractical in the irrigation area, involves extrapolating the total water consumption for the entire area based on representative pump stations. The calculation formula is as follows:

$$W = \sum_{i=1}^{n} \left(\frac{W_i}{A_i} \times A_{surface\ i} \right) \quad (1)$$

In the formula, W represents the irrigation water consumption for the entire irrigation area, m^3; W_i represents the water consumption at the metering point of the i typical pump station, m^3; A_i represents the controlled irrigation area of the i typical pump station, ten thousand mu; $A_{surface\ i}$ represents the on-surface irrigated area of the i typical pump station, mu; n represents the number of typical pump stations in the irrigation area. The water volume of typical pump stations can be obtained through direct measurement or converted using EWC.

Based on the method of using electricity consumption for rate calibration at typical pump stations, it is also a sampling method. Unlike gravity irrigation districts, pump stations have a natural advantage. Due to the necessity of collecting electricity fees, each pump station is equipped with a nationally standardized electricity meter, providing relatively accurate data that reflects the actual electricity consumption of the pump station. The electricity meter in irrigation pump stations primarily measures the electricity consumption generated during water lifting. Based on this premise, the irrigation water consumption can be estimated using the EWC factor, and the calculation formula is as follows:

$$W = \sum_{m} N_i K_i \quad (2)$$

In the formula, W represents the irrigation water consumption for the irrigation area, m^3; N_i represents the electricity consumption of the i pump station for the irrigation area, k·wh; K_i represents the EWC factor of the i pumping station, m^3/k·wh; m represents the number of pump stations in the irrigation area.

By acquiring the electricity consumption and EWC factor for each pump station, the water consumption for each pump station can be calculated through Equation (2) and subsequently aggregated to determine the total water consumption for the entire area—an ideal scenario. However, practical operations encounter significant challenges due to the extensive workload associated with calibrating the EWC factor for pump stations, compounded by the absence of calibration conditions in some stations (e.g., underwater or lacking a straight pipe section). To enhance the practicality of such methods, all pump stations in the region are classified based on certain criteria, often determined by pump types. Within the same category, the EWC factor remains constant, allowing the determination of water consumption for each pump station, which can then be accumulated. The formula is then transformed into:

$$W = \sum_m N_t K_t \tag{3}$$

In the formula, W represents the irrigation water consumption for the irrigation area, m^3; N_t represents the total electricity consumption of the t class water pump in the irrigation area, k·wh; K_t represents the EWC factor for the t class water pump, m^3/k·wh; t represents the number of typical pump stations classified in irrigation areas.

The key point of sampling statistics lies in the representativeness of typical pump stations. Beyond the pump station itself, agricultural irrigation water involves various factors such as crop water demand, irrigation area size, management level, topographic conditions, and regional distribution. When the area of water-consuming crops, such as rice, is significant, the irrigation water consumption of the pump station is large, and vice versa. The management complexity and associated challenges amplify with the larger irrigation area controlled by the pump station. Furthermore, pump station management is susceptible to the influence of administrators. For instance, larger landowners may have more meticulous practices in electricity bill payments, while smaller landowners, not involved in electricity billing, might lack awareness of water and energy conservation, resulting in elevated water consumption. Significantly, the actual lift has a notable on the EWC factor. Therefore, ensuring the representativeness of typical pump stations is challenging. The calculation method based on the average mu of typical pumping stations often involves a limited number of stations, significantly impacting the results. The accuracy of obtaining the actual irrigated area in the irrigation district, reliant on a small number of pump stations, poses a considerable challenge, significantly influencing the results. Based on the calculation method of rated utilization electricity of typical pumping stations, as it obtains the electricity of all pumping stations, it also has a comprehensive theoretical basis for statistics, and it does not need to consider the actual irrigation area factor, resulting in better accuracy.

3 Materials

The Shangtang River irrigation district, situated in Haining, Zhejiang, represents a typical southern plain river network lifting irrigation district. Employing river channels as its water sources, the district utilizes pump stations for nearby lifting irrigation. Each individual pump station irrigates an area of 300-500 mu, with a low lift (3-5 m) and mainly utilizes mixed-flow and axial-flow pumps. The primary crop in the district is rice, with some other economic crops also in cultivation. Statistics indicate the presence of 398 water pumps in the district, manufactured between 2000 and 2023, with the majority produced from 2010 to 2015—coinciding with an era of extensive small-scale agricultural water conservancy construction in key counties. The pump diameters range from 200 to 350. The district's peripheral area incorporates controlled backflow projects, lifting water from downstream to upstream. The river water level remains below the normal hydrological level, with small monthly fluctuations. The power supply company has access to the annual monthly electricity consumption data for all pump stations in the district. In selecting typical calibrated pump stations, various factors, including the district's transformation status, distribution of township pump stations, pump types, construction years, pipe diameters, lift, and managerial types, were considered to ensure representation of the overall characteristics of pumps in the region. Calibration activities were executed on 20 pumps in the field, concurrently measuring the actual net lift of the pumps, ranging from 1.24 to 3.77 m.

4 Data and Analysis

4.1 Pump station calibration

Through calibration, the EWC factor for the 20 water pumps ranged from 38 to 62 m^3/kWh, with an average of 50 m^3/kWh, showing significant differences between individual pumps. The field measurement is mainly based on a mixed flow pump. Generally, larger-diameter mixed-flow pumps exhibited a higher EWC factor. For example, the 350HW pump had a factor of 62 m^3/kWh, compared to 52 m^3/kWh for the 300HW model, representing a 19 % increase. In the comparison between the 250HW and 200HW pump models, the former showed a factor of 54 m^3/kWh, whereas the latter had 43 m^3/kWh, indicating a 20% increase. However, when comparing the 250HW and 300HW models, the former had a factor of 54 m^3/kWh, and the latter had 52 m^3/kWh. The calibration results for different pump models are shown in Table 1.

Table 1. Summary of calibration results for different types of water pumps

Model of pump	200HW	250HW	300HW	350HW	300HDB-7C
The EWC factor (m^3/kWh)	43	54	51	62	38

4.2 Water consumption calculation

(1) Method based on the typical pump station per-mu estimation.

According to the calculation and analysis results of the factor of Haining City in 2022, the water consumption for the entire irrigation area was estimated using measured data from four pump stations: Mugang Pump Station, Shengli Pump Station, Zhangjia Pump Station, and Xitang Pump Station. The per-mu irrigation water consumption for these typical pump stations was determined to be 531 m^3/mu. With an actual irrigation area of 70,000 mu in 2022, the calculated irrigation water consumption for the Shangtang River in 2022 was 37.2 million m^3.

(2) Method based on the typical pump station calibration using the electricity consumption.

The irrigation area comprises 398 machine stations, predominantly featuring mixed-flow pumps, with a few axial-flow pumps and submersible pumps, as illustrated in Table 2.

Table 2. Water consumption statistics of different types of pump stations in irrigation areas

Water pump type	200HW	250HW	300HW	350HW	300HDB	others	total
Number of pump stations (units)	151	40	148	24	16	18	398
Proportion	38%	10%	37%	6%	4%	4%	100%

By collecting the electricity consumption data from the 398 machine stations in the irrigation area, excluding some non-agricultural electricity consumption, and summarizing it based on pump types, we obtained the electricity consumption for each pump type, as shown in Table 3. By multiplying and summing the electricity consumption with the EWC factor for different pump types, the water consumption in the Shangtang River irrigation area was 46.25 million m^3, which is 19.6% higher than the per-mu estimation method based on typical pump stations, indicating a significant difference.

Table 3. Electricity and water consumption calculation of different types of pumping stations in irrigation Area (May–October 2022)

Water pump type	Electricity consumption (kWh)	EWC factor (kw)	Water consumption (10,000 m^3)
200HW	344,100	43	14,796,300
250HW	98,300	54	5,308,200
300HW	334,250	51	17,046,750
350HW	78,650	62	4,876,300
300HDB	49,150	38	1,867,700
Others	78,650	30	2,359,500
Total	983,100		46,254,750

As both methods are sampling methods, the absence of more authoritative data for comparison hinders an analysis of their relative accuracy. Consequently, we undertake a comparative examination of the two methods based on their underlying principles.

Method 1 considers the representativeness of pump stations for irrigation, incorporating factors like irrigation area, crop structure, and management methods. In contrast, Method 2 mainly considers the representativeness of pump station calibration work, including pump type, head, and status, and is more practical in implementation.

Regarding data utilization, Method 1 relies on a smaller dataset, with measurements from only four pumping stations, whereas Method 2 uses electricity data from all pumping stations in the region, which can be considered a comprehensive statistical approach. In terms of representativeness, Method 2 is superior to Method 1, as the latter fails to provide segmented water consumption for different parts of the irrigation area (assuming the irrigation area by township is not considered). In contrast, Method 2, dividing pumping stations and electricity data by townships, enables a more detailed breakdown of water quantities specific to each pumping station and township. In practical applications, Method 2 proves to be more practical and effective, while Method 1 relies on obtaining the actual irrigation area, which is challenging to accurately acquire, thus compromising the ultimate results' rationality.

In practical application, Method 2 still has room for improvement, such as increasing the representativeness and quantity of calibration and filtering pumping station electricity data. It's necessary to statistically account for and deduct electricity used by pumping stations for other purposes or due to regular damages.

5 Conclusions and Suggestions

5.1 Conclusions

1) This project focuses on the Hangjiahu Plain River Network irrigation area–Shanghai River irrigation area. We conducted on-site calibration for 20 water pumps, obtained the EWC factors for different types of pumping stations, and analyzed the impact of different pump types on calibration parameters.

2) Employing both the per-mu calculation method of typical pumping stations and the electricity consumption-based calibration of typical pumping stations, we approximated water consumption in the southern lifting irrigation area. A comprehensive analysis of the merits and drawbacks of both methods was conducted, leading to the recommendation of adopting the latter for water consumption calculations in the irrigation area.

5.2 Suggestions

Due to the time constraints of the calibration work, the calibration mainly focused on mixed-flow pumps. While these pumps may represent the majority, numerous pumping stations utilizing axial-flow pumps and variable frequency pumps lacked relevant attention. The EWC parameters of a pumping station are multi-factorial and closely related to the water level, the operating conditions of the pump, and the installation of the pump. Even within the same type of pump, there are significant differences in EWC factors. Therefore, continuous monitoring is necessary and relevant parameters should be further updated.

Fund project

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References

1. Waghmare S N , Sonde V M , Undirwade S K .Experimental Approach of Water Lifting Result in Minimizing Power[J].[2024-02-02].
2. Wang Y M , Traore S , Kerh T .Applying Evapotranspiration Reference Model and RainfallContribution Index for Agricultural Water Management Plan in Burkina Faso[J]. 2010.
3. Sun J., Qiao J., Geng H., Wan Y., Wang C., Architecture design of "discounting water with electricity" management system for agricultural irrigation machine well [J]. Ground Water, 2023(9).
4. Chen Qingzhang , Wang Peng , Chen Rongshu. The design and implement of intelligent TM card water-meter and its management system[J]. Key Engineering Materials, 2010, 439/440: 257-262.
5. Yao Ling, Wang Kaituo, Xu Liang. Rapid sample product trial manufacture technique for developing water meter new products[J]. International Journal of Plant Engineering and Management, 2008, 13(4) : 225 -231.
6. Department of Water Resources of Hebei Province. Notice on Issuing the "Measures for the Ratification of Agricultural Water Use Quota and Quantity in Hebei Province (Trial)" and the "Implementation Rules for the Measurement of Agricultural Water Use in Hebei Province by Electricity Conversion (Trial) [A], 2017.
7. Li F., Tao P., Qi Y. Q., Li H. J., Wang H. X., Wang N., Pei H. W., Zhang X. Y., Factors influencing EWC metering method for irrigation water consumption in Hebei Plain[J]. Chinese Journal of Eco-Agriculture, 2022, 30(12): 1993−2001.
8. Liang X. L., Lv W., Lan F., Exploration on Influencing Factors of Coefficient for Converting Electricity into Water [J]. Haihe Water Resources, 2020(01):68-70.
9. Peng H., Yan D., Chai Y. B., Wang S. Y., Discussion on Statistical Methods for Agricultural Water Use in Tianjin [J]. Haihe Water Resources, 2021(04):53-55.
10. Wang X. H., Zhou X. X., Chen J. X., Yu G. S., Kuang G. M., Wu D., et al., Calculation of total agricultural water consumption based on domestic GF-1 satellite [C]. Volume 1 of the Proceedings of the 2021 Academic Annual Conference of the Chinese Hydraulic Engineering Society, 2021:9.
11. Department of Water Resources of Zhejiang Province, Construction and Management Standards for Water Measuring Facilities in Irrigation Areas of Zhejiang Province (Trial) [A], 2019.