

WATER USE EFFICIENCY IN IRRIGATION SYSTEMS OF VIETNAM

Nguyen Tung Phong

Vietnam Academy for Water Resources

Vu Hai Nam, Tran Minh Chinh

Center for Training and International Cooperation

Vietnam Academy for Water Resources

Nguyen Van Kien, Nguyen Xuan Thinh

Center for Participatory Irrigation Management

Vietnam Academy for Water Resources

Abstract: *Water use efficiency in irrigation system is mainly determined based on irrigation efficiency and water productivity. According to the World Bank, water productivity in Vietnam attains at \$2.57/m³, approximately one-tenth of the global average of \$19.42/m³. The agricultural sector consumes over 80% of the total water demand, however, its contribution to the national gross domestic product is merely 13.96%. Therefore, improved water use efficiency in the agriculture sector will increase the value of water to the economy. This paper addresses water use efficiency in different irrigation schemes as well as evaluates the aspects that affects the water use efficiency. Results from this research are considered fundamental inputs for proposing solutions to promote the water use efficiency in Vietnam.*

Keywords: *Water Use Efficiency, Irrigation Efficiency, Water Productivity.*

1. INTRODUCTION

Across Vietnam, more than 900 irrigation systems have been built, covering over 200 ha per system, including 110 medium and large irrigation systems, which cover over 2,000 ha per system. There are more than 86,200 irrigation works across the country, including more than 7,100 dams and reservoirs, 19,400 pumping stations, 27,700 sluices/gates, 32,000 small or temporary weirs, and 291,000 km of canals. These irrigation systems supply water to approximately 4.28 million ha of land, equivalent to 36.5% of all agricultural land in Vietnam, including:

Rice paddies, which make up 7.68 million ha of agricultural land in Vietnam. Approximately 95% of this area requires year-round irrigation.

Water supplied for aquaculture covers approximately 686,600 ha.

Advanced water-saving irrigation technology for upland crops only covers 0.288 million ha out of 2.4 million ha (12%).

Approximately 6 billion m³ of water is supplied for domestic and industry through these irrigation systems.

The irrigation systems also support flood prevention and flood control for urban and industry areas and support power generation, navigation, and environmental protection.

As evident, these vast irrigation systems play a vital role in underpinning Vietnam's economic productivity and food security. The distribution of these irrigation systems by region and service area is shown in Figure 1 below. The size, type, and management model of irrigation system varies across the country, according to the changes in conditions and irrigation needs.

One of the most important challenges of the 21st Century is dealing with the water crisis

Receipt Date: August 10th, 2022

Review Approval Date: September 15th, 2022

Publish Approval Date: October 05th, 2022

2022

caused by water scarcity, as well as the degradation of ecosystems caused by water pollution. Significant resources have been invested in water development for agricultural purposes. However, despite Vietnam's efforts to develop water resources for food security, access to reliable and safe water is still a challenge that disproportionately impacts the poor. In addition, competition from other growing uses, such as residential and industrial, combined with water quality issues, potentially jeopardize the resources available for agriculture. In this context, the efficient use of water resources, especially in agriculture, is a concern in Vietnam, as in many countries around the world. Agricultural water use and management covers multiple scales: crops, fields, farms, irrigation systems, and river basins (national and transboundary).

In addition, according to the World Bank report "Vietnam: Towards an adaptive, clean and safe water system" [8], irrigation systems often operate below design capacity. Despite considerable investment in Vietnam over the past 40 years, the irrigation system is of poor quality and can only deliver about 50-60% of its design capacity [8]. As a result, Vietnam is amongst the countries with the highest irrigation costs in Southeast Asia [6]. Nationwide, only 26% of channels (by length) can operate at full capacity; this number is slightly higher for primary and tertiary channels, and slightly lower for secondary channels.

In the context of water scarcity and seasonal variability, as well as with limited and unevenly distributed water resources, the efficiency of water use in the agricultural sector must be studied and evaluated. This research is essential to underpin potential solutions for improved efficiency and safety of agricultural water use across Vietnam.

2. STUDY SITES AND METHODOLOGY

(1) Study sites selection

The study is carried out in different economic regions across the country, including in the (i) northern mountainous region; (ii) the Red River Delta region; (iii) the north-central region; (iv) the south-central region; (v) the central Highlands; (vi) the south-east region; and (vii) the Mekong River Delta. The illustrates the typical irrigation systems by region, according to the data from the Directorate of Water Resources (DWR) are shown in Figure 1.

In consultation with Irrigation Exploitation and Management Companies (IMC) based on typical form of irrigation system by region, and in consideration of the availability of operational and field data, the total 13 study sites for the research are proposed as shown in Figure 2.

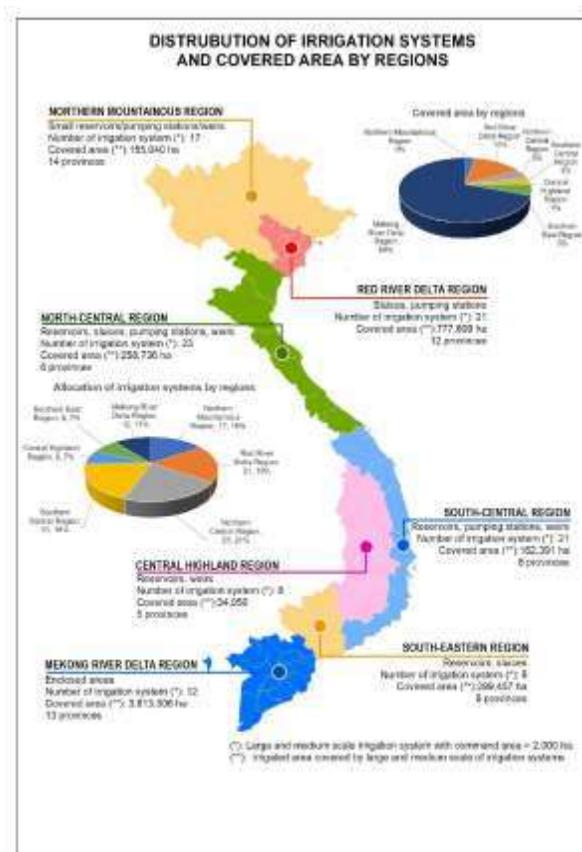


Figure 1: Distribution of irrigation systems by region and service area

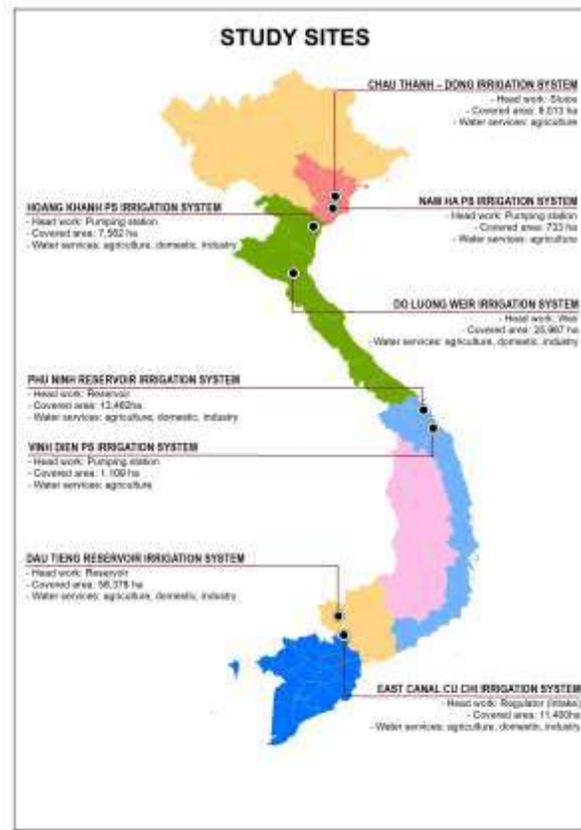


Figure 2: Selected study sites for the research

(2) Methodology

The water use efficiency in irrigation system is based on two indicators: (i) irrigation efficiency (IE), and (ii) water productivity (WP). In order to improve the efficiency of water for agriculture, and for the economy in general, indicators such as WP for water-using sectors and IE are useful to underpin improved management of these systems.

Irrigation efficiency

The irrigation efficiency, as defined by Jensen, 1977 [2], is:

$$IE = \frac{NET}{DIV} + Er * (1 - \frac{NET}{DIV})$$

Where:

IE: irrigation efficiency (%)

NET: net evapotranspiration of crop (mm)

$$NET = ET - Pe$$

Where:

ET: evapotranspiration (mm)

Pe: the effective precipitation (mm)

DIV: total amount of water withdrawn or diverted (mm)

Er: the rate of reuse (regression) of the lost water

Method of determining parameters:

ET: evapotranspiration of crops (water demand of crops) is determined through: (i) the reference evapotranspiration (ET_o) calculated using the CROPWAT software (CROPWAT is a computer programme which was developed by the Food and Agriculture Organization (FAO) for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data.

Pe (effective precipitation): utilize CROPWAT software to calculate Pe from rainfall data for each of the research sites, which is collected from official agencies, combined with the field crop characteristics (root depth in growth periods).

DIV: total amount of water withdrawn from the headwork, which is calculated or estimated from operational data from IMCs and/or WUOs.

Er: Consulting with IMCs and WUOs technical/operation staff to estimate the rate of reuse of lost water.

These parameters are estimated using the CROPWAT software with meteorological and rainfall data, as well as working with regional and local IMCs and WUOs for water accounting at the study sites. Water accounting is of utmost importance in this research.

Water productivity

Water productivity in the agricultural sector is determined by the formula [3]:

$$WP = \frac{P}{WC}$$

Where:

WP: Water productivity ($\$/m^3$)

P: Value of crop sold at the field (\$)

WC: Water consumption (m^3) includes effective precipitation and water withdrawn:

$$WC = DIV + Pe$$

Method of determining parameters:

To determine the value of crops sold at the field (P), crop yield data is collected through field surveys (from IMC/WUO) and the price of the product at the field (from farmer).

To determine water consumption (WC), the water accessed by irrigation systems (DIV) is collected or estimated from IMCs and WUOs.

Effective precipitation (Pe) is calculated from rainfall and climate data for the research sites using CROPWAT, combined with crop characteristics (root depth) and the growth periods of crops.

3. RESULTS AND DISCUSSIONS

(1) Irrigation efficiency

The irrigation efficiency indicator in the selected sites is shown in Figure 3 below

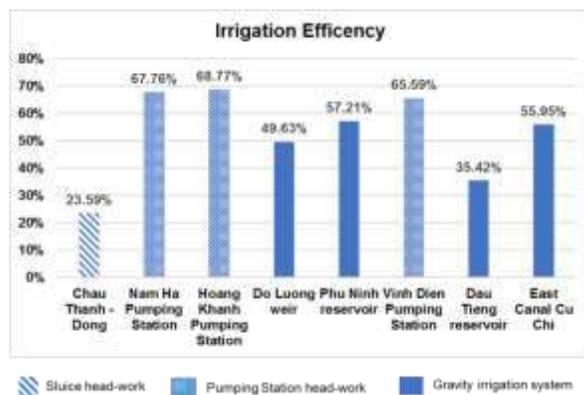


Figure 3: Irrigation efficiency in selected sites of the research

The resulting irrigation efficiencies illustrated in Figure 3 above, show key patterns. Firstly, when splitting the results into the three types of headworks (as shown in Figure 3), it becomes evident that: (i) gravity irrigation systems taking water from the river through sluices at the beginning of a canal (such as Chau Thanh - Dong irrigation system of Nam

Ninh IMC) have the lowest irrigation efficiency; (ii) gravity irrigation systems with the headworks as either reservoirs or weirs, and with some coordination of other water storage sources, have higher irrigation efficiency; and (iii) irrigation systems with electric pumping stations have the highest irrigation efficiency, although most of these systems do not have a professional water distribution plan or measuring method to ensure quality of water provision. High efficiency of these irrigation systems comes from the pressure on IMCs to minimize electricity expenditure, as a result of the operating costs.

It is also important to note that the Phu Ninh irrigation system has been modernized with irrigation improvement projects funded by the World Bank, such as WB3/WB7. The irrigation efficiency of this system reached 57.21%, more than double compared to 2013 (23.05%), when the WB7 project began. This shows the important role that regular updating and maintenance plays in improving the irrigation efficiency in irrigation system.

Finally, The Dau Tieng and the East Canal Cu Chi irrigation systems use irrigation management technologies such as SCADA [5]. These result in very high irrigation efficiencies compared to other gravity-fed irrigation systems nationwide. This shows the undeniably important role of irrigation management techniques in improving the functionality of these irrigation systems.

(2) Water Productivity

The water productivity indicator in selected sites is shown in Figure 4 below.

The results show that the value of water productivity in the studied irrigation systems in Vietnam reached an average value of 0.18 USD/ m^3 , which is higher than the average value of 0.10 USD/ m^3 found by the FAO in more than 50 systems studied, as well as the forecasted growth of water productivity in the agricultural sector for the period 1995-2025 of 0.095÷0.127 USD/ m^3 [1].

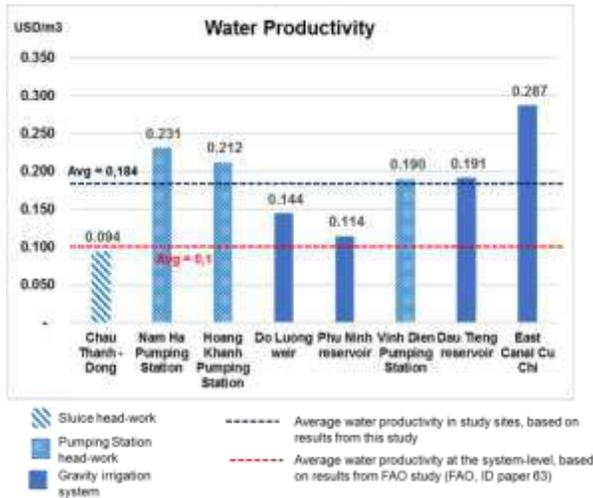


Figure 4: Water productivity in selected sites of the research

(3) Discussion

For Irrigation Efficiency:

Irrigation efficiency at the irrigation systems mainly depends on: (i) coverage area of irrigation systems; (ii) form of irrigation system works; and (ii) irrigation management techniques. Some main finding

Coverage of irrigation systems:

For gravity irrigation systems: Irrigation efficiency tends to decrease where the command area of the irrigation system increases. When comparing the irrigation efficiency across Dau Tieng, Do Luong, and Phu Ninh, which all share similar irrigation techniques and water sources (i.e., gravity irrigation and the main canal system is lined), a direct correlation was found between command area and efficiency. This shows that under the same conditions, the larger the command area, the lower the irrigation efficiency. This is attributed to the increased complexity in water management when the command area is greater.

For pumping station irrigation systems: There is not much difference in the efficiency between the Nam Ha (command area 733 ha and efficiency of 67.76%), Hoang Khanh (7,562 ha command area and efficiency of 68.77%), and Vinh Dien (1,109 ha command area and

efficiency of 65.59%). This is probably due to the pressure of operating costs (electricity) resulting in managers or operators stopping the operation of the pumping station when they feel enough water has been distributed.

Form of irrigation system works

Head works

The irrigation systems with electric pumping stations are the group with the highest irrigation efficiencies, at an average efficiency of 67.37%, despite most of these irrigation systems not having a professional water distribution plan or water measurement method to ensure quality of water services. The operation is typically manual and based on local experience. The pressures from electricity costs likely contribute to the higher-than-average levels of efficiency.

The reservoir-fed gravity irrigation systems have lower irrigation efficiencies than the systems with electric pumping stations, at an average efficiency of 49.55%. This could be attributed to the implementation of a professional water distribution plan. In addition, these irrigation systems typically have very effective SCADA equipment for their water distribution.

The gravity irrigation system that distributes water from rivers through sluices (such as the Chau Thanh - Dong irrigation system of the Nam Ninh IMC) has the lowest irrigation efficiency, at 25.97%. This could be attributed to the lack of coordination and oversight on water use allocation and cost pressures.

Canal system

For large-scale gravity-fed irrigation systems with completed and lined reservoirs and/or weirs, such as the Do Luong, Phu Ninh, Dau Tieng, and East Canal Cu Chia systems, higher irrigation efficiency is achieved.

For the Phu Ninh irrigation system (modernized through the WB3/WB7 project), the calculated irrigation efficiency is 57.21%, more than double its efficiency in 2013 [7], which was 23.05%.

For the Do Luong irrigation system (upgraded through the JICA2 project), the calculated irrigation efficiency is 49.63%, compared to 35% in 2014.

For irrigation systems with electric pumping stations, such as the Nam Ha, Hoang Khanh, and Vinh Dien systems, the irrigation efficiency with lined canal systems is 65.59% - 68.77%. The irrigation efficiency of these pumping stations depends on the form of the irrigation network and water source. It is clear however that lined canal systems improve efficiency outcomes.

Water management techniques

Normally, IMCs develop irrigation plans for agricultural production for each season specific to each system.

For irrigation systems with reservoirs or weirs, such as the Dau Tieng, East Canal Cu Chi, Phu Ninh and Do Luong systems, large command areas mean that water distribution is complicated, and the irrigation canal system is very long with high rates of water loss. For these systems, the water distribution plan is developed based on water demand for agricultural, domestic, and industrial users. The implementation of the water distribution plan is based on (i) the irrigation plan; (ii) specific weather conditions (rainfall); and (iii) the irrigation monitoring system. In particular, monitoring systems help with the IMCs' water distribution activities, enabling adaptation to different water demands, water quality variability, and resource availability.

For irrigation systems with pumping stations, such as the Nam Ha PS, the Hoang Khanh PS, and the Vinh Dien PS, seasonal water distribution plans are typically developed according to weather conditions and the operator's assessment of water demand. These water plans and their monitoring is very limited, so the quality of water management activities cannot be determined on the basis of science and technology.

For gravity-fed irrigation systems, such as the Chau Thanh – Dong, an irrigation plan exists

but is very general and not monitored. Water distribution from this system is operated manually, without electricity cost pressures and limited monitoring.

SCADA systems have gradually been applied in a number of the irrigation systems, specifically:

In the Dau Tieng irrigation system: The water distribution plan was developed using a bottom-up approach (from water users). The SCADA system at Dau Tieng can measure the water level and flow from the Dau Tieng Reservoir to the irrigation system. This SCADA system helps to manage and coordinate the quality and quantity of water supplied from the Dau Tieng reservoir.

In the East Canal Cu Chi irrigation system: SCADA application has reached a higher level following WB3 project support. This includes water demand and distribution from the East Canal Cu Chi irrigation system to different water users (agriculture, industry, domestic).

In the Phu Ninh irrigation system: The current SCADA system monitors water level and flow in order to adjust water distribution in accordance with the system's conditions.

In the Do Luong irrigation system: The application of SCADA has just started under the JICA2 project and completion and handover to IMC is expected in June 2022. Thus, the effectiveness of the SCADA system cannot be assessed yet. However, considering the current manual operation, it is expected the SCADA will provide a significant benefit to the system's irrigation efficiency.

For Water Productivity:

Through a preliminary analysis of the Water Productivity in the selected site of the research, no relationship was found between Water Productivity and the coverage area. The results of water productivity calculation show that the factors affecting Water Productivity indicator mainly include: (i) form of irrigation head works; (ii) water management techniques; (iii) diversity of water users; and

(iv) crop type and pattern.

Form of irrigation head works

Irrigation systems with electric pump stations achieved a relatively higher Water Productivity (higher than the average value of 1.84 USD/m³). This can be explained through cost pressures and the desire to reduce costs and close oversight by manual operators.

Gravity irrigation systems with Reservoirs/Weirs, (including the Do Luong, Phu Ninh, Dau Tieng and East Canal Cu Chi irrigation systems) showed uneven Water Productivity and no clear trend. This could be explained, in part, due to diversified water sources from different irrigation systems. (Further analyzed in section 6.2.3)

The irrigation system with gravity-feed sluices generated the lowest value of Water Productivity. This form of irrigation system does not need the coordination of water source and doesn't have as significant cost pressures. This leads to a high-water consumption and low productivity.

Water Management Techniques

Water management systems using SCADA showed a higher Water Productivity than those without or low level of SCADA usage.

Irrigation systems with electric pump stations such as Nam Ha, Hoang Khanh and Vinh Dien showed a higher-than-average Water Productivity due operation cost pressures (electricity bill) rather than water management approaches as there is almost no water monitoring or water measurement system in place.

The gravity irrigation systems have the lowest Water Productivity) due to the lack of water efficiency practices.

Diversification of water services

Irrigation systems with electric pumping station have similar Water Productivity.

The gravity irrigation systems can be divided into 2 groups: Group 1 mainly servicing water for agricultural production; and Group 2

Servicing water for agricultural production and water for domestic and industry.

Group 1: Do Luong irrigation system and Phu Ninh irrigation system mainly service agricultural production and only a very small percentage domestic and industrial users, so although Irrigation Efficiency is higher than other irrigation systems in Group 2, the Water Productivity is lower than the average Water Productivity in this form of gravity irrigation systems and much lower than the irrigation systems in Group 2.

Group 2: Dau Tieng irrigation system and East Canal Cu Chi irrigation system have a very high proportion of water for industrial and domestic sector, so the Water Productivity is higher than the average Water Productivity of the studied systems, especially in the East Canal Cu Chi irrigation system, the Water Productivity is higher than 56.8% average value.

This shows that the impact of non-agricultural water services on Water Productivity on irrigation systems is very clear. Calculation results of Water Productivity at irrigation systems also show that Water Productivity for non-agricultural water services (industrial - domestic) is higher than Water Productivity for agricultural irrigation services at 18,45%.

Crop pattern

The main task of irrigation systems is still to provide public irrigation services for agricultural production.

This group of irrigation systems with the form of head works as electric pumping station has a relatively similar Water Productivity and has an average value (for agriculture) at 0.210 USD/m³;

The group of gravity irrigation system with the form of head works as Reservoir/Weir has an average of Water Productivity at 0.174 (USD/m³) for agricultural production,

Thus, at the irrigation system, the cultivated area is mainly paddy rice and vegetables, so there is not much difference in crop pattern, but

the factors affecting Water Productivity in agriculture come from the other factors such as: (i) irrigation system characteristics; and (ii) Irrigation Management techniques.

4. CONCLUSION

Climate change is impacting water security and creating significant uncertainty for the agricultural sector. Population growth and increased water demand are compounding this challenge. Tensions between competing water users are on the rise. Efforts to increase irrigation efficiency and agricultural productivity are essential to help Vietnam manage these challenges, ensure food security, and contribute to Vietnam's economic development.

The results of this research on irrigation efficiency and water productivity in the irrigation systems in Vietnam are summarized as follows:

General: The average water productivity of the studied irrigation systems (0.184 USD/m³) was found to be higher than those studied by the FAO (50 irrigation systems in Vietnam), and also higher than the growth forecast of water productivity in agriculture for the period 1995 - 2025 (0.127 USD/m³) [9].

Scale of command area: In general, the larger the command area of the irrigation system, the lower the irrigation efficiency, when comparing irrigation systems of similar condition and water source.

Type of headworks: The irrigation systems using electric pumping stations have higher irrigation efficiencies and water productivities

due to the financial pressure on operating costs. Systems with reservoirs had medium efficiency and productivity, and gravity-fed irrigation systems were the least efficient and productive.

Canal system: Irrigation systems with lined canals showed significantly higher irrigation efficiencies than unlined, earthen canals.

Technical water management: Irrigation systems with good water management techniques, and applications of advanced water management technologies (such as SCADA) [4], have higher water use efficiency. With the application of an effective water measuring system and modern technology, the multi-purpose exploitation of the irrigation system is less complicated and results in a higher water productivity.

Diversification of water services: Irrigation systems with diverse water users (i.e., industrial and domestic) have a higher water productivity than irrigation systems that only serve water for agricultural production. Calculation results show that water productivity in non-agricultural sectors is about 18.45% higher than water productivity in the agricultural sector.

The results of this research will be the basis for proposal of solutions to improve Irrigation Efficiency and Water Productivity in irrigation works systems, contributing to improving the Water Use Efficiency in agriculture sector in particular as well as in the general economy of Vietnam.

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