Philippine Journal of Science
154 No. 1: 135-147, February 2025
ISSN 0031 - 7683
Date Received: 06 Sep 2024

Physico-chemical Analysis of Water in *Litopenaeus vannamei* Ponds in Dahican, City of Mati, Davao Oriental, the Philippines

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Litopenaeus vannamei **requires a specific range of water quality parameters for optimal growth and health. Monitoring these parameters, as water enters (inlet) and exits (outlet) the shrimp ponds and throughout the canal system, is crucial in optimizing shrimp production, nutrient management, disease prevention, environmental protection, and compliance with regulatory standards. This study aimed to analyze water quality parameters at three different sites in *Barangay* Dahican, City of Mati, Davao Oriental, the Philippines, where all shrimp ponds in the area are located. Sampling stations were established at the inlet, canal, and outlet of each site, with sampling conducted in February and March to assess residual impacts of pond operations, assuming that most residues would be flushed out by March, leading to improved water quality. Assessed water quality parameters assessed included temperature, pH, salinity, dissolved oxygen (DO), chemical oxygen demand (COD), total suspended solids (TSS), ammonia, nitrite, nitrate, phosphorus, and alkalinity. Statistical analyses were performed. Results revealed that the temperature (26–28 ºC), pH (7.5–8.0), salinity (26–37 ppt), DO (3.5–6.4 mg/L), TSS (8–29 mg/L), ammonia (< 0.007 mg/L), nitrite (< 0.055 mg/L), nitrate (1.73–2.36 mg/L), phosphorus (< 0.12 mg/L), and alkalinity (129–187 mg/L) had values that fall within the safe, recommended and optimal range (with insignificant deviations) for *L. vannamei* ponds except for COD, which was substantially high (1,383–1,805 mg/L), comparable to domestic wastewater, and beyond the safe limit set by the Philippine regulatory standards for shrimp pond effluents (300 mg/L). It is recommended to reduce COD levels through efficient water quality management and treat effluents before discharge. Regular monitoring and management of water quality in shrimp ponds must be done to maintain the optimal conditions of the water quality parameters, thus improving the growth and production of *L. vannamei* and ensuring that the effluents are safe and non-hazardous to the environment.**

Keywords: aquaculture, canal, effluents, inlet, shrimp farming, water quality

INTRODUCTION

Due to rising demand, shrimp farming dominates the estuaries and coastal lowlands in tropical and subtropical regions, which gives farmers better profit margins (Carvalho Pereira *et al*. 2022). According to Jory (2023), around 5.6 MMT of shrimp was produced worldwide in 2023, primarily dominated by *Litopenaeus vannamei*. The Philippines, one of the significant shrimp producers in Asia, produced 20,612.48 MT of *L. vannamei* in 2020, valued at USD 89,000 (DA-BFAR 2022). *L. vannamei* is the most cultured shrimp in the Philippines (Clapano *et al.* 2022). The optimal growth and production of *L. vannamei* depend on water quality.

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Improved productivity can be achieved if water quality is at the optimal range (Tumwesigye *et al.* 2022). Hence, regularly monitoring the water quality parameters at the inlet, through which water flows into the pond and throughout the canal system, is vital. Meanwhile, the effluents from the outlet of the shrimp ponds could be detrimental to the quality of receiving estuarine and marine waters (Bui *et al.* 2012). Since shrimp pond effluents are enriched in waste feed and shrimp excreta, they are a significant source of pollutants to nearby aquatic ecosystems – causing nutrient enrichment, eutrophication, and increased suspended solids (Tom *et al.* 2021). Shrimp ponds have created various environmental impacts due mainly to the locations of the shrimp ponds, the management and technology applied during operation, the scale of production, and the capacity of receiving waters. The harmful environmental consequences of the shrimp aquaculture industry, in turn, resulted in reduced production, disease outbreaks, and the need to implement more stringent regulations on the operations and management of coastal zones.

The study by Mercado *et al.* (2024) highlights the importance of monitoring water quality, showing seasonal fluctuations and frequent failures to meet Class A standards, underscoring the need for effective environmental management. Similarly, the current study on *Litopenaeus vannamei* ponds in Dahican, City of Mati, Davao Oriental, emphasizes the critical role of water quality in aquaculture for optimal shrimp growth and disease prevention. Both studies illustrate the significant impact of weather variables on water quality and stress the importance of continuous monitoring and targeted management to safeguard aquatic ecosystems and promote sustainable practices. Melad *et al.* (2024) further underscores the risks of water quality deterioration due to pollution from industrial and rural activities, highlighting the necessity of monitoring key physicochemical parameters such as pH, DO, TSS, and BOD. In both cases, consistent water quality assessments are essential to identify pollution sources, ensure compliance with standards, and support long-term ecological and economic sustainability.

The number and intensity of shrimp ponds along Dahican, City of Mati, Davao Oriental, the Philippines, has rapidly expanded this past decade. Among the provinces in the Davao region, Davao Oriental has the highest number of shrimp farms (36) with a total area of 50 hectares (DA-BFAR 2022). Despite the management measures that were initially in place, with the rapid proliferation of shrimp farms, regulations became invariably insufficient and inefficient. This culminated in the widespread and fatal viral disease contamination of ponds, where a significant portion of the *L. vannamei* cultured in Dahican got infected with the white spot disease, beginning in September 2021. The local government issued an executive order suspending all pond operations by December 2021 to contain further contamination. All pond operations in Dahican effectively ceased by January 2022, as the local government, through a technical working group (TWG), assessed the current situation to develop proper management interventions.

This study aimed to assess the water quality of shrimp ponds in Dahican. As the study was set to gather data in February and March 2022, the relative absence of pond operations beginning in the last quarter of 2021 meant that the data collected on water quality parameters from this study should reflect the residual impacts of shrimp pond operations after they had stopped. Moreover, as the cessation of pond operations was only temporary and the TWG had decided to allow some ponds to operate as of March 2022, the data also provided a baseline water quality conditions within which the ponds will likely operate. While ponds sanitize the influent to and effluent from shrimp ponds as required by regulations, the information on the water quality in and around the shrimp ponds will be significant as these are the parameters against which future monitoring should be based.

Water quality monitoring is crucial for maintaining optimal conditions for shrimp growth and health, as well as for protecting surrounding aquatic ecosystems from potential pollution caused by effluents (FAO 2023). This study aims to address a specific knowledge gap related to the adequacy of water quality management in the context of shrimp aquaculture in Dahican, City of Mati, Davao Oriental, the Philippines, where the rapid expansion of shrimp farming has outpaced regulatory measures, resulting in environmental challenges such as nutrient enrichment and disease outbreaks. The white spot disease that significantly impacted *L. vannamei* production in 2021 highlighted the need for effective management and monitoring practices. By assessing water quality parameters during the period of pond operation cessation in early 2022, this study seeks to provide critical baseline data on residual water quality and inform future regulatory and management practices to ensure the sustainability of shrimp farming, reduce disease risks, and minimize negative environmental impacts. This contribution will be valuable for shrimp pond operators aiming to optimize production, enhance sustainability, and comply with regulatory standards to support the long-term viability of their operations.

MATERIALS AND METHODS

Description of the Study Sites and Sampling Design

Three main sites were identified where all the shrimp ponds in *Barangay* Dahican operate: *Sitio* Maitom, *Sitio* Lahusan, and *Sitio* Butuasan. Three sampling stations (inlet, canal, and outlet) within each site were established. The inlet refers to the mouth of the canal where water from Pujada Bay enters the canal to be supplied to the farms. The canal is a system of channels through which water flows into and out of individual ponds. The outlet refers to the area that receives the effluents; data were gathered about 100 meters away (seaward) from identified point sources. Three replicates were collected from each sampling station, and data were gathered from 22–24 Feb and again from 22–24 Mar.

Physico-chemical Analysis of Water

The study was conducted to assess both physical and chemical water quality parameters. The physical parameters – which included pH, salinity, and temperature – were measured *in situ* using a calibrated multimeter equipped with appropriate probes. The chemical parameters – comprised of dissolved oxygen (DO), chemical oxygen demand (COD), total suspended solids (TSS), nitrate, nitrite, ammonia, phosphorus, and alkalinity – were analyzed in the laboratory. Water samples were collected in triplicate from the sub-surface at each sampling station using one-gallon sterile containers. These samples were transported on the same day to the Science Resource Center of the University of Immaculate Conception in Davao City, the Philippines, where laboratory analyses were performed immediately upon arrival to ensure sample integrity, following the Standard Methods for the Examination of Water and Wastewater (Baird *et al.* 2017).

For the analysis of DO, Winkler's titration method was employed. This involved the addition of a manganese solution and a reagent to the sample, followed by titration with sodium thiosulfate until a color change indicated the endpoint, and the DO concentration was then calculated using standard formulas. COD was determined using the closed reflux colorimetric method, where a known volume of the sample was digested with potassium dichromate in a reflux apparatus, and the absorbance was measured at 420 nm using a spectrophotometer to quantify COD. TSS was analyzed by filtration through pre-weighed Whatman GF/C filters; the sample was passed through the filter, which was subsequently dried at 105 °C for 24 h, and the increase in weight was used to calculate the TSS concentration. The measurements of nitrate and nitrite were performed using spectrophotometry and specific reagent kits such as cadmium reduction for nitrate and Griess reagent for nitrite, with absorbance readings taken at 540 nm for both parameters and compared to standard calibration curves. Ammonia was analyzed using the Nesslerization method, where the sample was reacted with Nessler's reagent to form a yellow-brown complex, and the absorbance was read at 420 nm using a spectrophotometer. Phosphorus, as orthophosphate, was measured by the molybdenum blue method, where ammonium molybdate was used to react with the sample and was reduced by ascorbic acid to form a blue complex, which was analyzed at 880 nm using a spectrophotometer. Alkalinity was determined through titration with a standard acid solution such as HCl using phenolphthalein and methyl orange as indicators; the endpoint was reached when the sample changed color, signifying complete neutralization of alkalinity.

All analyses were performed in triplicate to ensure the reliability of the results. Calibration of the analytical equipment was regularly conducted, and reagent blanks were used to prevent contamination and maintain accuracy. Regular checks with certified standards were implemented to support the precision and validity of the methods employed.

Statistical Analyses

Analyses were performed using SPSS version 21, and basic statistics were calculated. The normality of parameters was tested using the Shapiro-Wilk test for each parameter, a standard procedure in water quality data assessment (Zeinalzadeh and Rezaei 2017). The non-normally distributed water quality parameters were logarithmically transformed using log (x + 1). Nitrite, ammonia, and phosphorus parameters were not included in the analysis because they failed to conform to the assumptions of normality of data, and temperature was not included due to standard practices in which it is constantly measured and reported separately. To compare the differences in water quality parameters at different sampling points and periods, a one-way analysis of variance (ANOVA) was performed with a significance level of 5%. The primary objective of conducting the one-way ANOVA was to evaluate and compare differences in water quality parameters at various sampling points (inlet, outlet, and canal) across all study sites and over the two sampling periods (February and March). By employing this statistical test, statistically significant variations in the water quality parameters between these different points and timeframes were identified. This approach helps in understanding the influence of location (inlet, outlet, and canal) and temporal changes on water quality, which is critical for assessing the overall health and sustainability of the shrimp ponds. The one-way ANOVA was performed at a 5% significance level to determine whether the mean values of the water quality parameters differed significantly among the sampling points (inlet, outlet, and canal) across all sites. Each sampling point was treated as a factor, and the analysis allowed us to test if the variations in parameters such as temperature, salinity, pH, DO, COD, and others were statistically significant between the locations. This comparison across all sites provides insights into how water quality differs due to factors such as water flow, exposure to external influences, and pond management practices. *Post hoc* analysis using the Tukey test was used for parameters noted with a significant difference for the sampling points. A Pearson correlation test was performed on water quality parameters to determine their relationship.

RESULTS

Temperature, Salinity, and pH

Sampling was conducted from 07:00–09:00 AM to minimize the effect of temperature variation on the parameters to be analyzed. The temperature recorded throughout the sampling periods was 26.5–28.0 ºC, within the optimal temperature range of 25–30 ºC for *L. vannamei* (Kır *et al*. 2023). The salinity was 26–28 ppt for February and 26–37 ppt for March. There was an increasing salinity from February–March except for the Lahusan canal, which was consistent at 26 ppt. In March, the inlets in Maitom, Lahusan, and Butuasan had the highest salinity levels – which were at 35, 36, and 37 ppt, respectively – followed by the outlets with 34 ppt for both Maitom and Lahusan Butuasan had 35 ppt. Meanwhile, the canals of all three sites consistently had the lowest salinity – with 33, 26, and 29 ppt, respectively. The optimal salinity range for *L. vannamei* is 22–32 ppt (Hassan *et al.* 2021; Jaffer *et al.* 2020; Khanjani *et al*. 2020). The pH values were generally consistent at pH 7.5–8. The optimal pH range for *L. vannamei* is 7.5–8.5 (Ariadi *et al*. 2019). Moreover, all pH levels were within the recommended range of 6.5–8.5 for aquaculture shrimp ponds by the Department of Environment and Natural Resources (DENR) Administrative Order (DAO) 1990-34.

Dissolved Oxygen (DO)

DO levels varied among study sites and sampling periods (Figure 1). In all the sites, DO was lowest at the canal, compared with the inlet and outlet, with Butuasan (canal) recorded with the lowest DO level (3.5 mg/L). In February, DO levels were below the recommended level (> 5.0 mg/L). Improvements to the DO levels were generally observed in March, particularly at all the outlet stations reporting > 5.0 mg/L DO levels. The most notable improvements were at the inlet and outlet stations of Butuasan with 5–6 mg/L. There was an observed increasing trend of DO from February (3.5–4.8 mg/L) to March (4.4–6.4 mg/L). DO levels had generally improved (except at the inlets of both Maitom and Lahusan, where slight decreases in DO levels were recorded). However, only the outlet of all sites and the inlet of Butuasan recorded DO levels within the suggested DO levels. The optimal range of DO for *L. vannamei* is 4.4–8.6 mg/L (Ariadi *et al*. 2019).

Chemical Oxygen Demand (COD)

COD varied across sites and between the two sampling periods (Figure 2). The mean values, however, were

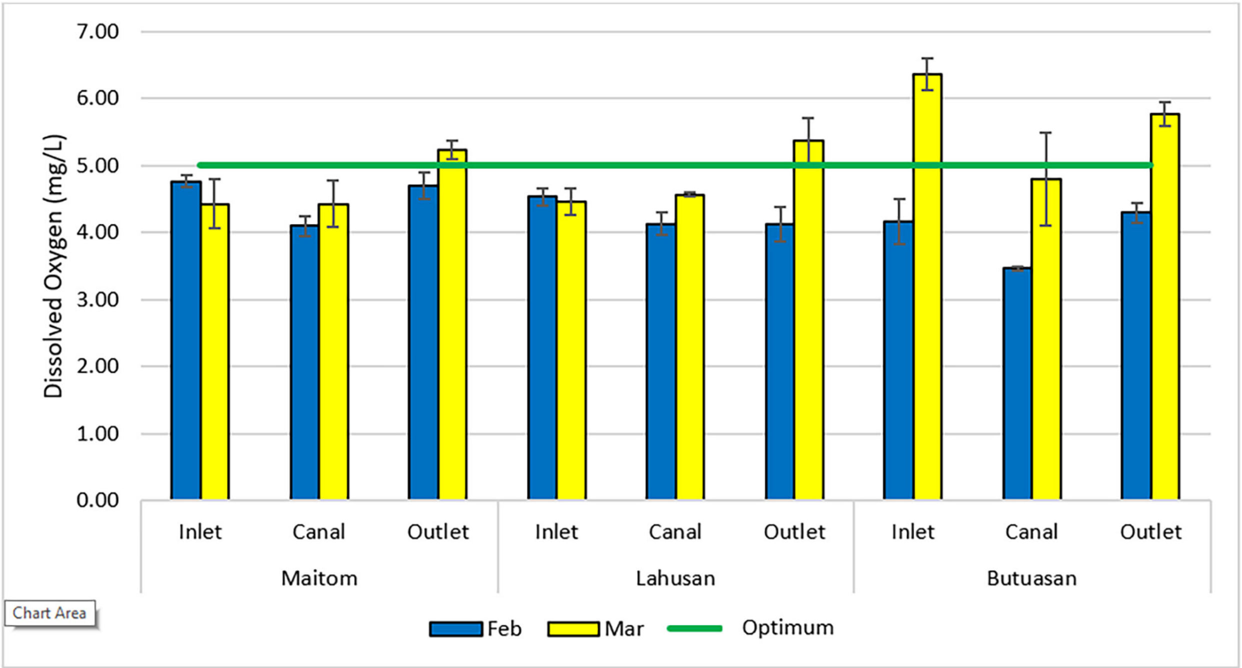

Figure 1. Mean values and standard error of the mean for DO (mg/L) at the shrimp ponds' inlet, canal, and outlet in Maitom, Lahusan, and Butuasan in Dahican, City of Mati, Davao Oriental, the Philippines. The recommended optimum value for DO is included for comparison.

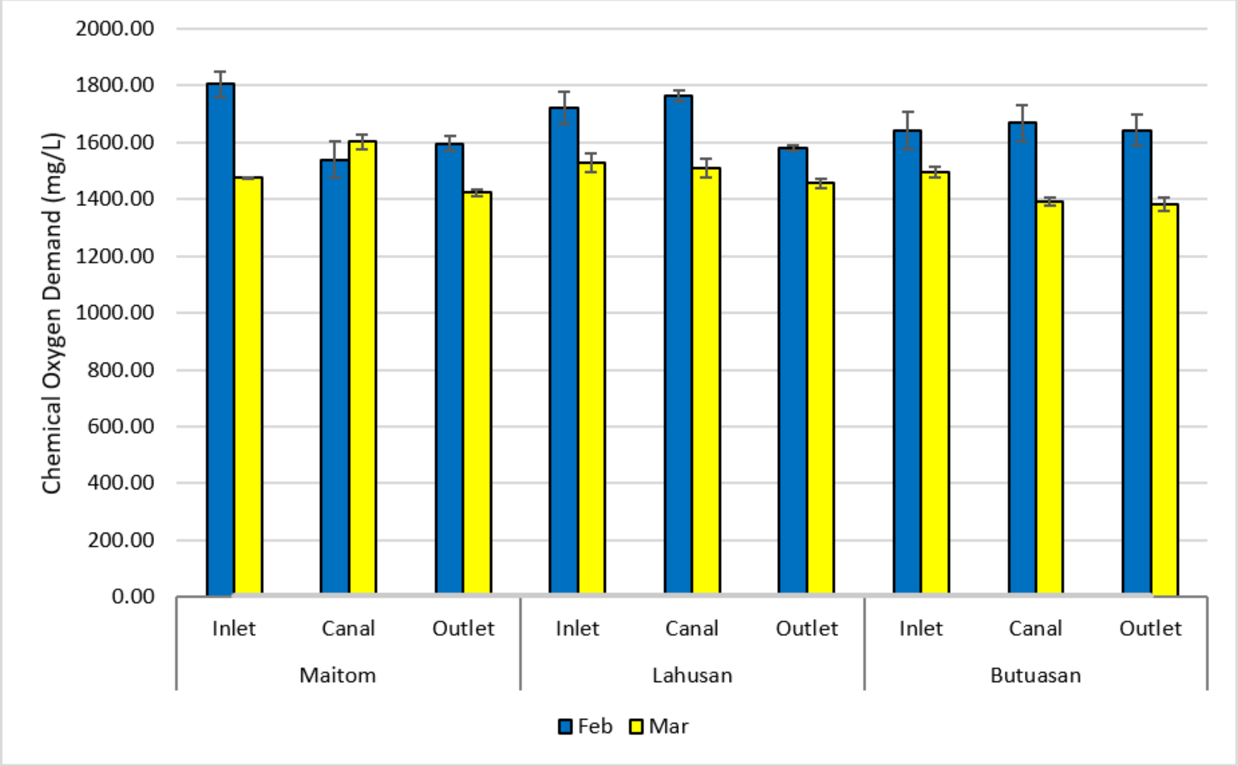

Figure 2. Mean values with the standard errors of the mean for COD (mg/L) at the inlet, canal, and outlet of shrimp ponds in Maitom, Lahusan, and Butuasan in Dahican, City of Mati, Davao Oriental, the Philippines.

inordinately high in all the sites, ranging from 1,383–1,805 mg/L. In February, the Maitom inlet had 1,805 mg/L COD, followed by the outlet, which was at 1,596 mg/L, and then the canal with 1,540 m/L. In Lahusan, the highest COD was observed in the canal with 1,764 mg/L, followed by the inlet with 1,723 mg/L, and then the outlet with 1,581 mg/L. In Butuasan, the inlet and outlet had a consistent COD of 1,642 mg/L, whereas the canal had 1,668 mg/L COD. All sampling stations recorded a decreasing trend in COD from February (1,540–1,805 mg/l) to March (1,383–1,602 mg/L) except for the canal in Maitom, which had a slight increase from 1,540 1,602 mg/L. COD of pond water can vary from 10–80 mg/L, with 15–20 mg/L being acceptable for aquaculture (Giao 2021). Moreover, the maximum COD for shrimp farm effluents that discharge to coastal waters, according to DENR, is 300 mg/L.

Total Suspended Solids (TSS)

TSS in the three sampling sites varied (Figure 3), with Butuasan generally having the lowest TSS among the three sites. On the other hand, Lahusan had the highest TSS, particularly at its inlet and canal. The DENR recommended maximum TSS value is 25 mg/L for Class SA waters, 50 mg/L for Class SB, 80 mg/L for Class SC, and 110 mg/L for Class SD. The canal at Lahusan was the only site exhibiting a TSS beyond the recommended level for Class SA but below the limit for Class SB. However, the Lahusan canal had markedly improved TSS levels from February (29 mg/L) to March (22 mg/L). In Maitom, the inlet had increased TSS from 17–21 mg/L, the canal had risen from 20–22 mg/L, and the outlet had increased from 14–16 mg/L. In Butuasan, the inlet, canal, and outlet had increased TSS from 8–13, 16–18, and 13–14 mg/L, respectively. For *L. vannamei,* the optimal TSS level is generally recommended to be below 30 mg/L.

Ammonia, nitrite, and nitrate. The safe level for total ammonia in *L. vannamei* ponds is set to be at < 1.0 mg/L (Venkateswarlu *et al*. 2019). Ammonia concentrations from most sampling sites were below the detectable levels of 0.007 mg/L. Although ammonia was detected in a few replicates, they were all below the recommended maximum limit of < 1.0 mg/L. Nitrite in all the study sites was mostly below the detectable levels of 0.007 mg/L. Still, they were recorded in a few replicates of the sampling stations with values that were below the recommended level of < 0.5 mg/L for *L. vannamei* ponds (Venkateswarlu *et al*. 2019). The suggested maximum nitrite level for pond effluents is < 0.055 mg/L (AWGCME 2008). Nitrate levels in all the sampling sites were 1.73–2.36 mg/L, below the maximum recommended level of 3–10 mg/L. The DENR recommended that the nitrate levels be kept at ten mg/L for Class SA to SC waters and allowed at 15 mg/L for

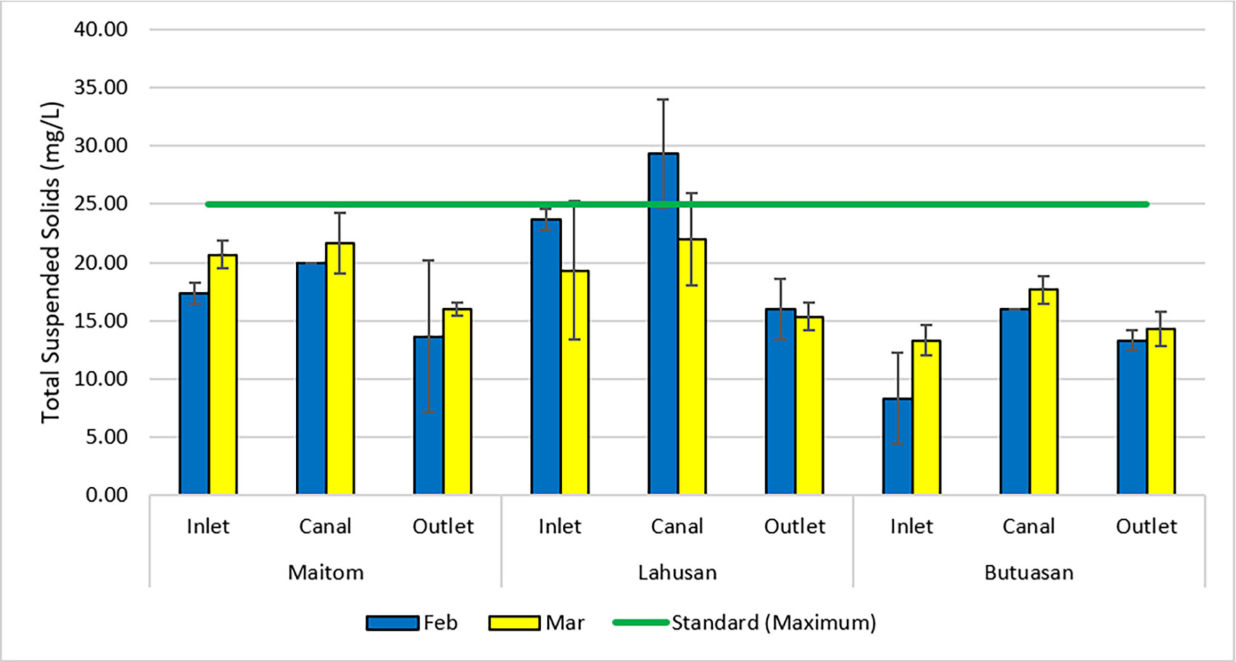

Figure 3. Mean values with the standard errors of the mean for TSS (mg/L) at the inlet, canal, and outlet of shrimp ponds in Maitom, Lahusan, and Butuasan, in Dahican, City of Mati, Davao Oriental, the Philippines. The recommended maximum value for TSS is included for comparison.

Class SD. General guidelines for aquaculture, however, set permissible levels to be at < 3 mg/L (PHILMINAQ n/d). Generally, the optimal nitrate level for *L. vannamei* ponds is 0.5–5.0 mg/L (Durai *et al*. 2021; Furtado *et al.* 2015; Maicá *et al.* 2014; Valencia-Castañeda *et al*. 2019).

Phosphorus. Phosphate levels in the three study sites' sampling stations were below the detectable levels of < 0.12 mg/L. DENR has set the phosphate levels to be 0.1 mg/L for Class SA and 0.5 mg/L for Classes SB, SC, and SD. Generally, the recommended phosphate levels for *L. vannamei* ponds are below 0.1 mg/L (Lien and Giao 2020).

Alkalinity. DENR has not set a standard for alkalinity but recommended alkaline levels in seawater have a mean value of 116 mg/L (PHILMINAQ n/d). All sampling stations reported alkalinity levels higher than the minimum recommended level, slightly higher in the inner portions of the Dahican cove (Maitom and Lahusan) than in the mouth of the cove (Butuasan). Alkalinity decreased in all sites from February (154–187 mg/L) to March (129–170 mg/L). The optimal alkalinity for *L. vannamei* ponds is > 120 mg/L (Venkateswarlu *et al.* 2019).

Statistical Data

Table 1. Results of one-way ANOVA of water parameters at different sampling points (inlet, canal, outlet).

Water quality parameters	df	Mean Square	F	*p*-value
DO	2	.020	4.800	0.012*
COD	2	.003	2.719	0.075
TSS	2	.132	4.107	0.022*
Nitrate	2	.003	0.492	0.614
Alkalinity	2	.006	2.659	0.080
pH	2	.000	0.853	0.432
Salinity	2	.015	5.336	0.008*

*The mean difference is significant at the 0.05 level

One-way ANOVA revealed significant differences in DO, TSS, and salinity at different sampling points (Table 1). DO was significantly higher in the outlet (4.92 mg/L) than in the canal (4.25 mg/L), whereas no significant difference existed between the inlet and outlet. A significant mean difference was noted for TSS between the canal (21.11 mg/L) and outlet (14.78 mg/L). For salinity, a significant difference was observed at three sampling points, where it was highest in the inlet (31.598 mg/L), followed by the outlet (30.954 mg/L), and then the canal (27.344 mg/L).

To account for the temporal difference in the water quality parameters, one-way ANOVA was also used to determine the significant difference between the sampling periods (Table 2). Results showed significant differences between the two periods for DO, COD, alkalinity, pH, and salinity. COD, alkalinity, and pH were significantly higher in February, whereas DO and salinity were significantly

Table 2. Results of one-way ANOVA of water parameters at different sampling periods (February and March).

Water quality parameters	df	Mean square	F	*p*-value
DO	1	0.069	18.991	0.000*
COD	1	0.036	56.300	0.000*
TSS	1	0.026	0.722	0.399
Nitrate	1	0.013	1.973	0.166
Alkalinity	1	0.049	32.397	0.000*
pH	1	0.000	4.306	0.043*
Salinity	1	0.092	62.732	0.000*

*The mean difference is significant at the 0.05 level

Table 3. Pearson r correlation between water quality parameters.

Parameters	DO	COD	TSS	Nitrate	Nitrite	Ammoniacal	Alkalinity	pH	Salinity
DO	–								
COD	–0.413*	–-							
TSS	–0.150	0.162	–						
Nitrate	–0.120	–0.061	–0.16	–					
Nitrite	0.075	–0.88	0.362*	0.134	–				
Ammoniacal	–0.117	0.257	0.227	0.102	0.12	–			
Alkalinity	–0.571*	0.620*	0.499*	0.041	0.41	0.228	–		
pH	0.146	0.302	–0.157	–0.121	–0.183	–0.144	0.075	–	
Salinity	0.625*	–0.512*	–0.44	0.001	0.218	0.026	-0.551*	–0.212	–

*Correlation is significant at the 0.01 level (two-tailed)

higher in March.

Pearson r correlation between water quality parameters revealed that DO was correlated with COD, alkalinity, and salinity, whereas COD was correlated with alkalinity and salinity. TSS was correlated with nitrite and alkalinity, whereas alkalinity and salinity were correlated.

DISCUSSION

Temperature, Salinity, and pH

Water quality is critical for shrimp survival and growth, with temperature being a significant factor affecting shrimp physiology and oxygen demand. A 10 °C increase in temperature can double the rate of chemical and biological reactions, meaning shrimp require more DO at higher temperatures. The optimal temperature for L. vannamei is between 25 and 30°C, aligning with tropical and subtropical conditions (Kır *et al.* 2023).

Salinity also plays a crucial role in shrimp growth and survival, whereas L. vannamei can tolerate salinities from 1–50 ppt; the highest growth and survival rates are observed at 22–32 ppt (Hassan *et al.* 2021; Jaffer *et al.* 2020; Khanjani *et al.* 2020). In this study, salinity varied significantly across the shrimp pond sites, with the inlet showing the highest levels (> 35 ppt) due to proximity to seawater and limited freshwater input (Ijaz *et al.* 2019). The outlet, which may also experience high salinity, could be influenced by evaporation and salt concentration or saltwater intrusion (Cardoso-Mohedano *et al.* 2018; Ridd and Stieglitz 2002). The canal exhibited the lowest salinity, likely due to freshwater dilution and salt removal. The increased DO from February–March may have been due to water evaporation, saltwater intrusion, or algal growth.

The pH is another critical parameter for shrimp health, with recommended levels ranging from 6.5–8.5 (DAO 1990-34). pH variations in ponds are influenced by water respiration, photosynthesis, and the use of lime for pH management (Yu *et al.* 2020; Fitrani *et al.* 2020). In this study, pH levels were stable (7.5–8) but decreased from February–March, possibly due to microbial decomposition, plant respiration, poor aeration, and mineral weathering. Maintaining optimal pH levels is essential to prevent adverse impacts on shrimp health and pond productivity.

Dissolved Oxygen (DO)

DO levels were significantly higher in the inlet and outlet compared to the canal, with higher DO concentrations in areas with faster water flow. This increased aeration is due to better oxygen exchange in dynamic water environments (Boyd *et al.* 2018). The slower or stagnant water flow in the canal likely reduced DO levels, exacerbated by bacterial decomposition of organic matter such as dead plankton and uneaten feed, which consumes oxygen (Ariadi *et al.* 2019). Maintaining optimal DO is crucial for shrimp health and growth, as low levels can slow growth and reduce feed conversion efficiency (Ariadi *et al.* 2019). The impacts of shrimp farming on DO levels are notable, especially from effluents during water exchanges and harvests, which can introduce high amounts of suspended particles, organic matter, and nutrients that deplete DO in surrounding waters (Bull *et al.* 2021).

In February, DO levels were slightly lower than the optimal range of 4.4–8.6 mg/L (Ariadi *et al.* 2019) but aligned with values from previous studies (Baldoza *et al.* 2020). This period occurred two months after shrimp pond operations ceased, suggesting that residual decomposing organic matter contributed to high oxygen demand. By March, DO levels improved significantly, except for slight decreases at the inlets of the Maitom and Lahusan sites, potentially due to sewage discharge from nearby coastal residential areas. This highlights the need to treat pond-influent water carefully to maintain healthy DO levels. The increase in DO from February to March may be attributed to improved water aeration, increased growth of aquatic plants and algae, higher freshwater input, and reduced organic matter in the system.

Chemical Oxygen Demand (COD)

COD levels varied across sampling sites and periods, with values notably high, indicating significant organic pollution in the shrimp ponds. COD, which measures the oxygen required to oxidize organic matter in water, typically ranges from 10–80 mg/L, with 15–20 mg/L considered acceptable for aquaculture (Giao 2021). COD levels above this threshold – such as those observed in this study – are concerning, as they suggest substantial organic waste. Compared to effluent COD levels in Vietnam (59.8–200 mg/L) and Brazil (average 564 mg/L) (Giao 2021), the recorded values in this study were alarmingly high, approaching the COD levels of domestic wastewater (1,909 mg/L), as reported by Ling *et al.* (2016) and beyond the standard limit set by DAO 2016-08. The decrease in COD over the sampling period suggests an improvement in water quality, likely due to enhanced biological decomposition, increased water exchange, better aeration, and aquatic plant growth (del Castillo *et al.* 2022).

These results underscore the need for confirmatory testing to identify the sources and causes of elevated COD. For instance, COD and BOD testing together can indicate the biodegradability of organic material (Qi *et al.* 2021); a COD/BOD ratio higher than 1.3–1.5 suggests that a significant portion of the organic material is non-biodegradable (Woodard 2001). Chloride ions, often present in shrimp pond water due to disinfection practices, can interfere with COD measurements, potentially causing overestimation (Zhao *et al.* 2021). To mitigate high COD levels, shrimp pond management should adopt efficient feeding practices, proper waste management, regular water exchanges, aeration, biological/mechanical filtration, reduced nutrient inputs, sediment management, and the use of probiotics (Hlordzi *et al.* 2020; Mahapatra *et al.* 2022; Munguti *et al.* 2020; Omidinia-Anarkoli and Shayannejad 2021; Sukmawati *et al.* 2021). Additionally, effluent treatment before discharge is crucial to minimize ecological impacts and maintain water quality in adjacent ecosystems.

Total Suspended Solids (TSS)

TSS levels varied significantly across sampling sites, with the canal showing the highest concentrations – particularly during high discharge events – potentially due to sediment resuspension (Onwuka *et al.* 2023). This can be attributed to sediment accumulation in canals, especially those affected by high erosion rates or sediment-laden runoff. Although the TSS level at Lahusan was slightly above the recommended limit for Class SA, it remained within Class SB standards and showed a marked improvement from February to March. Optimal TSS levels for L. vannamei are generally advised to be below 30 mg/L to prevent negative ecological impacts. High TSS concentrations can disrupt shrimp pond management and adjacent ecosystems by causing turbidity, which limits light penetration and impedes photosynthetic plankton growth, the base of the aquatic food chain. Additionally, TSS can contain nutrients that promote algal blooms, leading to oxygen depletion and potential health issues for aquatic life. In shrimp aquaculture, TSS levels can increase due to pond maintenance, vegetation removal, and waste from feed and shrimp excrement, impacting water quality and surrounding habitats.

Ammonia, nitrite, and nitrate. Ammonia, produced from the breakdown of feed protein or shrimp excretion, can accumulate in shrimp ponds – posing risks to water quality and adjacent ecosystems if feeding rates are excessive (Iber and Kasan 2021). Unionized ammonia levels exceeding 1.5 mg/L are harmful to L. vannamei – causing increased excretion, blood pH elevation, and gill damage, leading to impaired oxygen uptake. In this study, ammonia concentrations were consistently below the detectable limit of 0.007 mg/L, with any measurable values well below recommended thresholds.

Nitrite buildup occurs when ammonia oxidation surpasses the growth of heterotrophic bacteria in anaerobic conditions. While L. vannamei can tolerate nitrite concentrations below 6.67 mg/L, long-term exposure above this limit can hinder growth and disrupt gut health, impacting immunity (Huang *et al.* 2020). Nitrite was mostly undetectable at all sites and, when present, remained significantly below the threshold of 0.055 mg/L (AWGCME 2008).

Nitrate levels, which should remain under 3 mg/L for aquaculture according to general guidelines (PHILMINAQ n/d), were found to be compliant in all sampling sites. Nitrate can improve pond water and sediment quality by oxidizing anaerobic zones and altering phytoplankton communities (Torun *et al.* 2020). This process helps maintain water stability and prevents harmful metabolic by-products like hydrogen sulfide, benefiting shrimp health and surrounding ecosystems. The use of sodium nitrate in pond management has long been a practice to enhance water quality and support shrimp farming by stabilizing redox conditions (Torun *et al.* 2020).

Phosphorus. Phosphorus is an essential parameter for assessing coastal water quality in shrimp farming due to its role as a limiting nutrient. However, excessive phosphorus input from sources such as detergents, fertilizers, septic systems, and runoff can lead to eutrophication and algal blooms, negatively impacting shrimp health and pond productivity (Bai *et al.* 2023). Elevated phosphorus levels in shrimp ponds can stimulate harmful algal growth, disrupting water quality and oxygen levels. In this study, phosphate concentrations at all sampling sites were below detectable limits (< 0.12 mg/L) and fell within the range recommended by DENR. Previous studies, such as those by Lien and Giao (2020), reported phosphorus levels in *L. vannamei* ponds between 0.02–0.03 mg/L, while intensive shrimp ponds typically ranged from 0.1–0.15 mg/L. Over time, phosphorus concentrations can rise due to the dissolution of feed, microbial breakdown of organic matter, and the decomposition of dead phytoplankton. Regular monitoring and control of phosphorus inputs in shrimp ponds are essential to prevent nutrient overloading and maintain ecological balance in adjacent coastal ecosystems.

Alkalinity. Alkalinity is a critical water quality parameter for shrimp pond management, as it influences pH stability and the molting process of shrimp. In this study, alkalinity levels exceeded the recommended minimum of 116 mg/L and ranged from 124–192 mg/L, which aligns with findings by Ariadi *et al.* (2019). The interior sites of Dahican Cove (Maitom and Lahusan) showed slightly higher alkalinity compared to the cove's mouth (Butuasan). A significant drop in alkalinity was observed from February–March at all sites, potentially due to factors like carbon dioxide dissolution, organic matter decomposition, microbial respiration, heavy rainfall, and freshwater input. For *L. vannamei*, an alkalinity level greater than 120 mg/L is ideal to ensure healthy growth (Venkateswarlu *et al.* 2019). Low alkalinity can lead to pH fluctuations, affecting shrimp growth and survival, whereas excessively high alkalinity may disrupt molting due to excessive salt loss. Maintaining optimal alkalinity levels is essential for shrimp farm productivity and to mitigate potential ecological impacts on surrounding coastal areas.

Correlation among the water quality parameters and biotic factors. DO was correlated with COD, salinity, and alkalinity. Increased DO can lower COD levels because of increased aerobic decomposition, decreased anaerobic conditions, and accelerated oxidation processes. Increased DO can also decrease alkalinity because of improved aerobic conditions, biological activities, and nutrient dynamics. Conversely, higher DO is linked to lower salinity since oxygen becomes more soluble at lower salinity levels. On the other hand, COD was correlated with alkalinity and salinity. High COD levels can enhance alkalinity because organic matter decomposes and produces carbon dioxide, which combines with water to form bicarbonate ions. High levels of organic matter and nutrients cause high COD, which can change the dynamics of nutrients in the water or raise the concentration of dissolved salts, which raises salinity. TSS was correlated with nitrite and alkalinity. Most of the suspended particles in the shrimp ponds' TSS are made up of organic materials, uneaten feed, feces, and other wastes. These can break down and cause bicarbonates and nitrite to develop in the water. As a result, nitrite and alkalinity may increase along with TSS. Lastly, alkalinity and salinity were correlated. Water's pH levels are kept steady by alkalinity. The solubility and chemical forms of salts in water, particularly those that contribute to salinity, can be affected by pH changes. Biological processes in water and nutrient dynamics can affect salinity and alkalinity.

The relationships among water quality parameters can be influenced by various biotic factors such as algal blooms and microbial activity, which play key roles in shaping water chemistry. For example, increased DO levels, often driven by algal photosynthesis, can promote aerobic decomposition, leading to a reduction in COD as organic matter is broken down more efficiently. This enhanced aerobic activity can also affect alkalinity, as carbon dioxide produced during decomposition reacts with water to form bicarbonate ions, buffering pH levels. Furthermore, algal blooms can alter nutrient dynamics, causing shifts in salinity and alkalinity; for instance, the growth and decay of algae can lead to increased biological activity that influences the concentration of dissolved salts and pH balance. TSS is particularly relevant, as they often consist of organic matter, uneaten feed, and fecal material in aquaculture ponds, which can decompose and release nutrients such as nitrite that further impact water quality parameters. The resulting increase in TSS, along with associated microbial processes, can contribute to elevated levels of alkalinity and nitrite, demonstrating the complex interplay between biotic factors and water quality metrics.

CONCLUSION

The water quality parameters, such as the temperature, pH, salinity, DO, TSS, ammonia, nitrite, nitrate, phosphorus, and alkalinity, of the inlet and canal of the shrimp ponds can support the optimal growth and production of *L. vannamei* except for COD, which was relatively higher than the optimal range and beyond the maximum recommended limit set by the Philippine regulatory standards for shrimp pond effluents. Shrimp pond operators must reduce the COD levels at the inlet and throughout the canal system of the ponds by implementing various strategies and maintaining proactive management practices. The effluents with high COD should be treated before discharge to protect environmental health. Since DO, TSS, and salinity significantly varied at the inlet, outlet, and canal, it is recommended that proper pond design be implemented and water quality management practices be improved to achieve uniform values in these parameters.

Based on the specific gaps identified in the findings, further studies should focus on exploring the complex interactions between water quality parameters such as DO, COD, TSS, alkalinity, and nutrient levels to identify the pathways through which these factors influence shrimp health and pond productivity. The correlations observed between DO, COD, and salinity – along with the impact of organic matter on alkalinity and TSS – highlight the need for deeper investigation to develop targeted management strategies. Additionally, examining the influence of algal blooms and microbial activity on nutrient dynamics and water chemistry is crucial, as these biotic factors significantly impact the solubility of salts, pH stability, and oxygen levels, aiding in better ecological management practices. Research into more effective methods for reducing organic waste and improving decomposition rates is also recommended to control COD levels, including the assessment of waste management, sediment management, and probiotic use for enhancing beneficial microbial activity. Studying the impact of external inputs such as freshwater exchange, runoff, and adjacent land use – like residential sewage – on variations in water quality parameters such as DO, salinity, and COD can inform practices to mitigate environmental impacts and maintain water quality within optimal ranges. Addressing these research gaps will enhance water quality management, promote environmental sustainability, and support efficient aquaculture practices. Lastly, future research to explore the relationship between water quality and shrimp productivity is recommended to enhance management strategies and support sustainable aquaculture practices.

ACKNOWLEDGMENT

The authors would like to thank the Department of Agriculture, through its Philippine Rural Development Project, for funding this study.

STATEMENT ON CONFLICT OF INTEREST

The authors report there are no competing interests to declare.

NOTES ON APPENDICES

The complete appendices section of the study is accessible at http://philjournsci.dost.gov.ph.

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