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Spatial Distribution and Correlation of Water Quality Parameters and Plankton Density in Traditional Tiger Shrimp (*Penaeus monodon*) Ponds, East Kalimantan, Indonesia

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ABSTRACT

Suaran Village, located in Berau Regency, East Kalimantan Province, is an aquaculture area with tiger shrimp (*Penaeus monodon*) as its primary commodity. Farmers practice traditional farming, relying on natural inputs without supplemental feed or chemical treatments. This study aims to evaluate the physicochemical water quality and plankton density in the ponds, both of which are critical parameters in traditional shrimp aquaculture. The research was conducted in an aquaculture zone covering approximately 5,404 hectares, consisting of shrimp ponds, mangrove forests, riparian buffer zones, and river systems. Data were collected from four stations and used to analyze the spatial distribution of water quality parameters and plankton density using interpolation techniques—specifically, the Spline with Barriers and Kriging methods. Pearson correlation analysis was applied to assess interactions among all measured parameters. Results indicated that temperature (28–31 °C), pH (7.1–9), dissolved oxygen (4–6 mg/L), and conductivity (423–3,900 mS/cm) generally remained within favorable ranges for *P. monodon* culture. Pond salinity was relatively low (8–15 ppt), which, despite the species' broad tolerance, may impose physiological constraints during early developmental stages. Plankton density ranged from 1,650 to 2,275 ind/L, reflecting overall adequate natural productivity, although some locations exhibited suboptimal concentrations. These measurements are influenced by environmental conditions and seasonal variations, making them inherently dynamic. Overall, the results contribute to a better understanding of ecosystem dynamics and can support improved water quality management practices in the aquaculture zone of Suaran Village.

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INTRODUCTION

Aquaculture significantly contributes to ensuring global food security and fostering economic growth, especially within tropical regions. Among various aquaculture commodities, the black tiger shrimp (*Penaeus monodon*) is one of the most commercially valuable species cultivated in Southeast Asia, including Indonesia. Traditional shrimp farming systems—characterized by low-input management without artificial feed, fertilization, or aeration—are still widely practiced, especially in remote and rural coastal areas. While such systems are environmentally friendly and cost-effective, their productivity is highly dependent on natural environmental conditions, particularly water quality and plankton dynamics. Water quality parameters such as temperature, pH, salinity, dissolved oxygen, and conductivity are critical determinants of shrimp growth, survival, and overall pond ecosystem health **(Ponce *et al.*, 2019; Apresia *et al.*, 2024; Do *et al.*, 2024)**. Fluctuations in water quality parameters can significantly affect shrimp metabolism and health **(Apresia *et al.*, 2024)**. Moreover, plankton, as a primary food source and ecological indicator, plays a central role in the energy transfer within the pond ecosystem. This natural feed can be consumed by both larvae and adult shrimp, thereby providing high-quality nutrients to support their growth **(Tran Ngoc, 2024)**. The density and composition of plankton communities are directly influenced by water quality conditions, and in turn, affect shrimp productivity **(Palupi *et al.*, 2023)**. The most influential environmental factors for both phytoplankton and zooplankton density were temperature, C-organic, salinity, pH, alkalinity, and dissolved oxygen (Kristiana). In traditional pond systems, where water quality is not artificially regulated, understanding the natural spatial variability of these parameters becomes essential.

Suaran Village in Berau Regency, East Kalimantan, Indonesia, is an important traditional production area for black tiger shrimp, where ponds are operated under low-input, natural productivity–driven systems. Despite the sector's socio-economic relevance, studies examining the link between water-quality dynamics and plankton productivity in this landscape remain limited. Understanding the spatial behavior of key physicochemical parameters and their relationship to plankton density is critical for designing evidence-based management strategies that enhance the sustainability of these traditional systems. This study therefore investigates the spatial variability of water-quality indicators and quantifies their correlations with plankton density in Suaran's tiger shrimp ponds. By elucidating the interactions among these environmental variables, the research provides essential baseline information and ecological insight to support future monitoring and adaptive management in the region's aquaculture sector.

MATERIALS AND METHODS

Study Area and Sampling Design

This study was conducted in January 2025, coinciding with the dry season, when rainfall intensity in the region is generally low and water salinity tends to increase due to limited freshwater input. This period was deliberately chosen to represent stable environmental conditions, as hydrological fluctuations and runoff from surrounding mangrove and river systems are minimal during the dry season. Water sampling was carried out over several consecutive days under consistent weather conditions to ensure data reliability and reduce temporal variability. The study area comprised four observation stations located within the tiger shrimp (*Penaeus monodon)* aquaculture zone in Suaran Village, Berau Regency, East Kalimantan Province, Indonesia. The total potential area for aquaculture in this region covers approximately 5,404 hectares, including shrimp ponds, mangrove forests, riparian buffer zones, and river systems. Sampling stations (Fig. 1) were positioned within the existing aquaculture ponds, which together encompass a total of 718 hectares.

Fig. 1. Map of study area and sampling stations. Sampling locations within the study area, showing the geographic coordinates of each point:
(4) 117.6498645°E, 2.077652105°N;
(8) 117.6778257°E, 2.067569453°N;
(10) 117.6369754°E, 2.055927629°N;
(11) 117.6462197°E, 2.044708467°N.

Water Quality Assessment

Water quality parameters measured in this study included: (1) temperature, (2) pH, (3) salinity, and (4) conductivity, all of which were measured *in situ* using a multiparameter water quality probe. In addition, (5) dissolved oxygen and (6) plankton density were determined through laboratory analyses. Dissolved oxygen in collected water samples was determined in the laboratory by the Winkler titration method following standard procedures and Plankton were sampled, preserved and enumerated using the modified Utermöhl method under inverted microscopy. The laboratory analyses were carried out at PT Bestari Casa Laboratory, Bogor, following standard protocols for aquatic environmental quality assessment.

Data Analysis

The collected data were analyzed using Pearson correlation analysis to determine relationships among water quality parameters. Furthermore, spatial analysis using Geographic Information System (GIS) tools was employed to visualize the distribution patterns of water quality variables across the study area. This analysis was conducted to develop a spatial model that considers the river as both a limiting factor and a source of influence in the distribution of environmental values from sample points. The approach used involves two stages of interpolation, namely Spline with Barriers and Kriging, with the river serving as the main spatial barrier.

RESULTS AND DISCUSSION

Water Quality Parameters at Sampling Stations

Water quality measurements were conducted at four sampling stations (4, 8, 10, and 11) within the pond area. The measured parameters included temperature, dissolved oxygen (DO), pH, salinity, conductivity, and plankton density. The results are summarized in Table (1).

Table 1. Results of water quality measurements and plankton density

Parameter	Station 4	Station 8	Station 10	Station 11
Temperature (°C)	31.0	29.6	28.0	28.0
Dissolved Oxygen (mg/L)	4.0	5.0	6.0	5.0
pH	9.0	7.1	8.2	8.2
Salinity (ppt)	8.0	9.5	12.0	15.0
Conductivity (mS/cm)	423	2000	1950	3900
Plankton Density (ind/L)	1950	2275	1650	2075

There were significant differences in several parameters at each sampling station, particularly in conductivity and salinity, which varied considerably from station 8 to station 11. Temperature showed slight variations, with the highest value recorded at station 4 (31°C) and the lowest at station 10 and 11 (28°C). DO ranged from 4.0 to 6.0 mg/L, generally increasing as the temperature decreased.

The Influence of Water Quality in Black Tiger Shrimp (Penaeus monodon) Aquaculture

Temperature

Water temperature plays a crucial role in aquaculture, particularly in influencing oxygen consumption, growth, and shrimp survival **(Muliyadi, 2022)**. It affects various biological, physical, and chemical processes in aquatic environments, which in turn shape the shrimp's morphology, behavior, metabolism, and reproductive performance in pond systems **(Boyd & Litchkoppler, 1982)**. As water temperature rises, the level of dissolved oxygen tends to decrease. Based on the **Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia No. 75 (2016)**, the ideal temperature range for traditional black tiger shrimp farming is between 28°C and 32°C. Encouragingly, the temperatures recorded at the study site fall within this optimal range, indicating suitable conditions for shrimp farming

Dissolved Oxygen (DO)

Dissolved oxygen (DO) levels have a direct impact on hemocyanin concentrations in the blood of crustaceans. Hemocyanin plays a vital role in transporting oxygen, which is essential for nutrient oxidation and energy production. This energy supports key physiological functions such as digestion, feed assimilation, and tissue building **(Putra *et al.*, 2014)**. A decline in DO levels in aquaculture ponds is often linked to increased sediment oxygen demand, typically caused by high bacterial activity and reduced algal photosynthesis **(Dien *et al.*, 2019)**. According to **Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia No. 75 (2016)**, the minimum recommended DO level for traditional shrimp farming is 3 mg/L. The DO measurements at the study site fall within this acceptable range, indicating a suitable environment for black tiger shrimp farming.

pH

The pH level shows essential indicator of the acidity or alkalinity of aquatic systems **(Ikbal *et al.*, 2019)**, and it is affected by total alkalinity and carbonate ion concentrations **(Supriana, 2020)**. In shrimp aquaculture, suboptimal pH—particularly low values—can interfere with the molting process, potentially resulting in unsuccessful exoskeleton formation and the occurrence of soft-shelled shrimp. Additionally, low pH levels may elevate hydrogen sulfide (H_2S) concentrations, increase nitrite toxicity, trigger physiological stress, and ultimately reduce growth performance and survival rates. On the other hand, pH values that are too high can exacerbate ammonia toxicity, posing further risks to aquatic life **(Arsad *et al.*, 2017)**. According to **Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia No. 75 (2016)**, the recommended pH range for traditional black tiger shrimp farming is between 7.5 and 8.5.

In this study, water pH at all three sampling stations generally fell within the optimal range, although station 4 recorded a slightly elevated pH value reaching up to 9.

Water conductivity

Water conductivity is determined by the concentration of ions such as magnesium, calcium, and various dissolved salts. A decline in magnesium concentration and an imbalanced Mg:Ca ratio—particularly ratios as low as 0.1:1—can substantially impair shrimp growth, feed conversion efficiency, yield at harvest, and survival rates. Maintaining good water quality, including appropriate conductivity levels, is essential for minimizing the accumulation of harmful compounds such as ammonia, nitrite, and nitrate, which in turn supports optimal shrimp health and development **(Moura *et al.*, 2023)**. The application of specific strains of microalgae or beneficial bacteria has been shown to help stabilize water conditions, reduce pollutant concentrations, and indirectly maintain conductivity within ideal limits—factors that collectively promote improved growth and production performance in shrimp farming systems **(Huang *et al.*, 2022)**. The minimum recommended water conductivity for shrimp farming is 900 mS/cm **(Luthfi *et al.*, 2022)**. In the current study, measurements taken from four stations sampling revealed that station 4 exhibited conductivity levels below this threshold. In contrast, the remaining three stations reported conductivity values within the optimal range for supporting the tiger shrimp farming.

Salinity

Salinity levels significantly influence the growth performance and survival of black tiger shrimp, with 20 ppt identified as the optimal salinity for aquaculture. Variations in salinity impact free fatty acid concentrations, free amino acid levels, and hemolymph osmolality, while also affecting the expression of genes involved in osmoregulation and growth regulation **(Rahi *et al.*, 2021)**. Salinity is also a crucial factor in hatching, larval, as well as postlarval, survival. Black tiger shrimp (*Penaeus monodon*) would have an optimum salinity level between 30–35 ppt for early development. Deviation from this optimum salinity and/or temperature would negatively impact hatching as well as further survival, especially in early developmental stages, as these are more sensitive to environmental fluctuations **(Ndunguru *et al.*, 2022)**. According to the **Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia No. 75 (2016)**, traditional black tiger shrimp farming can be conducted within a salinity range of 5–40 ppt. Therefore, the salinity conditions observed in the study area still meet the minimum threshold. However, it is possible that the relatively low salinity levels may negatively impact pond productivity.

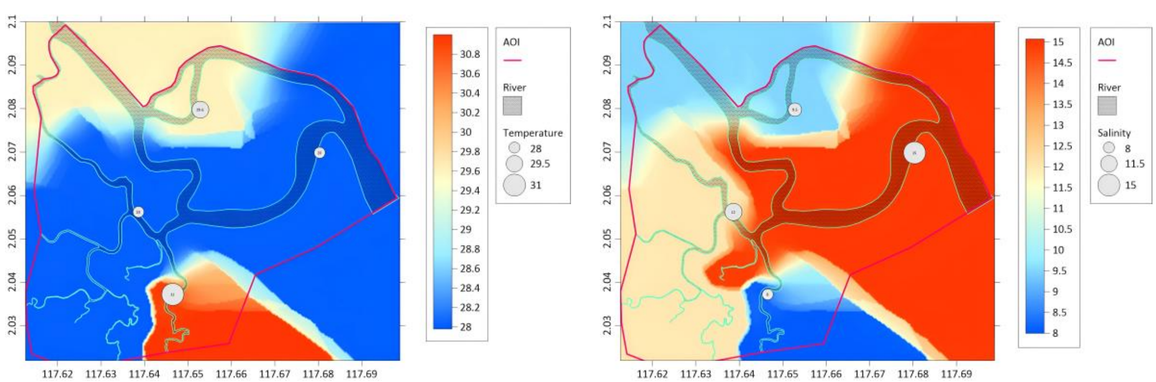
Plankton density

Plankton play a vital role as a natural food source that supports shrimp growth, especially in traditional aquaculture systems where supplemental feeding is minimal or absent **(Tilahwatih *et al.*, 2019)**. Beyond their nutritional function, plankton communities also serve as important bioindicators of water quality, with their composition and population density reflecting the ecological condition of shrimp ponds **(Case, 2008)**. The density and diversity of plankton are influenced by water quality parameters, including salinity, organic matter, and nutrient levels such as nitrogen (N) and phosphorus (P) **(Munjayana *et al.*, 2024)**. According to the **Indonesian Ministry of Marine Affairs and Fisheries Regulation No. 75 (2016)**, the minimum recommended plankton density for tiger shrimp farming is 2,000 individuals per liter. Field observations in this study indicated that stations 4 and 10 recorded plankton densities below this standard threshold.

Overall, the spatial variation of water quality parameters across the tiger shrimp (*Penaeus monodon*) aquaculture ponds in Suaran Village indicates that environmental conditions are primarily influenced by freshwater inflow from nearby rivers and the frequency of pond-water exchange. Areas with greater freshwater input generally exhibited lower salinity and conductivity, reflecting dilution effects, while ponds with more frequent water exchange maintained better dissolved oxygen and more stable pH levels due to enhanced aeration and reduced organic accumulation. These interactions highlight that the balance between freshwater inflow and managed water exchange plays a crucial role in sustaining optimal physicochemical conditions for shrimp cultivation in this region.

Distribusi Spatial of Water Quality and Plankton Density

This study also conducted interpolation of water quality and plankton density data within the study area to examine the spatial distribution of these variables. The following are the results of the data interpolation (Fig. 2)



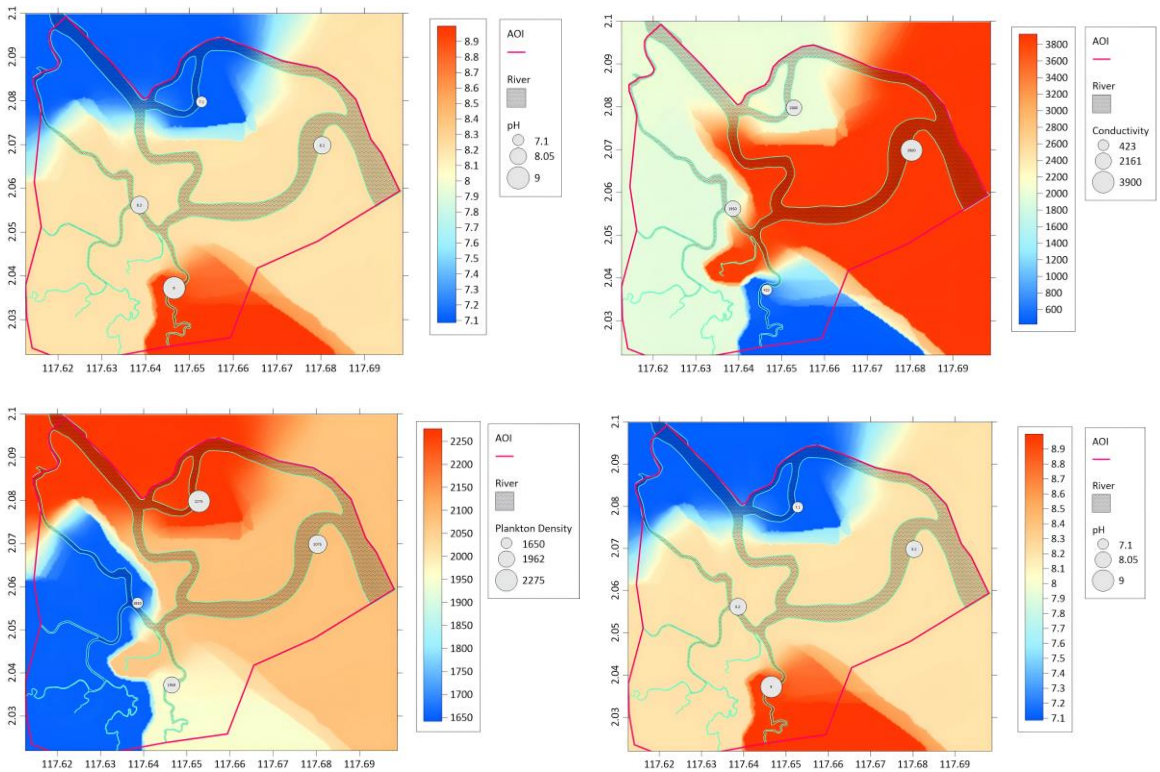


Fig. 2. Spatial Distribution of Water Physicochemical Variables and Plankton Density (AOI: Area of Interest)

The temperature in the study area ranged from 28°C to 31°C, with most locations showing temperatures between 28.0°C and 28.4°C. Dissolved oxygen (DO) levels varied between 4 and 6 mg/L, but generally centered around 5 mg/L. The pH values ranged from 7.1 to 9.0, with a common value of around 8.2 in most parts of the area. Conductivity and salinity showed a positive relationship, with the highest conductivity recorded at 3900 mS/cm, corresponding to a salinity of 15 ppt in many locations. Plankton density ranged from 1650 to 2275 individuals per liter, with the most frequent densities found at around 2075 and 1650 individuals per liter.

The Correlation Between Water Quality and Plankton Density

Pearson correlation analysis between water quality parameters show different correlations between water physicochemical variables and plankton density (Fig. 3). The p-values are generally above 0.05, which is expected given the small sample size ($n = 4$), so these correlations should be interpreted as indicative trends rather than statistically significant findings.

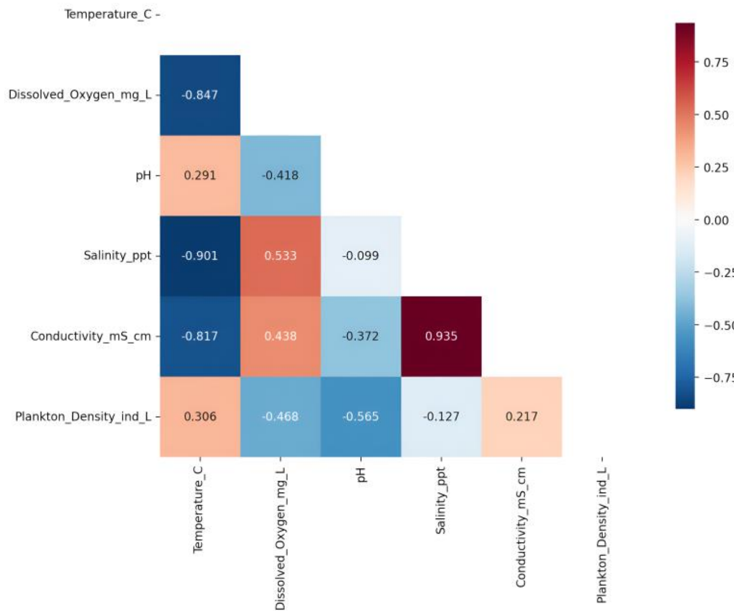


Fig. 3. Pearson correlation matrix between water quality and plankton density

Water temperature had a strong negative relationship with dissolved oxygen (r = -0.85), implying that higher temperature has a strong association with a decrease in oxygen levels. This observation is consistent with the physical law that solubility of oxygen in water is reduced with increasing temperature. A negative association between temperature and dissolved oxygen levels was also identified by **Mavropoulou *et al.* (2020)**, indicating the influence of temperature on the solubility of oxygen in aquatic environments. A decrease in water temperature enhances the solubility of dissolved oxygen, whereas higher temperatures reduce oxygen solubility. The oxygenation process can also induce a reduction in water temperature, as the introduction of microbubbles may may stimulate the upwelling of colder deep water layers **(Burke *et al.*, 2022)**. Temperature also had strong negative correlations with salinity (r = -0.90) as well as with conductivity (r = -0.82), implying that at times or locations with higher temperatures, salinity as well as conductivity would be lower. These would be, however, contingent on local hydrology including mixing of waters as well as freshwater input. The negative correlation between salinity and temperature has a significant impact on the density field and is dominant on a seasonal period **(Ando *et al.*, 2022)**.

Salinity had a very positive, strong correlation with conductivity (r = 0.94), as there would be a direct association between dissolved salt levels and how well the water conducts an electric current. This is a consistent finding often observed in studies on water quality. A similar negative correlation was also observed by **Laosuwan *et al.* (2024)**, who reported a strong positive relationship between salinity index and conductivity, with correlation values ranging from r = 0.75 to 0.87. At the same time, pH did not significantly relate to other parameters, although it correlated weakly negatively with conductivity (r = -0.37) as well as weakly positively with temperature (r = 0.29). pH variation is more controlled by biological activity and dissolved chemical compounds in the water.

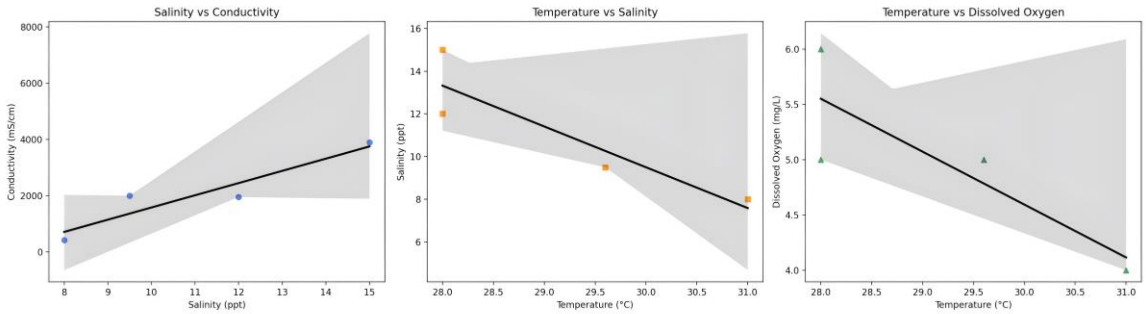


Fig. 4. Correlation between water physicochemical variables

Plankton density represents a critical parameter in traditional shrimp pond aquaculture systems, where no supplementary feed is provided. In such systems, cultivated shrimp rely entirely on natural food sources, one of which is plankton. The following section presents the correlation between water physicochemical variabels and plankton density.

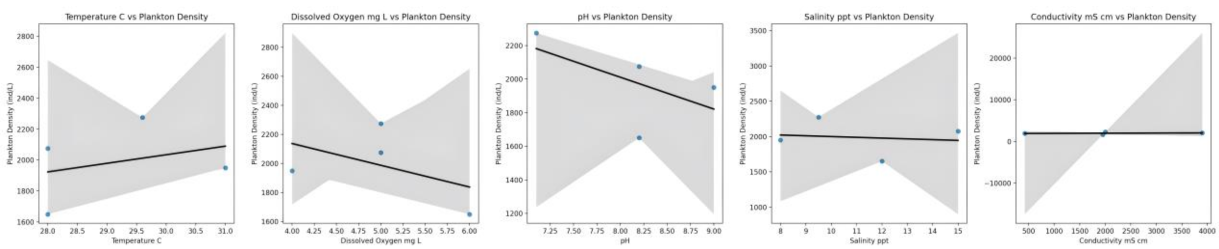


Fig. 5. Correlation between water physicochemical variables and plankton density

Plankton density (Density_ind/L) was found to have a moderate negative relationship with pH (r = -0.56) and dissolved oxygen (r = -0.47) levels, implying plankton density might be greater with lower amounts of oxygen and pH levels. This condition could be caused by enhanced plankton respiration processes, especially at night, as well as dead plankton biomass decomposition, which requires oxygen as its energy source and releases acidic compounds as products. Dissolved oxygen was one of major factors that restrict the abundance and diversity of the zooplankton communities **(Go´zdziejewska *et al.*, 2018)**. **Essa *et al.* (2024)** also reported that pH exhibits a negative correlation with plankton density, and as one of the key water quality parameters, pH is influenced by CO_2 circulation and various contaminants, where elevated pH values indicate increased biological activity and higher photosynthetic rates **(Rahman & Huda, 2012)**. Based on the analysis conducted in this study, plankton density exhibited only weak correlations with temperature (r = 0.306) and salinity (r = –0.127). These imply plankton distribution is not significantly influenced by these physical water characteristics in this location. **Essa *et al.* (2024)** reported that species diversity, abundance, and evenness of plankton were higher during the summer than in the winter season. The survival of many phytoplankton species is influenced by the salinity of the surrounding waters. Salinity plays a critical role because it directly regulates the organism's osmotic pressure **(Muhsoni, 2021)**.

CONCLUSION

The results of physicochemical assessments in the waters of Suaran Village show that temperature, dissolved oxygen (DO), conductivity, and pH are all within appropriate levels to support the farming of tiger shrimp (*Penaeus monodon*). While salinity meets the minimum requirement for shrimp culture, its relatively low levels could present difficulties during the early stages of shrimp development. Plankton density also generally falls within the acceptable range for shrimp farming, although some locations have lower concentrations. Each environmental factor demonstrated either a positive or negative correlation with other parameters. These measurements, including correlation patterns and spatial distribution, are influenced by natural environmental conditions and seasonal variation making them inherently dynamic. Therefore, routine monitoring of water quality in ponds and rivers is highly recommended to ensure the sustainability of aquaculture activities and to serve as a reference for developing a planting-season calendar that aligns with the optimal water quality conditions of the area.

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