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Assessment of Water Recycling Effectiveness for a Super-Intensive White Leg Shrimp Farm in Ca Mau Province

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ABSTRACT

Recycling shrimp farming water is a way to address the trend toward a circular economy in Vietnam's coastal regions while also reducing the quantity of effluent that is released into the environment. In order to explore the potential for waste recycling, this study investigates the pond system of a highly intense *Littopenaeus vannamei* culture area in Ca Mau province. The water balance approach was used to assess how effectively shrimp farms use water. In order to determine how much water helps to the financial success of shrimp farming, the value of water was also evaluated. According to the results of the water balance calculation, the current system could result in water losses of up to 1000 m^3, accounting for over 20% the total water use. Only 33 m^3 of water loss was estimated for the proposed water recirculation system, which was 3% of the current system. By recirculating the treated water back into the shrimp ponds, the farm also saved 20% of the water utilized for those ponds. The economic value of water was 6000 VND/m^3 for the current farming system. The water value in the system would be decreased by 20% for the suggested treatment system. The high cost of investing in water recirculating technologies is related to the high water exchange rate. When deciding how much water to allocate, it should be taken into account.

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1. Introduction

As a more eco-friendly substitute for black tiger shrimp, the Vietnamese government has recently pushed the development of white leg shrimp (*Littopenaeus vannamei*) [1]. One of the primary aquaculture industries in the coastal region of Ca Mau province is the growing of white leg shrimp [2]. The majority of shrimp farms have released their wastewater and sludge directly into the environment throughout each farming season, which has led to a significant increase in the risks [3]. When released, this untreated waste rapidly contaminates water [3], [4]. Water recycling for shrimp farming is therefore a way to match the circular economy trend for Vietnam's coastal regions while simultaneously reducing the quantity of wastewater discharged into the environment.

The goal of this study is to evaluate the potential for waste recirculation in the pond system of a region of super-intense shrimp farming in the Ca Mau province. The water balance (WB) approach was used to assess how effectively shrimp farms use water. Using the residual value method (RVM), the value of water was also evaluated to take into account its contribution to the financial success of shrimp farming.

For the evaluation of water resources, WB analysis is crucial [5], [6]. The inputs and outputs of the water volume from the system's ponds were used to determine the WB. For agricultural irrigation in the Mekong Delta, a WB analysis was conducted [7], [8]. For use in calculations related to water allocation in integrated aquaculture in Malawi, the WB equation was created [9]. The allocation of water resources for aquaculture connected to small-scale irrigation cultivation is then outlined.

The provisioning services (ecosystems) that contribute to the output benefits are valued using the RVM [10]. This approach has been used to determine the financial worth of irrigation water for agriculture [11], [12], and agri-aquaculture [13]. Based on the quantity of water supplied for shrimp farming, input expenses, and output advantages, the water value is estimated.

The WB calculations in this study evaluate the current farming system's water loss and recommend using it for water circulation. The RVM determines the economic worth of water contributions in the current and water circulation systems. The findings would help with water resource allocation for the case study farm in particular, and for the entire Ca Mau province coastline in general.

2. Materials and Methods

2.1. Materials

A *Littopenaeus vannamei* shrimp farm in Ca Mau province had a total rearing area of about 1 hectare, with an average of 2200 m^2 of each pond and 2.35 rearing ponds per farm [14]. A farm featured one or more settling ponds to ensure good water quality before pumping it into rearing ponds [14]. As a result, Cai Doi Vam town, Phu Tan district, Ca Mau province was chosen as the case study area in this study to investigate the water use efficiency of shrimp farming households. Table 1 displays the pond parameters of a case study shrimp farm.

Table 1. *Pond characteristics of the current shrimp farming system*

Pond type	Quantity	Parameter (notation, unit)		
		Acreage (S, m^2)	Depth (H, m)	Volume (W, m^3)
Settling pond 1	1	3000	2	6000
Settling pond 2	1	3000	2	6000
Nursery pond	2	100	1.5	300
Shrimp pond	2	1500	1.5	4500

Water was used to supply the ponds in the present system's shrimp culture process, which included two settling ponds, nursery ponds, and shrimp ponds (raising ponds) (Figure 1). The stocking density determines the size of the nursery and shrimp ponds. Shrimp were raised for 20 days in a nursery pond with 3,000 shrimp/m^2 before being transferred to the pond to continue the growing process. Density reached 200 shrimp/m^2 in the shrimp pond. Commercial shrimp would be collected when the shrimp size reaches around 40–60 shrimp/kg and for about 90 days. Because of the high stocking density, approximately 20% of the water in the shrimp pond was replaced each day to manage water quality, resulting in 20% of the water being released into the environment.

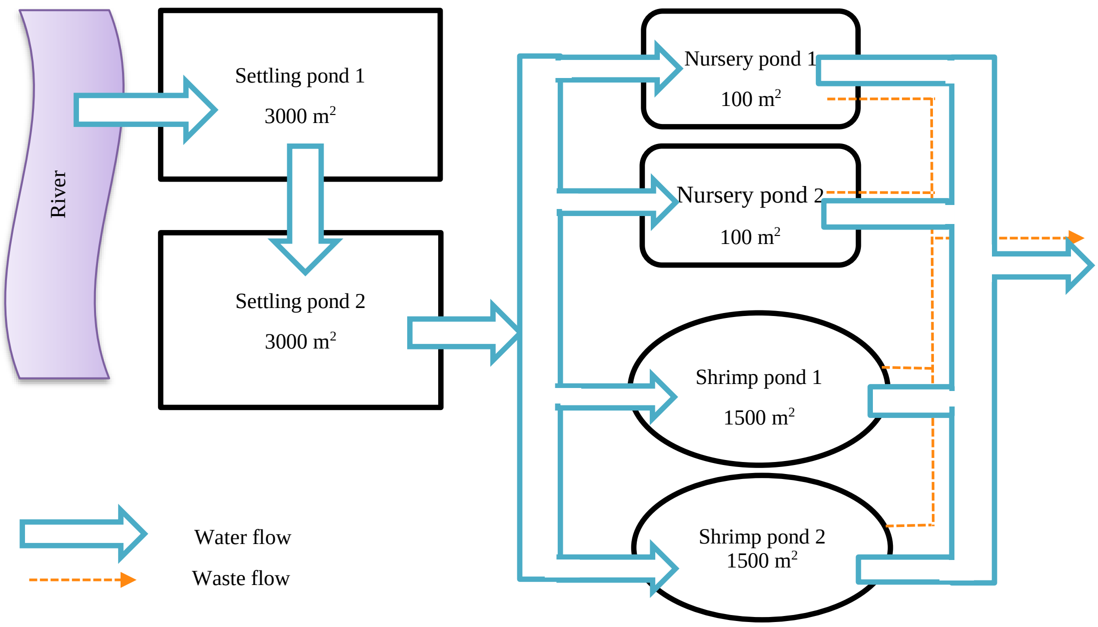

Figure 1. *Super-intensive shrimp farming system in Ca Mau*

2.2. Methods

2.2.1. Water balance method

Equations from (1) to (6) are used to calculate the WB in the pond system including calculating the pond capacity (W), the total water surface area of the current shrimp farming system (s), the amount of water in the wastewater settling pond (W_{wsp}), siphon water (W_{swp}), the amount of water occupied in the sludge, the total water surface area of the shrimp pond in waste recirculation pond area.

Pond capacity (W):

$$W_i = S_i \times H_i \quad (1)$$

Where S is the pond's surface area and H is its height; examples of i are the pond type, such as the settling pond (stp), the commercial shrimp pond (csp), and the nursery pond (nsp).

Total water surface area of the current farming system:

$$s = \sum_1^n S_i \quad (2)$$

The number of wastewater settling ponds (wsp) must be at least 10% of the total pond area, according to QCVN 02-19:2014/BNNPTNT. They contain exchange water and wastewater that have been separated from the siphon sludge. One day was the retention period in the wastewater settling pond [15]. The following formula is used to determine the volume of daily wastewater in total:

$$W_{wsp} = 20\% \times W_{csp} + W_{swp} \quad (3)$$

The waste in the siphon, with a daily outflow of around 2% of pond volume (https://www.camau.gov.vn), is computed as follows:

$$W_{swp} = 2\% \times \sum W_i \quad (4)$$

Water content of the siphon sludge:

$$W_{ws} = 90\% \times W_{swp} \quad (5)$$

Total water surface in the area used for recirculation:

$$s' = S_{wsp} + S_j \quad (6)$$

Where S_j is the types of treatment pond

Evaporation and percolation from the settling ponds, which average about 2 mm/day [16], will contribute to the total amount of water lost during shrimp culture. With an average yearly evaporation of Ca Mau of 1022 mm [17], the amount of water evaporated (W_{ev}) in the ponds in a day is determined using the following formula (7):

$$W_{ev} = S_i \times \frac{1022}{365} \quad (7)$$

2.2.2. Residual value method

Aquaculture water that is drawn straight from rivers is not priced in accordance with the local market. Formula (8) [13] shows how to calculate the value of used water by subtracting the total output (TO) value from the cost of non-water inputs (TI) in VND and dividing the result by the volume of water used to produce Q (m^3). Unit pricing and output from recent production data are used in the estimation of RV valuation.

$$RV = \frac{TO - TI}{Q} \quad (8)$$

The total amount of settling pond water, infiltration and evaporation, and replacement water minus rainwater during a culture season make up the amount of water needed for the current system. With an average annual rainfall of 2360 mm in the region, 85204.73 m^3 of water is required to grow 1 hectare of shrimp.

According to formula (9), the supply pump flow (m^3/h) for a pumping cycle is calculated:

$$Q_p = \frac{W_i}{t} \text{ or } Q_p = \frac{W_i}{d \times g} \quad (9)$$

Where t is the time in hours (h), d is the number of days (days/batch) of water delivery, and g is the number of hours (hours/day) of water supply.

The production investments for 1 hectare of land were used in Table 2 to calculate the value of water for the case study shrimp farm. Feed, medication, shrimp seed, power, fuel, equipment (pump, waterwheel, aerator), land rent, and labor were examples of inputs. Labor costs would not be included because family members were used by many homes in the area. When people owned land, the investment cost did not account for the land rent.

Table 2. *Investment in the current farming system*

No.	Item	Unit	Selling price (x 1000 VND)	Quantity
1.	Water Pump 3Hp 2.2kw 28 m^3/h	A set	5000	6
2.	Net tarpaulin	m^2	25	6000
3.	Tarpaulin for nursery pond	m^2	25	300
4.	Tarpaulin for shrimp pond	m^2	25	4500
5.	Aerator 2.2 kw (3HP); 1500 rpm; 2 m^3/min	A set	5000	6
6.	Fan with 15 blades 3 kW, 380 V-50Hz; 70 rpm	A set	16000	10
7.	Shrimp seed for nursery ponds	1000 heads	700	600
8.	Feed	kg	30	15000
9.	Fuel (Electricity)	kWh	15	30000

3. Results and Discussion

In the current farming system, evaporation, infiltration, and wastewater from siphons were all examples of water loss during the farming process. Sludge settling ponds and biological ponds were examples of waste treatment ponds for the proposed system. Their sizes were derived from the siphon water volume and water replacement calculation results. They are presented in Table 3 and Figure 2. The water treatment solutions do not cost much for the farm-holder.

Table 3 shows the results of calculating the volume of water used in the existing shrimp farming technique. Waste treatment ponds were proposed based on the daily wastewater volume. To improve the efficiency of wastewater treatment, this study recommended two biological ponds following the settling pond. Nguyen Thi Hoai Giang et al. (2018) [15] proved the efficacy of wastewater treatment for shrimp systems using a mixed biological pond system of fish, seaweed, and shellfish in their study. However, the addition of more than one biological pond will be determined by the household's financial situation. In the discussion section of this study, the value of water in the suggested system with one or two biological ponds would be examined.

Seepage water, evaporation water, replacement water, and water in the sludge all contribute to the overall amount of water lost in the current system without a water circulation system. Only seepage and evaporation are included in the total water loss for the shrimp aquaculture with waste recirculation system. One recycling interval was calculated for a four-month shrimp farming culture. It all started when the daily exchange water from the nursery and shrimp ponds was recycled into the initial settling pond via the waste treatment system. As the result, the current system discharged 1079.68 m^3 of wastewater per day. This quantity included 20% replacement water, seepage, evaporated water, replacement water, and siphon water. The proposed treatment system resulted in a daily loss of 33 m^3 of water, primarily due to evaporation and seepage, totaling to 3% of the effluent.

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Table 3. *The volume of water participating in the current shrimp farming system for one crop*

No.	Category	Value (m^3)
Current farming system		
1.	Settling pond 1	6000
2.	Settling pond 2	6000
3.	Nursery pond	300
4.	Shrimp pond	4500
5.	Exchange water	81900
6.	Seepage	1440
7.	Evaporation	2398.2
8.	Siphon	7371
	Total water loss	93109.2
Water recirculation system		
1.	Settling pond 1	6000
2.	Settling pond 2	6000
3.	Nursery pond	300
4.	Shrimp pond	4500
5.	Wastewater settling pond	1056
6.	Biological ponds 1 and 2	1046.4
7.	Seepage	1440
8.	Evaporation	2398.2
	Total water loss	3838.2

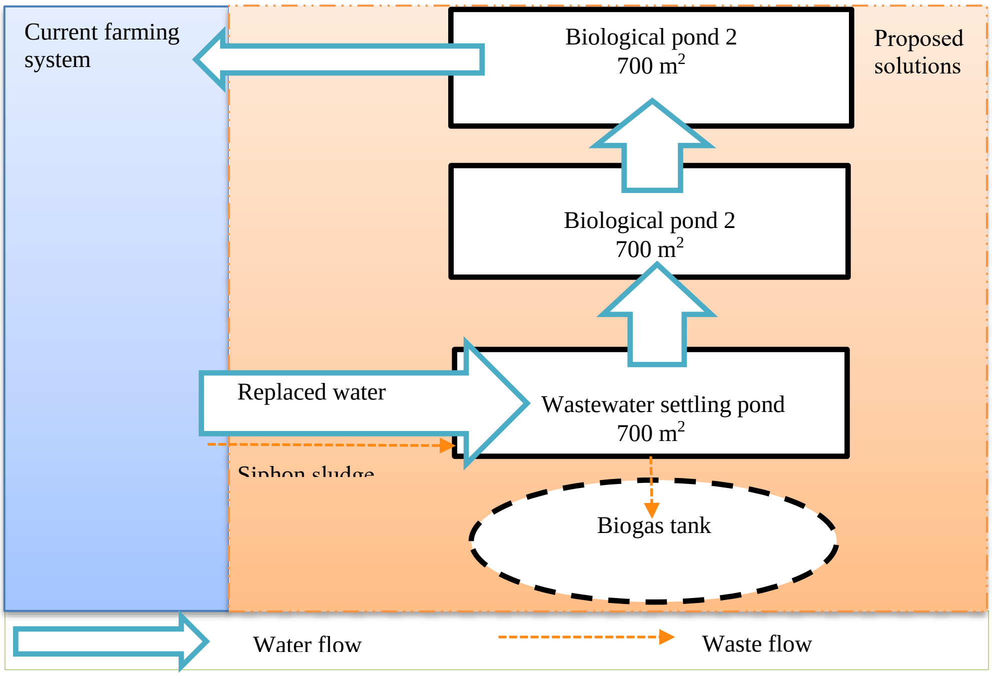

Figure 2. *Proposed waste recirculation system*

In Figure 2, the first biological pond would feed tilapia, which turns the leftover shrimp farming waste in the water stream into food. A second biological pond that supports the growth of algae and aquatic plants receives water from this first pond. The water will remain clean and safer for shrimp as a result of these plants continuing to devour contaminants. The second biological pond's water would then be recirculated to the water supply pond. The settling pond would be used to process the waste from the siphon. The amount of solid sludge removed from the settling pond would be fed through the biogas tank. The biogas tank's sludge would be converted into compost for use in agriculture.

Figure 3 displays the outcomes of the WB analysis for the present and suggested systems. Up to 1000 m^3 of water per day were currently lost. Only 33 m^3 of water would be lost during water circulation, which would reduce the amount of waste in the current system by 960 m^3. The amount of water saved in the crop was ten times more than the amount of water used. Water quality and water exchange rate are related [1]. Costs for input and operating pollution treatment were increased by the high water exchange rate (i.e. 16%) [18]. Therefore, lowering the volume of exchange water should be taken into account for effective shrimp farming.

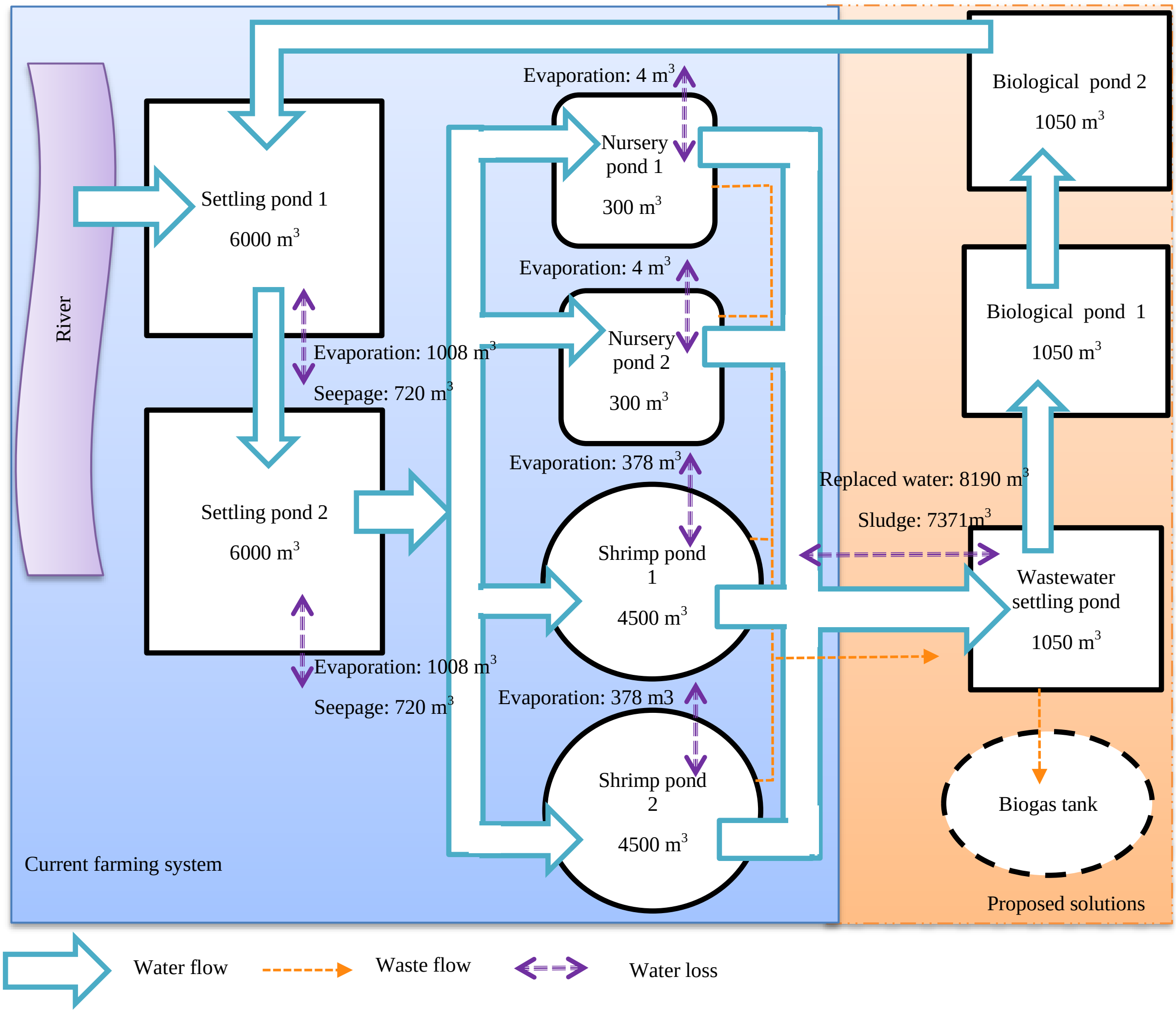

Figure 3. *Water balance in the current and proposed systems*

When shrimp are assumed to have a 90% survival rate from the nursery to the commercial shrimp stage, a crop yields a profit of 500 million VND. For the case study area, the economic value of water is 6000 VND/m^3 (0.25 USD/m^3). It is 2.5 times smaller than shrimp farming in Soc Trang province and 2 times smaller in Bac Lieu province when compared to its value in the study by Dao et al. (2017) [13]. This is because the amount of exchange water rate in the case study was many times higher than in [13]. The cost of a water circulation system, which includes the price of purchasing tarpaulin and two aerators for two biological ponds, would be around 100 million VND. The water value in the system would be then decreased by 20%, to 4500 VND/m^3. The additional cost for the suggested treatment system, which consists of only one biological pond, would be 50 million VND, resulting in a water value of 5000 VND/m^3. The water value changed only slightly in the proposed system with one or two biological ponds. These findings imply that adding treatment solutions to the existing system has little effect on the value of water's contribution to its costs and benefits. As a result, choosing a supplemental ponds will be easier.

The findings of this study will help water resource managers make water distribution decisions. Intensive shrimp farming can generate a high return but incur substantial input costs due to the volume of water needed. The high water exchange rate (20%) increases treatment requirements while decreasing water value and shrimp aquaculture profitability. The waste treatment should be concerned with the costs of investing in water recirculating technologies. This should be taken into account while making water allocation decisions.

4. Conclusions

In order to explore the potential for waste recycling, this study examined the pond system of a highly intense shrimp culture area in Ca Mau province. Since wastewater from shrimp farms is released directly into the environment, WB calculations are used to propose water-saving solutions at prices that are affordable for the average householder. Additionally, the value of water was evaluated in order to take into account how water affects shrimp farming's financial success. The amount of water lost by the current agricultural method could reach 1000 m^3. The suggested water recirculation system had a water loss of only 33 m^3, or 3% of the current system. By recirculating the treated water back into the shrimp ponds, the farm also saved 20% of the water utilized for those ponds. For the current farming system, the economic value of water was 6000 VND/m^3. The suggested treatment system would reduce the water value in the system by 20%. As a result, adding treatment solutions to the current system has little effect on the contribution of water to its costs and benefits. This indicates that selecting additional ponds will be simpler. However, the high replacement rate of water would result in significant investment expenditures for water recirculating technologies. This should be taken into account while making water allocation decisions.

Abbreviation

RVM: Residual value method; WB: Water balance.

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