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Research Article

Seasonal Variations in Surface Water Physicochemical Quality and Pollution Assessment in the Can Gio Estuary, Vietnam

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About Article

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ABSTRACT

Assessing physicochemical characteristics of surface water is essential for understanding environmental quality and managing aquatic resources in estuarine ecosystems. This study evaluated the current status and seasonal variation of surface water in the Can Gio area, Ho Chi Minh City, Vietnam, based on 14 sampling sites surveyed during the dry and rainy seasons of 2023. The results revealed that COD and BOD₅ exceeded permissible limits at all sites (100%), while nitrite exceeded the standard at 71% of sites during the dry season, indicating widespread organic and nutrient pollution. Mean COD (51.2 mg O₂/L) and BOD₅ (29.6 mg O₂/L) in the dry season were significantly higher ($p < 0.05$) than in the rainy season (42.7 and 23.7 mg O₂/L, respectively), confirming strong seasonal variation. Paired t-tests showed significant seasonal differences ($p < 0.05$) in most parameters, with pollution more severe in the dry season due to reduced dilution capacity and enhanced anthropogenic discharge. Although pH, DO, ammonia, and phosphate remained within regulatory thresholds, elevated organic loads and nitrite accumulation reflect limited self-purification during low-flow conditions. These results establish quantitative evidence of organic enrichment and seasonal oxygen stress in the Can Gio estuarine system, providing a critical baseline for water quality management and modeling under climate and hydrological change.

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1. INTRODUCTION

Surface water quality is one of the key factors determining the sustainable development of aquatic ecosystems as well as socio-economic activities related to water resources. In Vietnam, coastal and estuarine areas are often under pressure from aquaculture, mining, water transportation as well as waste from urban and industrial areas (Vu *et al.*, 2020). Assessing the current physicochemical characteristics of surface waters is crucial for effective environmental management and sustainable aquaculture planning. Can Gio, Ho Chi Minh City, is known as a world biosphere reserve with a characteristic mangrove ecosystem. This is also a key aquaculture area, especially with shrimp, fish and mollusks with economic value (Le, 2019). However, increasing aquaculture and fishing activities have put great pressure on the water environment, leading to organic enrichment, microbial contamination, and alterations in hydrochemical dynamics (Ta & Huynh, 2017). The phenomenon of water quality degradation in estuaries is increasingly pronounced due to increased nutrient and organic matter loads from land sources, leading to eutrophication and DO depletion at the bottom layer (Hu *et al.*, 2024). In addition, the emergence of emerging organic pollutants is becoming a new concern for downstream ecosystems (Luo *et al.*, 2023).

Important physicochemical indicators such as pH, DO, BOD, COD, TSS, inorganic nutrients (ammonia, nitrite, phosphate) are often used to assess surface water quality (Monitoring Center - Vietnam Environment Administration, 2010). In this context, this study focuses on assessing the current status of the physicochemical environment quality of surface water in Can Gio area through field surveys and analysis of the above-mentioned indicators according to national technical regulations (National Technical Regulation on Surface Water Quality - QCVN 08-MT:2015/BTNMT; National Technical Regulation on Seawater Quality - QCVN 10:2023/BTNMT). The research results not only provide background data for environmental management but also contribute to providing solutions to control and ensure the goal of sustainable development of the local aquaculture industry. Therefore, this study aims to provide an updated assessment of the current physicochemical characteristics and seasonal variations of surface water in the Can Gio area, Ho Chi Minh City. The findings serve as a scientific basis for evaluating environmental quality and support the sustainable management of aquatic resources in the estuarine system. Although several studies have examined water quality in the Mekong and Saigon river systems, limited information is available on the physicochemical characteristics and seasonal variations of surface water in the Can Gio estuarine area. To address this gap, this study aims to assess the current status of surface water quality, quantify seasonal changes and exceedances of key parameters relative to national standards, and identify major environmental factors influencing organic and nutrient pollution in the region.

2. LITERATURE REVIEW

Water quality in estuarine and coastal systems has been widely investigated due to increasing anthropogenic pressures and climate-related variability. Numerous studies have

demonstrated that physicochemical parameters such as DO, BOD₅, COD, ammonia, and nutrients are reliable indicators of environmental change and human disturbance (Hu *et al.*, 2024; Luo *et al.*, 2023). In Vietnam, research has mainly concentrated on the Mekong and Saigon River systems, revealing organic enrichment and nutrient accumulation linked to aquaculture, domestic wastewater, and industrial discharge (Vu *et al.*, 2020; Ta & Huynh, 2017). Studies in other tropical and subtropical regions have similarly reported organic and nutrient pollution in estuarine waters. For example, Hu *et al.* (2024) identified rainfall-driven nutrient dynamics and pollution source variations in northern China, while Igwegbe *et al.* (2022) highlighted biotechnological treatment approaches that effectively reduced COD and BOD concentrations in aquaculture effluents. Moreover, Hlordzi *et al.* (2020) demonstrated that *Bacillus* species could improve aquaculture water quality by reducing organic loads and enhancing microbial balance.

Despite these advances, few studies have quantitatively assessed the seasonal exceedances of key physicochemical parameters relative to regulatory standards in small estuarine systems of Southeast Asia. In the Can Gio area, available research has mainly focused on resource management and aquaculture development (Le, 2019; Thai, 2023) rather than on systematic water quality monitoring and environmental assessment. This gap underscores the need for an updated quantitative evaluation of surface water quality and seasonal variations in the Can Gio estuarine system - the primary objective of the present study.

3. METHODOLOGY

3.1. Sampling location and time:

Water samples were collected twice: the first time in March 2023 (dry season) and the second time in September 2023 (rainy season), at 14 locations marked from CG1 - CG14 (Figure 1). Fourteen sampling sites (CG1 - CG14) were distributed across the Can Gio estuarine system to represent different environmental settings, including river mouths, aquaculture areas,.... In particular, sites CG6, CG7, CG11, and CG14 are located near oyster farming areas where local communities actively conduct aquaculture activities. This spatial arrangement provides a representative coverage of both anthropogenic and natural influences on surface water quality.

3.2. Analytical Methods

The standards applied to collect water samples for the process of assessing surface water quality in river and estuary areas in the study area according to QCVN 08-MT:2015/BTNMT and water quality in coastal waters according to QCVN 10:2023/BTNMT. To analyze the content of nutrients, the water sample was collected into a 2L plastic can after rinsing with water at the collection point. The sample is then refrigerated, brought back to the laboratory and analyzed for 48 hours.

DO (Dissolved oxygen) concentration and pH values were determined using a HI98198 meter (Hanna Instrument, Romania); turbidity and salinity were determined using a Orion (USA). The concentrations of COD, BOD₅, TSS, ammonia, nitrite, and phosphate were analyzed according to the "Standard Methods for the Examination of Water and Wastewater" and



measured using a Jasco V-730 Spectrophotometer. The data were processed using Microsoft Office Excel 365 software, and

the analytical results were statistically treated based on the method of three replicate analyses for each parameter.

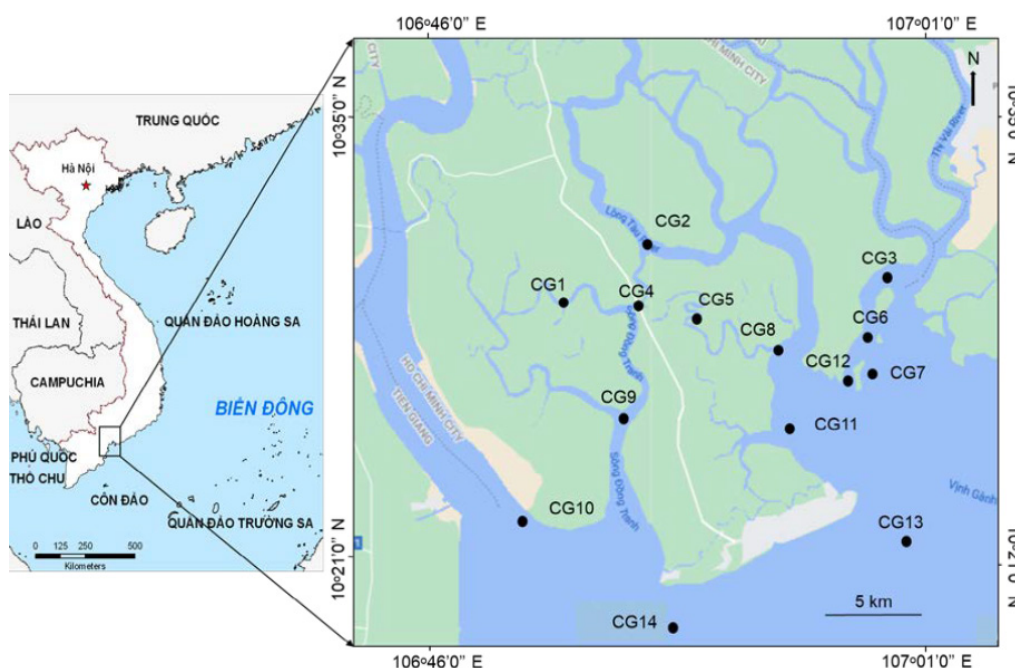


Figure 1. Location of the samples collection area (Thai, 2023)

4. RESULTS AND DISCUSSION

4.1. pH and Dissolved Oxygen (DO)

All samples collected at 14 survey sites of both sample collections had pH values within the permissible limits of the national technical regulation on surface water quality used for aquaculture purposes QCVN 08-MT:2015/BTNMT, Column B1 as well as seawater quality in coastal areas QCVN 10:2023/BTNMT. The results of rapid pH measurement at the site of the sample collection surveys showed that the pH value was

within the permissible threshold of the norm: $5.5 < \text{pH} < 9.0$ and the pH of the samples did not have a large difference, similar across the survey sites, fluctuating around the neutral pH threshold (Figure 2). The average pH of the dry season was 7.46 ± 0.13 higher than that of the rainy season of 7.18 ± 0.10 , reflecting the trend of decreasing pH in the rainy season due to dilution, increased rainfall and upstream runoff that changed the chemical properties of the water sources in the survey areas.

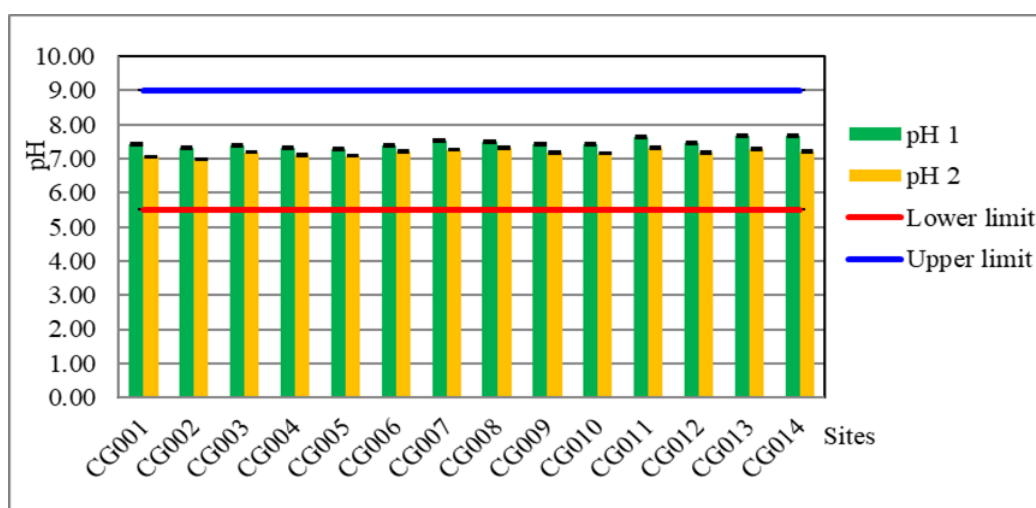


Figure 2. pH Parameters

The dissolved oxygen (DO) of the samples ranged from 4.1 to 5.8 mgO₂/L (Figure 3). The average DO value during the dry

season reached 4.76 ± 0.18 mgO₂/L, lower than the rainy season of 4.96 ± 0.27 mgO₂/L. This difference reflects the pronounced



influence of seasonal hydrological conditions on the ability of oxygen to dissolve in surface water. In the dry season, water levels and flow rates decrease, high temperatures, along with limited oxygen diffusion and stronger biooxygen consumption, result in lower DO values. In contrast, during the rainy season, abundant water enhances the dilution of organic matter, reduces the demand for biological oxygen, and promotes the diffusion

of oxygen from the atmosphere into the water, increasing DO. These results show that seasonal DO fluctuations are an important feature of the Can Gio river-estuary system, reflecting the sensitivity of water quality to regional hydrological and climate change. Paired t-tests revealed that both pH and DO exhibited significant seasonal differences ($p < 0.05$), with higher DO values typically observed during the rainy season.

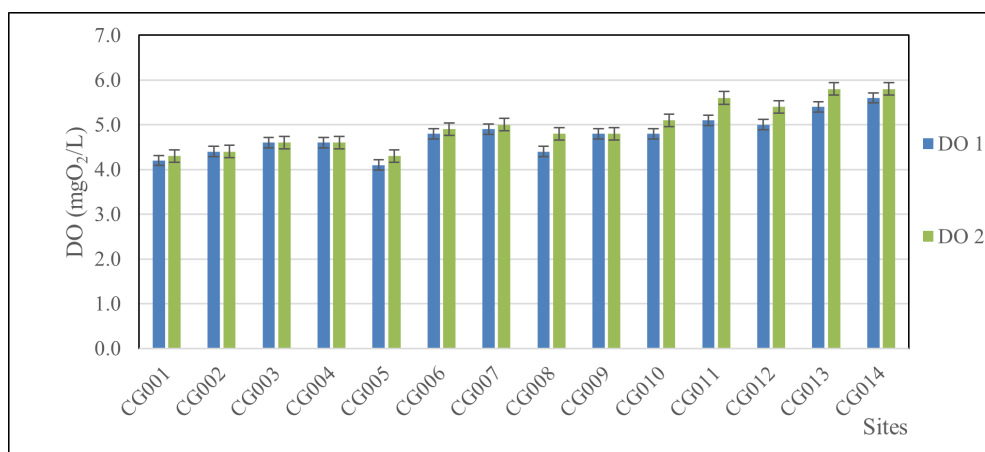


Figure 3. DO parameters

4.2. Turbidity and total suspended solids

The turbidity and total suspended solids (TSS) values are shown in Figure 4. In sample collection 1, turbidity values ranged from 20 - 28 NTU. In sample collection 2, turbidity ranged from 24 - 34 NTU. Meanwhile, the National standards does not stipulate the limit threshold of this parameter. The first sampling period recorded TSS concentrations of 36 - 50 mg/L, all within the allowable limit of < 50 mg/L. In contrast, during the second period, values rose to 43 - 62 mg/L, and 8 of the 14 sites slightly exceeded the regulatory limit, suggesting enhanced suspended matter input likely associated with runoff and tidal resuspension. Turbidity and TSS are sensory indicators that can be used to evaluate water quality. These two indicators are closely related to each other and the value increases and decreases proportionally. Suspended particles appear due to soil erosion, water degradation or from stirred bottom sediments... will entail a

sudden increase in the turbidity of the water and vice versa. However, turbidity is not a direct measurement of the TSS index, but only a relative measurement. In terms of water quality, high concentrations of suspended solids will increase the water temperature and reduce dissolved oxygen. This is because suspended particles absorb more heat from solar radiation than water molecules. This heat is then transferred to the surrounding water, warming the water, so it cannot keep dissolved oxygen as much as cold water. In addition, increased surface temperatures can cause stratification or layering. When water stratifies, the upper and lower layers do not mix with each other. Decomposition and respiration often occur in the lower layers, which become too oxygen-deprived for organisms to survive. High turbidity will block sunlight, cause photosynthesis inhibition, reduce the survival of plants at the bottom of the ocean, and reduce the amount of dissolved oxygen.

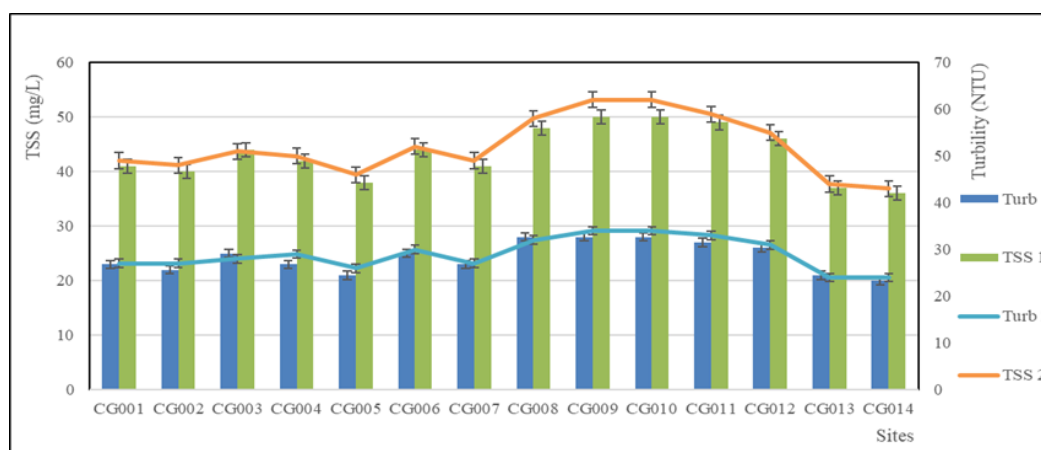


Figure 4. TSS and turbidity values



4.3. Ammonia, nitrites and phosphates

The analytical values of ammonia, nitrite, phosphate parameters are presented on Figure 5. Ammonia is a valence state of the element nitrogen, which is an important criterion when determining the concentration of water pollution. Nitrogen compounds present in water are the result of the decomposition of organic compounds found in nature, in waste products, and in fertilizer sources that humans directly or indirectly introduce into water sources. Ammonia exists in 2 forms, ionic (NH_4^+) and dissolved gas (NH_3), which can be shifted in reverse equilibrium (pH and temperature dependent): $\text{NH}_3 + \text{H}^+ \rightleftharpoons \text{NH}_4^+$. In particular, NH_3 is a colorless gas, has a strong odor, dissolves a lot in water, is toxic to fish and shrimp, aquatic plants and plants in the water, NH_4^+ is less toxic. At pH close to 7.0, there is only a very small amount of NH_3 compared to NH_4^+ . When the pH is raised to 9.5, the ratio $[\text{NH}_3]/[\text{NH}_4^+] = 1$, and the more the pH is increased to 11, the more the equilibrium shifts towards forming NH_3 . The ammonia of the samples had analytical values ranging from 0.15 to 0.37 mg/L meeting the national technical regulation QCVN 08-MT:2015/BTNMT (<0.9 mg/L).

In water, nitrite is an intermediate product of chemical reactions

under the action of bacteria from ammonia to nitrite and finally nitrate. The lifetime of nitrite in water is very short because when it encounters oxygen, the air converts to nitrate. Nitrite is present in water sources that have been contaminated for a long time. This is a toxin that affects the life and development of aquatic organisms. All water samples collected in the dry season had nitrite values ranging from 0.07 to 0.24 mg/L exceeding the permissible norm (QCVN 08-MT:2015/BTNMT) (>0.05 mg/L). In the rainy season, 10/14 samples met the permissible norms (<0.05 mg/L).

Phosphates are essential for the growth of plants and animals, but having a lot of phosphate in water can contribute to eutrophication. The rapid growth of algae will limit light and drastically reduce the dissolved oxygen content, affecting aquatic life. The biomass produced by algae will contribute to the increase of the sludge layer and over time the area of rivers and lakes will shrink and cause environmental pollution. The analysis results showed that all water samples collected had phosphate values ranging from 0.02 to 0.22 mg/L, which is within the permissible threshold of the national technical regulation on surface water quality used for aquaculture activities QCVN 08-MT:2015/BTNMT (<0.3 mg/L).

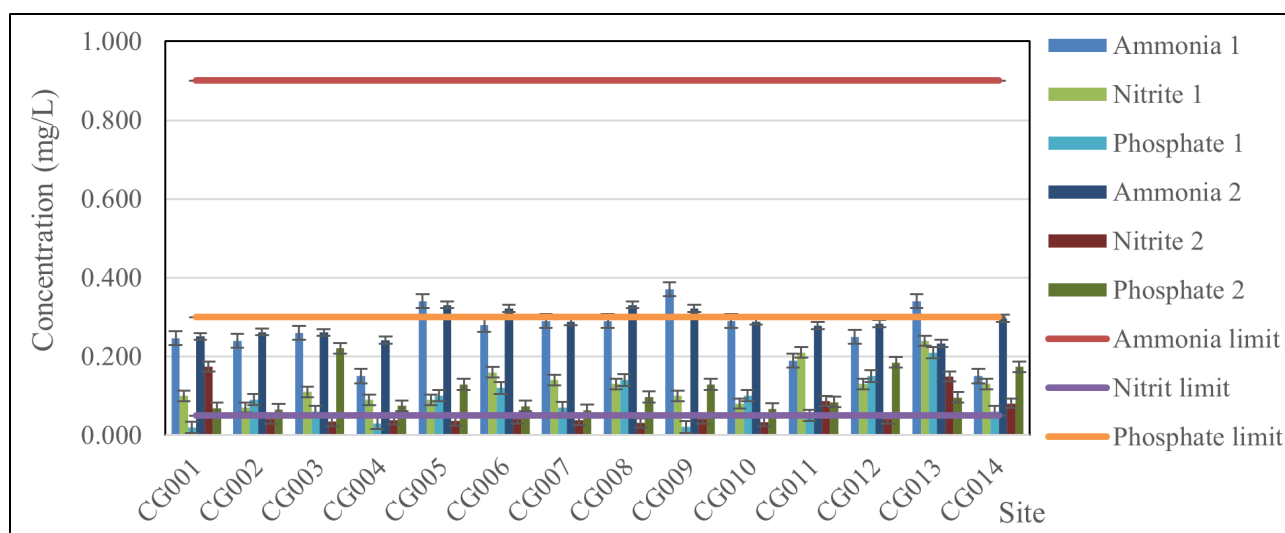


Figure 5. Parameters of ammonia, nitrite, phosphate

Ammonia and phosphate in the surveyed water samples have low values, below the threshold specified by the regulations, causing the phenomenon of eutrophication in the water area is at a safe level. However, nitrites exist in water with high values, becoming a toxin that affects aquatic life. The results of the statistical analysis show that the seasonal fluctuations of inorganic nutrient forms (ammonia, nitrite and phosphate) have distinctly different characteristics, reflecting the biochemical mechanisms characteristic of different hydrological conditions between the dry and rainy seasons.

The average ammonia concentration during the rainy season (0.285 ± 0.033 mg/L) was slightly higher than in the dry season (0.263 ± 0.067 mg/L), however this difference was not statistically significant ($p\text{-value} > 0.05$). This suggests that the accumulation or leaching of reduced nitrogen in the study area is relatively stable between the two seasons. During the rainy season,

although surface runoff can carry significant amounts of nitrogen from soils and domestic or agricultural wastes, the dilution effect caused by a sharp increase in water volume has reduced overall volatility. In addition, biochemical processes in water, such as nitrification and ammonification, can occur simultaneously, resulting in a dynamic balance of ammonia in water.

In contrast, nitrites showed a statistically significant difference between the two seasons ($p\text{-value} < 0.05$), with the average concentration of the dry season (0.127 ± 0.049 mg/L) being twice as high as the rainy season (0.062 ± 0.046 mg/L). The increase in NO_2^- during the dry season reflects low dissolved oxygen conditions and limited microbial activity, especially *Nitrobacter* responsible for oxidizing nitrites to nitrates during the second phase of nitrification. Local anaerobic conditions during the dry season, along with low flow rates and strong evaporation, resulting in an intermediate accumulation of nitrites.



Meanwhile, the rainy season is characterized by large flow, high DO and strong dilution, which promotes the oxidation of nitrite to nitrate, which greatly reduces nitrite concentration. Recent studies have also shown the synergistic effects of ammonia and nitrites that impair the viability and reproduction of plankton species such as *Daphnia* (Yu *et al.*, 2022).

For phosphate, the average rainy season concentration of 0.109 ± 0.051 mg/L was higher than that of 0.087 ± 0.054 mg/L in the dry season, but the difference was not statistically significant (p -value > 0.05). This reflects the relative stability of phosphate in the aqueous environment, due to the strong adsorption properties of PO_4^{3-} ions on soil particles, sediments, and metal oxides (Fe, Al). During the rainy season, although leaching from the soil can increase the phosphate load, the dilution effect and strong assimilation of aquatic organisms can balance the concentration in the water. In contrast, during the dry season, the deposition of phosphate into the sediment and adsorption into the bottom substrate can slightly reduce the soluble concentration.

Overall, the results show that biochemical processes in aquatic systems react differently to seasonal regimes, with nitrite being the most sensitive parameter reflecting oxygen fluctuations and microbial activity, and ammonia and phosphate showing a more stable trend. These characteristics should be considered in seasonal water quality management, especially in the context of climate change and hydrological changes that can alter the nutrient cycle in inland water ecosystems.

4.4. COD and BOD₅

COD (Chemical Oxygen Demand) is one of the very important indicators to assess the level of water pollution. COD is commonly used in the quantification of pollutants present in surface water or wastewater. The results of the analysis showed that all water samples obtained had COD values exceeding the permissible threshold of the national technical regulation on surface water quality used for aquaculture activities (>30 mgO₂/L) (Figure 6). The COD of the survey samples ranged from 38 to 130 mgO₂/L during the dry season and 49 to 76 mgO₂/L during the rainy season.

BOD (Biochemical Oxygen Demand) is the amount of oxygen that needs to be supplied to oxidize organic substances in water

by microorganisms. BOD is an indicator used to determine how quickly or slowly organisms use up oxygen in water. It is used in water quality management and surveys as well as in ecology or environmental science. The BOD indicator does not fully reflect the total amount of organic matter in the water because it does not take into account organic matter that is not oxidized by biochemical methods and also does not take into account the part of organic matter consumed to create new bacterial cells. The analysis results showed that the BOD₅ of the survey samples had values ranging from 18 to 39 mgO₂/L, exceeding the permissible threshold of the national technical regulation on surface water quality used for aquaculture activities (>15 mg/L) (Figure 6).

The COD and BOD₅ indicators reflect the level of organic contamination of the water sample. Both are the oxygen requirements needed to oxidize the organic matter present in the water sample: oxidation by microorganisms (BOD), by strong oxidizing agents - chemicals (COD), the higher the COD and BOD values in the water, the greater the degree of organic contaminated water quality. In addition, the high demand for chemical oxygen and biooxygen will reduce the dissolved oxygen (DO) concentration of water, which is harmful to aquatic organisms and aquatic ecosystems in general. However, the activity of microorganisms depends on pH, temperature and other factors in the water environment, so the oxidation efficiency of organic matter depends on the conditions of microorganisms. Whereas, the oxidizing agent is independent of water conditions hence COD always gives higher results than BOD. The study by Hlordzi *et al.* (2020) showed that the addition of *Bacillus spp.* in aquaculture systems can significantly reduce COD and BOD values, thereby improving water quality. Meanwhile, Igwegbe *et al.* (2022) demonstrated the possibility of using biofloculants from *Picralima nitida* seeds to remove COD and BOD with high efficiency. The correlation between COD and BOD may or may not exist depending on sample composition, seasonal variation, and other factors. The results of the analysis at the laboratory, showed that 100% of the water samples in the survey areas were contaminated with organic matter. The control of organic pollutants in the country is a dilemma and difficult to solve definitively related to the problem of aquaculture planning, people's livelihoods and the environment.

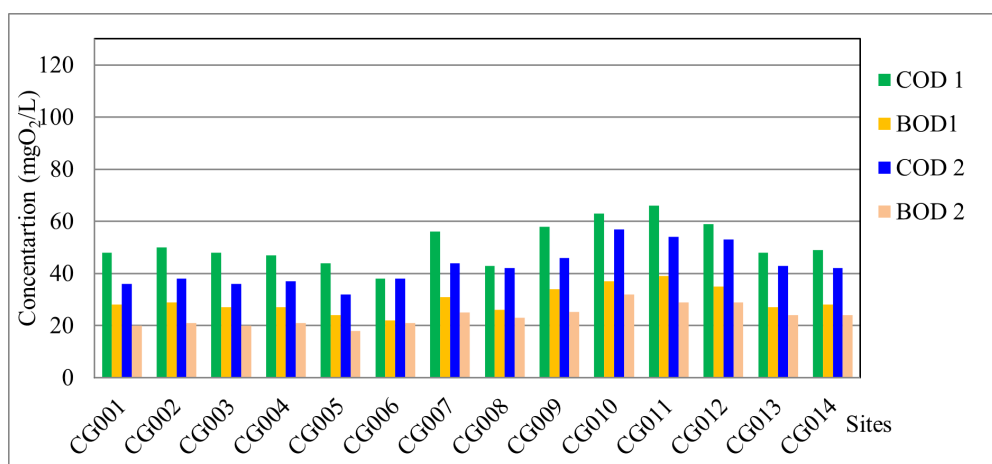


Figure 6. COD, BOD values



The results of the paired t-test for the chemical oxygen demand (COD) parameters between the two periods of the dry season - COD 1 and the rainy season - COD 2 showed a very statistically significant difference (p -value < 0.05). The average COD value during the dry season reached $51.2 \text{ mgO}_2/\text{L}$, which was significantly higher than in the rainy season ($42.7 \text{ mgO}_2/\text{L}$). This shows that the level of organic matter pollution in surface water in the Can Gio river and estuary tends to increase sharply in the dry season. This is mainly due to a decrease in flow during the dry season, which leads to poor pollutant dilution, while the evaporation and accumulation of organic matter from domestic waste, aquaculture, and riverine activities increase. In addition, salinity intrusion and reduced agitation also limit the biodegradation of organic compounds, causing COD to increase. On the contrary, during the rainy season, abundant water and strong currents help dilute and wash away organic matter, and enhance dissolved oxygen, facilitating oxidation and biodegradation, so the COD value is significantly reduced. This result clearly reflects the influence of seasonal hydrological cycles on surface water quality in the Can Gio estuary, shows that organic matter load fluctuates sharply between the two seasons and emphasizes the importance of waste control measures and water quality monitoring during the dry season, which is the most prone to water quality degradation.

The results of the paired t-test between the biological oxygen demand value (BOD_5) in the dry season - BOD 1 and the rainy season - BOD 2 at 14 sample collection points showed a very statistically significant difference (p -value < 0.05). The average BOD value during the dry season was $29.6 \text{ mgO}_2/\text{L}$, which was significantly higher than in the rainy season ($23.7 \text{ mgO}_2/\text{L}$). This reflects higher levels of organic pollution during the dry season, when flow rates drop sharply, limiting oxygen dilution and diffusion, while domestic, aquaculture, and riparian wastes remain stable or increase locally. In addition, high temperatures during the dry season promote the decomposition of organic matter, which increases dissolved oxygen consumption, resulting in higher BOD. In contrast, during the rainy season, large water flow and agitation help to better dilute, leach, and oxidize organic matter, resulting in a significant reduction in BOD values. This decrease reflects the hydrodynamic and self-cleaning conditions of the Can Gio river system and estuary improved during the rainy season. The above results show that seasonal BOD fluctuations are a distinct feature of coastal estuaries, and at the same time affirm the important role of hydrological factors and waste sources in determining surface water quality.

5. CONCLUSION

In recent times, machine learning methods have been successfully applied to forecast real-time ammonia and nitrite concentrations in circular farming systems, supporting early warning of pollution (Chen et al, 2024). The application of a forecast model combined with field monitoring data will help manage pollution loads more flexibly in estuarine areas. The results of the study show that the physicochemical quality of surface water in Can Gio area is generally still within the permissible limits of the national technical regulation on surface water (QCVN 08-MT:2015/BTNMT) and coastal waters

(QCVN 10:2023/BTNMT), except for COD parameters, BOD_5 and nitrite have values that exceed the standard at many survey sites. This clearly reflects the pressure of organic and nutrient pollution in the region, mainly stemming from aquaculture, daily life and riverside exploitation.

Seasonal fluctuations are evident in most indicators, with the dry season recording higher values of COD, BOD_5 and nitrite than the rainy season, indicating that the dilution and self-cleaning capacity of the water system is limited under low flow conditions. In contrast, pH, DO, ammonia, and phosphate parameters all fluctuate within the permissible threshold, reflecting a relatively stable biochemical balance between the two seasons.

Summarizing the results, it shows that the surface water source in the Can Gio river - estuary is significantly affected by organic waste sources, especially in the dry season. The strengthening of periodic monitoring, control of waste load from aquaculture, combined with rational planning of farming areas and restoration of mangrove ecosystems are necessary solutions to protect and maintain the quality of the water environment for the sustainable development of the economy and ecology in the Can Gio area.

Overall, the results provide a baseline assessment of the physicochemical status of surface waters in the Can Gio estuarine area. These findings supply essential reference data for future research applying multivariate analysis and water quality index (WQI) methods to better understand the spatial and temporal dynamics of this coastal ecosystem.

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