ISSN: 3029-0724

Research Article

Journal of Environmental Science and Agricultural Research

Application of IOT Technology and Sensor Networks in Environmental Management Solutions and Improving the Efficiency of Rice – Shrimp Farming Models in a Bien Dictrict, Kien Giang Province

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Received: July 23, 2025; **Accepted:** July 28, 2025; **Published:** August 08, 2025

ABSTRACT
The project "Application of IoT technology and sensor network in environmental management solutions and improving the efficiency of rice - shrimp farming model in An Bien district, Kien Giang province" was conducted from December 2019 to January 2022 to develop and refine technical operation processes, environmental management, and increasing profitability for rice - shrimp farming in An Bien district, Kien Giang province. The survey results indicated that the shrimp-rice production method combines traditional farming practices, mainly based on local folk experience. In the experimental application of IoT technology and sensor network for environmental management in the shrimp-rice farming area, data from 4 observation stations installed in Tây Yên A, Nam Thái - Nam Yên, and Nam Thái A village, combined with web-based data management software and mobile provided rapid and convenient support for local management officials and farmers in monitoring environmental conditions in the rice shrimp farming areas. The technological solutions have been effectively applied by farming households. The financial efficiency analysis of the experimental shrimp-rice model using IoT technology and sensor network in A Bien has demonstrated high profit cost ratio, ranging from 285.5% to 327.6% in practice.

Keywords: Rice-Shrimp, Growth, Survival Rate, Diversity and Sustainable Development, IOT Technology and Sensor Network

Introduction

The orientation in planning the development of a green technology models, high-quality, and efficient agriculture - aquaculture farming systems based on high-tech applications has been the focus of investment and research at the College of Aquaculture and Fisheries Sciences, Can Tho University [1]. The results obtained from rice–shrimp farming models have contributed significantly to scientific and technological knowledge, forming a scientific database, improving product quality for both domestic and export markets, and gradually reducing reliance on natural fisheries resource exploitation [2-4].

Identifying the limitations in actual aquaculture practices, especially under the ecological conditions of the rice–shrimp model in An Bien district, Kien Giang province, along with development-oriented planning for rotational or integrated farming of tiger shrimp (Penaeus monodon), mud crabs, and freshwater prawns (Macrobrachium rosenbergii) in saline- and acid-sulfate-influenced rice fields using extensive and improved extensive farming systems characterized by low stocking density, multiple stocking cycles per year (4–6 times/year), reliance mainly on natural feed, and inadequate water quality management - has resulted in relatively low shrimp yields (80 -120 kg/ha) and limited profitability compared to the model's potential under various ecological regions [5].

Additionally, in recent years, climate change has affected water environments, with fluctuating salinity and pH levels, leading to the emergence of various shrimp diseases [6,7]. Poor-quality shrimp seed with low survival rates and yields has caused significant losses for farmers. Therefore, to make sustainable

Citation: Duong Nhut Long, Truong Minh Thai, Akiko Ikeguchi. Application of IOT Technology and Sensor Networks in Environmental Management Solutions and Improving the Efficiency of Rice – Shrimp Farming Models in a Bien Dictrict, Kien Giang Province. J Envi Sci Agri Res. 2025. 3(4): 1-9.
DOI: doi.org/10.61440/JESAR.2025.v3.77

development of the rice–shrimp model, there is an urgent need for integrated technological solutions to address the issues of seed quality control, multiple stocking densities, decreasing water quality management, and improving production in farming system. It is also essential to enhance technical capacity through the application of IoT technology and sensor networks for efficient monitoring and management of the environmental farming, contributing to rice – shrimp sustainable development models.

This paper presents results obtained after two years of practical research on applying IoT technology and sensor networks, aiming to establish a scientific and practical foundation for technical solutions in the operation and environmental management of a sustainable rice–shrimp farming models in the Mekong Delta region.

Research Methodology

Research Location and Duration

The rice - shrimp farming model research project was implemented from December 2019 to December 2021 at three villages: Nam Thai A, Nam Thai, and Tay Yen A, located in A Bien district, Kien Giang province.

Research Contents and Methodology

Content 1: Survey on current status of the operational techniques and financial efficiency of the rice–shrimp farming models. During the implementation process: (1) the secondary data were collected from documents and annual summary reports provided by local specialized management agencies; (2) the primary data were obtained through direct interviews with 60 households that have participated or are currently participating in rice - shrimp farming models in A Bien district, Kien Giang province.

Content 2: Experimental development of a model applying IoT technology and sensor networks for environmental monitoring and management in rice - shrimp farming areas.

The practical experiment concerned 18 participating households, covering a total rice field area of 27 ha, with an average of 1.5 ha per household for practical experiment. The experimental design followed the technical protocol for rice - shrimp cultivation, and developed in two stages - nursing and commercial farming at three treatments with different farming models: (1) Model 1 (MH1): Development of a shrimp farming (Penaeus monodon) model (with the addition of one crab per 10 m²) in rice fields during the dry season, in rotation system with freshwater prawn (Macrobrachium rosenbergii) in rice field at rainy season in Nam Thai A village; (2) Model 2 (MH2): Development of a shrimp rotation farming model (with the addition of one crab per 10 m²) during the dry season with rice – prawn intercropped farming model during the rainy season, in Nam Thai village; (3) Model 3 (MH3): Development of a diversified and sustainable rice-shrimp farming models (including tiger shrimp, freshwater prawn, crabs, rice (ST 24) and vegetable crops) during the dry and rainy seasons in Tay Yen A village, An Bien district, Kien Giang province [8].

Concerning to the IoT and sensor network application, the project conducted site surveys on farms to select appropriate locations for installing four environmental monitoring stations. The installation included hardware and software systems, as well as technical training for local management staff and participating households on operation and system management. The components of the IoT system and sensor network included:

Agent-based monitoring system model

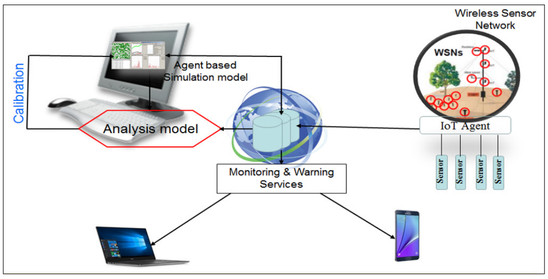


Figure 1: Agent-based Environmental Monitoring System

The development of an environmental monitoring system has been carried out based on wireless sensor network (WSN) technology, IoT, data storage, and analysis on a multi-agent simulation platform integrated with a data warehouse. The core component of the AEMS (Agent-based environmental monitoring system) is the monitoring and alert service server, which provides the following services [9]:

- Data storage.
- Agent-based analysis and simulation.
- Alerts and appropriate solutions for users.

IOT Agent

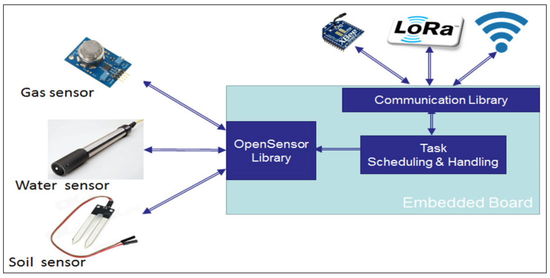


Figure 2: Components of the IoT Agent

The IoT Agents are built based on the following components: (1) Task scheduling and processing unit; (2) Sensor communication module, which interacts with sensors to collect environmental data; and (3) Transmission communication module, which transmits the collected environmental data to the central data storage and receives commands from users. The operations of the sensor stations are scheduled and executed by the task scheduling processor. Based on the configuration of the sensor station and the scheduler, the data reading intervals (e.g., every 5 minutes, 10 minutes, etc.) are stored in the system config and are activated accordingly to trigger the sensors. The IoT Agents used in the deployment of water environment monitoring stations in the farming areas and ponds consist of a main circuit board, microprocessor, memory card reader, real-time clock IC, and sensor connection ports.

Table 1: Technical specifications of the sensor station controller

Microcontroller	ATmega 2560
External Memory Card Slot:	MicroSD type
Real-Time Clock Module:	Included
Number of Sensor Ports:	6 DIN/BTA ports
Communication Port:	USB 2.0 Type B Female
Communication Standard:	WIFI 802.11 b/g/n (Zigbee 2.4GHz optional)
Dimensions (L x W x H):	238 158 x 90 mm

Model for Deploying a Water Quality Monitoring System

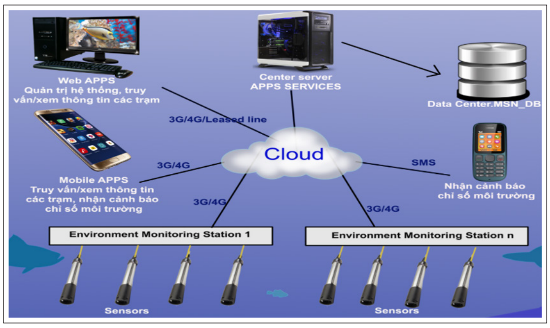


Figure 3: Model for deploying an environmental monitoring system in rice - shrimp farming models

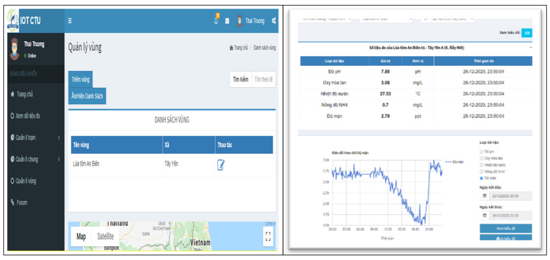


Figure 4: Web-based software for monitoring station and environmental data management

The practical implementation of the water quality monitoring system in rice–shrimp farming areas has been developed with monitoring stations connected to five types of sensors: salinity, temperature, dissolved oxygen (DO), pH, and ammonium (NH_4). The system is designed to be expandable, allowing integration with additional sensors as needed. The monitoring stations are installed at water sources within the production area, including irrigation and drainage canals, ponds, and rice fields.

The service server for the environmental monitoring system is cloud-based, which helps reduce hardware costs and allows for easy integration of new services. The water quality monitoring system provides management and data visualization services through a web-based software platform as well as a mobile application (Figure 5).

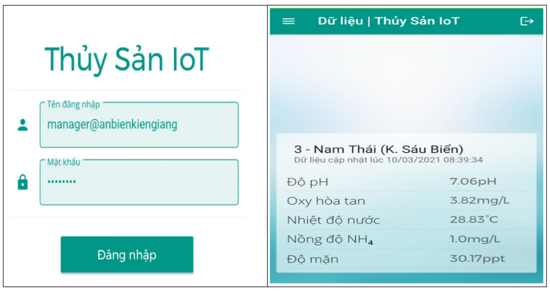


Figure 5: Monitoring environmental data via mobile application

Methods for Verifying and Comparing Data Collected from the Monitoring System

- Water quality measuring devices used for comparison with the monitoring system Handheld DO meter HI9142, pH tester HANNA HI98127, and temperature and DO meter by OxyGuard (Denmark).
- Verification, comparison, and analysis of data collected from the monitoring system with handheld measuring instruments: To assess the accuracy and stability of the IoT-based environmental monitoring and management system under actual water conditions in rice–shrimp fields and water sources, the project measured key parameters of water temperature, pH, salinity, DO, and $N\text{-}NH_4$ using handheld devices. The results were then calculated and compared with those from the monitoring system, and the Root Mean Squared Error (RMSE) was used to evaluate deviations.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)}{n}}$$

Where:

- x_i is the i measurement values made in the field (rice shrimp farming)
- y_i is the I measurement values recorded by the monitoring system at the water supply canal.

Data Analysis

All of data collected during the practical experiment in rice shrimp models were recorded, calculated, analyzed, and compared using bio-statistical analysis methods.

Results and Discussions

Technical Status of the Operation and Management of the Rice - Shrimp Farming Model in an Biên District, Kiên Giang Province

General Technical Characteristics of the Rice–Shrimp Farming Model

Data analysis shows that the current status of water level in ditches surrounding the rice fields ranges from 0.95 to 1.11 meters, while the water level covering the field surface is relatively low, ranging from 0.48 to 0.52 meters. This shallow water depth during the dry season, when temperatures rise significantly, increasing the risk of shrimp disease and mortality - one of the major limitations of the rice - shrimp models (Duong et al., 2016). According to Vromant et al., an effective rice–shrimp model requires the surrounding ditches to be wide and deep, exposed to sunlight, and rich in plankton [10]. Poor management may lead to algal blooms, deteriorating water quality and negatively affecting shrimp growth [11]. Additionally, during model operation, most shrimp farmers rarely change the water, with 72% only replenishing water into the fields, and only 28% actually performing water exchanges. The survey also reveals that 8% of households feed shrimp using locally available agricultural by-products such as trash fish and mollusks at feeding rate of 2 – 3%/t/weight/day, while the remaining 92% do not provide feed to the shrimp.

Water Quality Characteristics in Rice - Shrimp Farming Areas

The research data presented in Table 2 indicate that the average water temperature in tiger shrimp ponds throughout the farming months ranges from 31.1 to 33.1°C. Water pH ranges from 7.3 to 7.9, salinity from 19.8 to 31.8‰, dissolved oxygen (DO) levels from 4.5 to 5.6 mg/L, and ammonium nitrogen ($N\text{-}NH_4^+$) concentrations from 0.23 to 0.50 mg/L. Further analysis shows that water conditions in shrimp fields across different locations in An Bien District are quite similar, especially during the peak dry season (March–April), when temperature and salinity levels rise significantly (31.8 ± 4.4‰), adversely affecting growth, molting, and shrimp survival rates in the model [12].

Table 2: Current status of water quality parameters in rice shrimp farming systems during the dry season in A Bien district

Parameters	March 2020	April 2020	May 2020	June 2020
Temperature (°C)	32.2 ± 2.1	32.1 ± 1.7	33.1 ± 1.1	31.1 ± 0.6
Water pH	7.4 ± 0.7	7.3 ± 0.4	7.7 ± 0.5	7.9 ± 0.4
Salinity (‰)	23.0 ± 3.8	25.5 ± 3.0	31.8 ± 4.4	19.8 ± 1.5
DO (mg O_2/L)	5.6 ± 0.3	5.1 ± 0.3	4.7 ± 0.4	4.5 ± 0.4
NH_4^+ (mg/L)	0.23 ± 0.13	0.27 ± 0.23	0.30 ± 0.24	0.50 ± 0.06

Yield and Survival Rate of Shrimp, Crabs, and Rice in the Farming Systems

Data analysis (Table 3) shows that harvested tiger shrimp commonly range from 20 to 30 individuals per kilogram, with survival rates across models varying from 18.4% to 19.7%. For giant freshwater prawns, harvest sizes range from 25 to 30 individuals per kilogram, with survival rates ranging from 14.7% to 16%, and yields reaching 115.8 to 121 kg/ha/year. Harvested crabs range from 3 to 6 individuals per kilogram, with a survival rate of 2.95 ± 1.80%, and yields reaching 115.5 ± 47.9 kg/ha/year.

Overall, shrimp and crab yields in the surveyed models remain relatively low, and the profit efficiency from these farming models has not yet reached high levels.

Table 3: Yield, survival rates of shrimp, crabs, and rice from farming model

Species	Harvest size (ind./kg)	Yield (kg/ha)	Survival rate (%)
Tiger shrimp	20 – 30	298 – 311	18.4 – 19.7
Freshwater prawn	25 – 30	115.8 – 121.0	14.7 – 16.0
Crab	3 – 6	115.5 ± 47.9	2.95 ± 1.80
Rice (varieties 2517, 5451)	–	4,728 – 4,900	–

Advantages and Constrains

Advantages

The land area allocated for rice–shrimp farming models in the three surveyed village is relatively large (> 2 ha/household), which is favorable for the model's diversified and sustainable development. Additionally, the products from the model - such as eco-friendly shrimp and specialty rice varieties like Dai Thom; 2517, 5451, and ST24 are highly preferred in the consumer market, offering great potential for the further expansion of the rice shrimp models.

Constrains

- Farmers' knowledge and technical capacity in operating and managing the model remain limited
- The design of infrastructure for integrated rice - shrimp farming does not meet the technical standards recommended by specialized agencies [8]. The water depth in the rice fields is too shallow (0.3 – 0.5 m), which leads to increased temperatures and unstable water conditions, negatively affecting shrimp growth [13,12]. Moreover, the quality of shrimp post-larvae is low, the nursery ponds are lacking and small size, and shrimp are not fed during the nursery stage, all of which adversely impact to the model's productivity and profitability for rice shrimp farming.

Financial Efficiency of Surveyed Rice - Shrimp Farming Systems

Financial analysis shows that profits from rice–shrimp models in A Bien District remain relatively low values, ranging from VND 30.9 to 43.4 million/ha. The profit cost ratio ranges from 80% to 82%, which is higher than that reported for rice - shrimp models in Thoi Binh District, Ca Mau province, where the profit averaged VND 34.4 ± 14.8 million/ha/year and the average profit cost ratio was only 59% [8].

Development of an IOT and Sensor Network Application Model for Monitoring and Managing Environmental Conditions in Shrimp Farming Areas in an Bien District, Kien Giang Province

System design and Installation for Environmental Monitoring

Through the application of technology, the project has designed, built, and installed the hardware and software for a management system. In addition, it organized training sessions on the use of the management software for monitoring systems and accessing data measurement from the stations. This enables local managers and participating farmers to understand the environmental conditions in the production area. The project has installed 4 water quality monitoring stations in the following village: (1)

Tay Yen A; (2) Nam Thai – Nam Yen and (3) Nam Thai A. Among these, three stations monitor and manage the water quality from canal water supply to the rice shrimp system, while one station monitors water quality within the infield area of the shrimp farming models.

Figure 6: Environmental monitoring stations at Ray Moi canal and in rice field areas for rice - shrimp farming systems

Technical Efficiency Analysis of the IOT-Based Rice–Shrimp Farming Model

IOT and Sensor Network-Based Rice–Shrimp Farming Model

Survey and analysis results revealed fluctuations and differences in water environmental conditions between two types of water bodies: water inlet sources (rivers and canals) and in rice field water bodies. There were also discrepancies in measured environmental parameters between areas directly connected to the water source (Nam Thai A) and infield locations such as rice fields in Nam Thai and Tay Yen A villages (at the end of the supply network).

This characteristic was clearly reflected in the salinity variation among the rice–shrimp fields and the salinity level (‰) in the supply canals during January 2021. Notably, Nam Thái villages had the highest average salinity at 17.8‰. The early detection of salinity presence and its fluctuation in the supply canals enabled timely implementation of appropriate salinity control solutions, helping farmers to manage and maintain stable environmental conditions. This, in turn, supported the healthy and stable development of shrimp farming.

In contrast, due to the greater distance of the rice - shrimp fields in Tay Yen A from the main water source, the appearance and increase of salinity in its supply canals occurred more slowly and at much lower levels. However, the stability of salinity concentrations in the rice shrimp farming in Tay Yen A played a significant role in maintaining a stable environment, which allowed for successful application of technical interventions in seed nursing (shrimp and giant freshwater prawn), leading to high survival rates and production.

An evaluation of the root means square error (RMSE) for measured indicators across the different water body types also showed the greatest variation in water temperature between shrimp fields and supply canals in Nam Thai A (4.3°C). Meanwhile, the RMSE values for water pH and N-NH_4 levels between shrimp fields and intake sources were relatively small. This indicated stable water quality conditions from the intake source to the infield water bodies, supporting a favorable environment for shrimp respiration, feeding, growth, and development in the rice–shrimp farming models (Pillay, 1990; New, 2000) at the local level.

Table 4: Comparison of water quality in rice shrimp models and water quality in canal results and RMSE deviations from samples collected in January 2021

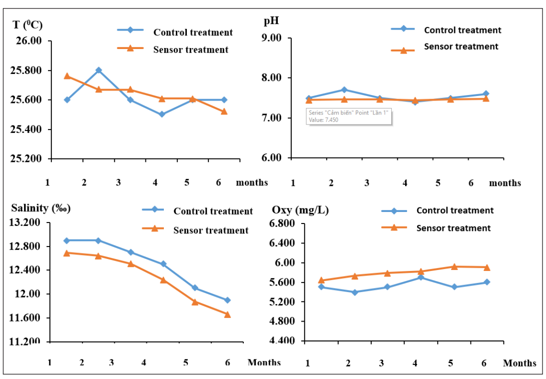
1.	Nam Thai village									
Farmers	Water quality in rice – shrimp models					Water quality in canal water supply				
	T (°C)	pH	SAL (‰)	DO (mg/L)	NH_4 (mg/L)	TMP (°C)	pH	SAL (‰)	DO (mg/L)	NH_4 (mg/L)
Farmer 1	31,5	8,5	6	4,2	0,71	28,9	7,4	26,0	4,4	0,59
Farmer 2	30,8	8	9	4,2	0,52	28,9	7,4	26,0	4,4	0,59
Farmer 3	30,6	8,3	7	4,1	0,62	28,9	7,4	26,0	4,4	0,59
Farmer 4	31	7,9	10	4,5	0,53	28,9	7,4	26,0	4,4	0,59
Farmer 5	30,7	8,1	12	4,3	0,64	28,9	7,4	26,0	4,4	0,59
Farmer 6	30,9	7,8	6	4,6	0,52	28,9	7,4	26,0	4,4	0,59
RMSE (TMP)	2,0									
RMSE (pH)	0,8									
RMSE (SAL)	17,8									
RMSE (DO)	0,2									
RMSE (NH_4)	0,1									

2.	Nam Thai A village									
Farmers	**Water quality in rice – shrimp models**					**Water quality in canal water supply**				
	T (°C)	**pH**	**SAL (‰)**	**DO (mg/L)**	**NH_4 (mg/L)**	**TMP (°C)**	**pH**	**SAL (‰)**	**DO (mg/L)**	**NH_4 (mg/L)**
Farmer 7	29,5	8,2	12	4,3	0,81	25,5	9,8	20,2	3,6	0,29
Farmer 8	29,7	7,8	7	4,6	0,72	25,5	9,8	20,2	3,6	0,29
Farmer 9	28,9	8,3	13	4,4	0,63	25,5	9,8	20,2	3,6	0,29
Farmer 10	30,2	8,1	12	4,5	0,52	25,5	9,8	20,2	3,6	0,29
Farmer 11	30,4	7,6	6	4,3	0,71	25,5	9,8	20,2	3,6	0,29
Farmer 12	29,7	7,9	7	4,2	0,55	25,5	9,8	20,2	3,6	0,29
RMSE (TMP)	4,3									
RMSE (pH)	1,8									
RMSE (SAL)	11,0									
RMSE (DO)	0,8									
RMSE (NH_4)	0,4									
3.	**Tay Yen A village**									
Farmers	**Water quality in rice – shrimp models**					**Water quality in canal water supply**				
	T (°C)	**pH**	**SAL (‰)**	**DO (mg/L)**	**NH_4 (mg/L)**	**TMP (°C)**	**pH**	**SAL (‰)**	**DO (mg/L)**	**NH_4 (mg/L)**
Farmer 13	30,2	8,2	2	4,4	0,52	28,6	7,9	4,5	3,1	0,35
Farmer 14	29,7	8	1	4,3	0,51	28,6	7,9	4,5	3,1	0,35
Farmer 15	30,1	7,8	2	4,3	0,46	28,6	7,9	4,5	3,1	0,35
Farmer 16	29,2	7,9	2	4,4	0,61	28,6	7,9	4,5	3,1	0,35
Farmer 17	29,6	7,7	1	4,3	0,62	28,6	7,9	4,5	3,1	0,35
Farmer 18	30,1	7,8	3	4,2	0,61	28,6	7,9	4,5	3,1	0,35
RMSE (TMP)	1,3									
RMSE (pH)	0,2									
RMSE (SAL)	2,8									
RMSE (DO)	1,2									
RMSE (NH_4)	0,2									

In summary, the establishment of water quality monitoring stations for managing environmental conditions in rice–shrimp farming areas, based on IoT technology and sensor networks, implemented at water intake points in Nam Thai A, Nam Thai, and Tay Yen A villages, has provided practical support to both technical staff and farmers. It has enabled early access to information and data on fluctuating water quality parameters (pH, DO, salinity, and N-NH_4^+) occurring during the farming process. As a result, farmers can proactively analyze the situation, consult with experts, and make informed decisions on the most appropriate and effective technical solutions for operating their farming models.

Table 5: Evaluation table of average Min and Max root mean square error (RMSE) between monitoring stations and handheld meters by environmental indicators

RMSE	Mean	Min	Max
RMSE (TMP)	0,18	0,12	0,30
RMSE (pH)	0,15	0,10	0,21
RMSE (SAL)	0,25	0,21	0,29
RMSE (DO)	0,21	0,17	0,29
RMSE (NH_4)	0,19	0,17	0,22



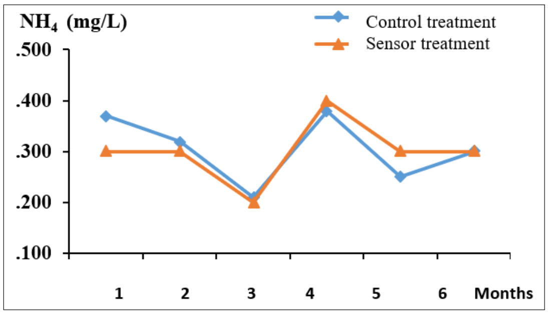


Figure 7: Comparison chart of environmental parameters collected by field staff and data from the monitoring station in Nam Thai A village, Kien Giang on 20/12/2020

Based on the results presented in Table 4 and the RMSE error analysis in Table 5, the root mean square error (RMSE) for dissolved oxygen (DO) in water between the two devices was less than 0.3 mg/L, with an average deviation of 0.21 mg/L. The highest temperature deviation was less than 0.3°C, and the average temperature deviation between the handheld Hanna meter and the monitoring station was 0.18°C. Similarly, the lowest, average, and highest RMSE values between monitoring stations and handheld meters for various environmental indicators are detailed in the tables.

These deviations can be explained by differences in sampling depth and variations in sampling procedures when analyzing environmental conditions. However, the differences are minor for example, the average RMSE for salinity concentration was less than 0.25‰. The comparison and error assessment indicate that environmental data collected from monitoring stations and handheld devices are quite consistent. All measured values fall within the acceptable range for sensor devices used to monitor environmental parameters.

Survival Rate and Productivity of Farmed Shrimp in Rice–Shrimp Farming Models

Table 6: Survival rate and yield of shrimp in rice–shrimp farming systems

No.	Model	Tiger shrimp (kg/ha)	Mud crab (kg/ha)	Freshwater prawn (kg/ha)	Rice (kg/ha)
1	Model 1	451.7	249.5	660	–
2	Model 2	421.3	119.8	188	6,900
3	Model 3	456.7	135	232	6,300

The experimental results in Table 6 showed that the average production of Penaeus monodon in model 1 (MH1) was 451.7 kg/ha, with the highest reaching 490 kg/ha. This yield is significantly higher than the reported of P. monodon yields of 185–285 kg/ha in Hong Dan district, 181–250 kg/ha in Gia rai, Bac Lieu Province (Duong et al., 2016), and 264 kg/ha in Thoi Binh, Ca Mau province [8]. The technical improvement of applying a two-stages nursery and grow-out system is a key factor contributing to the increased shrimp productivity in the model [8]. For freshwater prawns (Macrobrachium rosenbergii) the average survival rate in the rice fields of 24.6 ± 4.3%, with an average productivity of 660 ± 129 kg/ha. In Model 2 (MH2), the survival rate of tiger shrimp was relatively high, ranging from 20.5% to 23.5%, with an average of 22.3%. The yield of shrimp (Penaeus monodon) farming system ranged from 375 to 440 kg/ha, averaging 421.3 kg/ha. The average yield of freshwater prawns was 188 ± 37 kg/ha. Among the six participating households, rice yields were quite high, ranging from 6,000 to 7,850 kg/ha. In Model 3 (MH3), the average production of tiger shrimp was 456.7 ± 70.3 kg/ha. Although the salinity in this area tended to appear later and at lower levels, the stability of salinity at the experimental sites was an important factor supporting shrimp respiration, metabolism, and growth, ultimately contributing to high productivity [6,12]. The average yield of freshwater prawns was 232 ± 17 kg/ha. The average yield of rice (variety ST24) was 6,125 ± 140 kg/ha, with the highest yield among the six households reaching 6,300 kg/ha.

Financial Efficiency Analysis of Farming Models

Research results in Table 7 showed that, among the three experimental models, Model 1 (MH1) had the highest investment cost at 46,770,000 VND/ha, significantly different ($p<0.05$) from Model 2 at 36,507,000 VND/ha and Model 3 at 40,039,000 VND/ha. Model 1 also produced the highest profit at 140,069,000 VND/ha, which was not statistically different ($p > 0.05$) from Model 3 (131,264,000 VND/ha), but significantly different ($p < 0.05$) from Model 2, which had a profit of 109,023,000 VND/ha. The profit cost ratio in all three models was very high, exceeding to 280%.

Table 7: Financial efficiency of three rice - shrimp farming models (VNĐ/ha)

Model	Total invest. cost	Total gross income	Profit (VND/ha)	Profit cost ratio (%)
MH 1	46,770,000 ± 1,943^{b}	186,839,000 ± 18,906^{b}	140,069,000 ± 17,959^{b}	299.3 ± 34.8^{a}
MH 2	36,507,000 ± 3,534^{a}	147,369,000 ± 2,038^{a}	109,023,000 ± 3,104^{a}	285.5 ± 24.7^{a}
MH 3	40,039,000 ± 2,816^{a}	171,303,000 ± 15,259^{b}	131,264,000 ± 12,834^{b}	327.6 ± 17.9^{a}

Note: MH = Model; Mean values followed by different letters in the same column indicate statistically significant differences ($p < 0.05$).

* Opinions and evaluations of local people participating in the implementation of the rice – shrimp farming models.

Table 8: Evaluation of the effectiveness and benefits of using IoT technology and sensor networks

No	Contents	Evaluation rate (%)			
		Poor	Normal	Good	Very good
1	Could the fluctuations of water environmental factors in the farming field be monitored quickly and accurately?	-	-	74.3	25.7
2	Does it save time and effort compared to traditional water sampling and measurement methods?	-	-	87.2	12.8

3	Monitor the fluctuations of water environmental factors anytime (24/7), anywhere.	-	-	12.9	87.1
4	Monitor the water quality from both the water supply source and the farming field.	-	-	62.7	37.3
5	To assist in water exchange for shrimp ponds and fields, and in water environment treatment.	-	-	84.8	15.2
6	To expand technical knowledge and the ability to apply new technologies in practical production.	-	12.3	54.0	33.7
7	Reduce risks through early warning of adverse environmental factors.	-	-	43	57
8	Enhance the skills and knowledge of producers using the system.	-	-	86.5	13.5

The survey of feedback and evaluations from technical staff and farmers participating in the application project (Table 8) shows that most local officers and farmers involved in the model highly appreciated the practicality and immediate effectiveness of applying IoT technology and sensor networks for environmental monitoring and management in rice - shrimp areas. Specifically, 74.3% rated the system as "**good**" and 25.7% as "**very good**," highlighting that it helped farmers save time, effort, and costs associated with sampling and measuring environmental indicators - reflected by 87.2% rating it "**good**" and 12.8% as "**very good**".

Notably, the application of IoT technology and sensor networks in collecting and forecasting environmental factors in canals for water supply significantly assisted rice shrimp farmers in early detection of environmental changes. This enabled them to determine the safest timing for water inlet and replacement in their farming fields, thereby reducing risks previously encountered.

In addition, the activity helped farmers enhance their awareness, adopt new technical perspectives, and improve their capacity to apply science and technology in shaping and innovating farming practices. These efforts support adaptation to climate change and promote sustainable development, aligning with local policies and directives on restructuring livestock and crop systems to improve productivity, product quality, and profitability of production models.

Conclusions

1. The rice-shrimp farming models is a traditional cultivation method that primarily relies on the experience of local farmers. In production, it is essential to implement multiple solutions and apply scientific and technological advancements to effectively develop operation and management procedures, thereby contributing to improved quality of culture systems and profitability for local farmers.
2. The practical experiments on application of IoT technology and sensor networks for environmental management in rice-shrimp farming areas, with four water monitoring stations installed in village such as Tay Yen A, Nam Thai – Nam Yen, and Nam Thai A, integrated with a web-based data management system and mobile software, has enabled rapid access to data on environmental fluctuations in the rice – shrimp farming areas. This has supported local officers and farmers in the operation and management of the rice-shrimp farming models, allowing timely implementation of technological solutions and the most effective management practices.
3. The financial results from three rice-shrimp farming models applying IoT technology and sensor networks are as follows: Model 1 achieved a profit of 140 million VND/ha/year with a profit cost ratio of 299.3%; Model 2 reached 109 million VND/ha/year with a profit cost ratio of 285.5%; and Model 3 achieved 131.3 million VND/ha/year with a profit cost ratio of 327.6%. These results affirm the effectiveness of the project and suggest that the model should be recommended for development and replication, allowing more farmers in An Bien District, Kien Giang province to adopt and benefit from it in the future.

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