

Assessment of Physicochemical Characteristics of Surface Water in the Full-Dyke and Semi-Dyke Systems: A Case Study

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ABSTRACT

The present study aimed to assess the physicochemical characteristics of surface water in the full-dyke (FD) and semi-dyke (SD) systems of the An Giang province. Water samples were collected in both seasons in 2019 (1) the first monitoring phase in the dry season (April) and (2) the second monitoring phase in the rainy season (October). At each season, the surface water samples were collected at 15 sites in the FD system and 15 sites in the SD system to analyze the water quality parameters. The results showed that the concentrations of DO, COD, BOD, TSS, NO₃⁻, NH₄⁺, TKN, PO₄³⁻ and TP parameters in the FD system were higher than in the SD system and there was a significant difference ($p < 0.05$), except the value of pH and DO in the dry season. The DO, COD, BOD₅ and TSS concentrations in the FD system tended to exceed the Vietnamese standard threshold (QCVN 08:2015/BTNMT, column B1), but in the SD system, these values were within the allowable limits of Vietnamese Standard. Other parameters, such as NO₃⁻, NH₄⁺, TKN, PO₄³⁻ and TP exceeded the threshold of the Vietnamese standard in both systems. The results of this study provide the scientific information on water pollution inside the FD system. Therefore, it was expected that the local government of the An Giang province should have long-term strategies to manage the FD system to improve the water quality inside the FD system.

Keywords: An Giang province; full-dyke system; semi-dyke system; surface water quality.

INTRODUCTION

The An Giang province is one of the largest rice producers in the Vietnamese Mekong Delta (VMD), contributing around 16.1% of the rice production in VMD in 2019 (GSO, 2019). An Giang is located upstream of the Vietnamese Mekong Delta and along the Hau rivers of the Mekong river system. Therefore, it has been affected by the natural floods that usually start from July to November (Tong, 2017) and August to October every year (Phung et al., 2017). In order to increase the rice yield and protect the crops, the government of Vietnam implemented the five-year development plan 1996 – 2000 for the VND region (Government of Vietnam, 1996). As a result, the low dyke system was constructed and helped against the early flood peak

arriving around mid-July to mid-August (Triet et al., 2017). After the disastrous flood in 2000, the high dyke system (i.e., the so-called FD system today) was built in the An Giang province to protect the floodplains against a flood. Initially, the FD system showed positive impacts in agriculture fields, such as increased rice crops (i.e., farmers could produce three rice crops per year) and yield and decreased the risk of flood damage (Kien et al., 2019). Moreover, it also protected the living of farmers and stabilized the livelihoods of people (Thieu and Dung, 2014). In parallel with the positive impacts, the FD system also revealed some adverse environmental effects. Previous studies suggested that the input of sediment deposits and natural fertilizers (as NPK) in sediment were prevented by the FD system (Triet et al., 2017), and the biodiversity of fish were lost in the

recent year (Kien et al., 2019). Besides, the construction of the FD system has impacted human health (Berg, 2002), wild fisheries (Nguyen et al., 2018), surface water quality (Nha, 2006; Chau et al., 2015), and degradation of soil quality (Xuan, 2004). Therefore, in the long term, farmers could apply too much agrochemicals in rice cultivation for rice growing and contribute to the surface water pollution (Abe et al., 2016).

Cho Moi is one of the districts of the An Giang province that has long historically constructed the FD system, especially in the My Luong townlet of the Cho Moi district (Duyen et al., 2015). Previous studies showed that the FD system prevented the water exchange inside and outside of the system; thus, this issue could degrade the surface water resources (Duyen et al., 2015; Hoa et al., 2006). However, these studies just focused on evaluating

surface water quality parameters inside the FD system, but were not compared with the semi-dyke (SD) system. Therefore, the present study was performed to compare the physicochemical properties of surface water between the FD and SD systems during sampling times in the dry and rainy seasons.

MATERIALS AND METHODS

Site description

Cho Moi is one of the 11 districts of the An Giang province. Cho Moi consists of 18 administrative regions, including 2 townlets and 16 communes (Fig. 1). The total natural area is 36,906 ha, of which agricultural land is 30,030 ha, accounting for 81.4% of the total area (GSO, 2019). Most rice paddy fields were protected by different

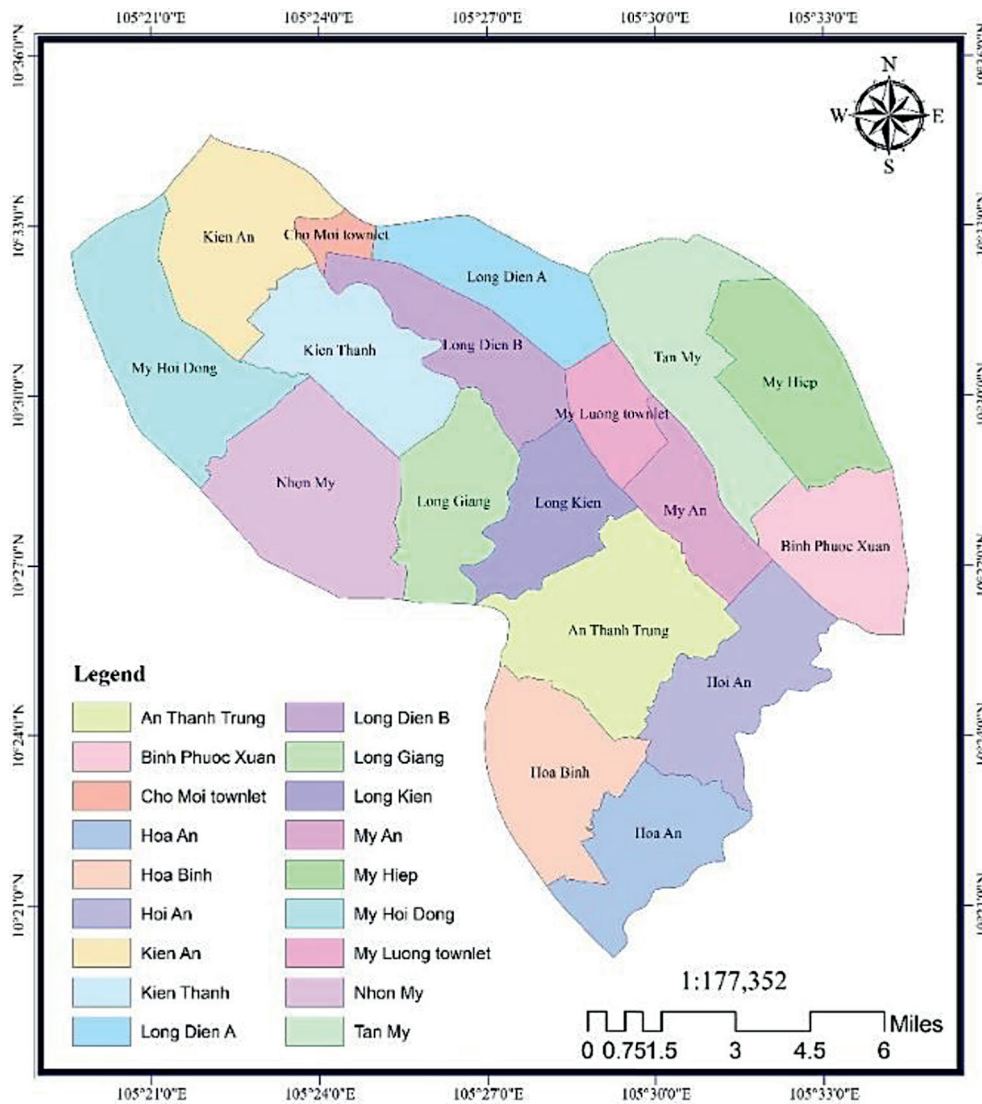


Figure 1. Map of Cho Moi district in the An Giang province

dyke systems. The FD systems protected the rice field over the whole flooding period, and the SD system (i.e., the so-called August dyke systems) protected the rice field only in the early peak of the annual flood in August.

Identifying the study site

According to the Sub-Department of Irrigation of the An Giang province (2013), Cho Moi has 85 dyke regions, including 82 regions in the FD system and 3 regions in the SD system. My Luong townlet has a long history of constructing the FD system; therefore, it was selected to represent the area inside the FD area for collecting the water samples. In addition, the An Thanh Trung district was selected as the control region for collecting

samples, because it is located near the Hau river and is easily affected by the flood season.

The water samples were collected two times per year in 2019, including the first phase in April, which represented the dry season, and the second phase in October, which represented the flood season. A total of 30 samples in each sampling time were collected, including 15 samples in the FD system and 15 samples in the SD system. The locations of water samples in both seasons were presented in Fig. 2.

Water sampling and analysis

At each site, 11 environmental variables, including pH, temperature, dissolved oxygen (DO; mg/L), chemical oxygen demand (COD; mg/L), biological oxygen demand (BOD₅;



Figure 2. Sampling sites in the FD system (a) in My Luong town (S1–S15) and the SD system (b) in the An Thanh Trung commune (S16 – S30)

mg/L), total suspended solids (TSS; mg/L), ammonium (N-NH_4^+ ; mg/L), nitrate (N-NO_3^- ; mg/L), total Kjeldahl nitrogen (TKN; mg/L), phosphate (P-PO_4^{3-} ; mg/L), and total phosphorus (TP; mg/L) were assessed.

The water samples were collected from 20–30 cm below the water surface and at three sampling points far from each other of 3–5 m, then mixed to collect a representative sample. The sampling plastic bottles (1 L) were rinsed three times with the water samples at the sites. All water samples were stored in the ice chest and transported to the laboratory, where they were kept at 4°C in the refrigerator prior to analysis. The water temperature, pH, and DO were directly measured *in situ* with Hanna portable meters. In the laboratory, the following water parameters, such as COD (mg/L), BOD_5 (mg/L), TSS (mg/L), N-NH_4^+ (mg/L), N-NO_3^- (mg/L), TKN (mg/L), P-PO_4^{3-} (mg/L), and TP (mg/L), were analyzed by using the standard methods for water and wastewater (American Public Health Association [APHA], 1998).

Statistical analysis

All environmental parameters in the present study were analyzed to compare the surface water quality between the FD system and the SD system in two seasons. All statistical analyses were performed in Statistical Package for Social Sciences (SPSS) version 26.0 (SPSS Inc., Chicago, IL, USA). The data were analyzed using the two-independent samples analysis of variance to compare the water quality difference between the FD system and SD system in

each season. The Mann-Whitney U test was employed to determine the significant differences between means at 5% level of significance ($p < 0.05$). All computations and the figures were prepared in the Origin 2021 software (OriginLab, Northampton, MA, USA).

RESULTS AND DISCUSSION

Temperature, pH and DO concentration of the surface water samples in the FD and SD systems

The temperature of the water samples was presented in Fig. 3. The first monitoring phase (dry season), the water temperature in the FD system ranged from 29 – 30.8°C with the average value at $30.8 \pm 1.04^\circ\text{C}$ and in the SD system ranged from 28.3 – 29.5°C with the mean value at $29.5 \pm 0.98^\circ\text{C}$ (Fig. 3). The second monitoring phase (rainy season), the temperature value in the FD and SD systems fluctuated from 28.3 – 31.2°C with the average at $29.2 \pm 0.78^\circ\text{C}$ and 28 – 32°C with the mean value at $31.0 \pm 0.97^\circ\text{C}$, respectively. The results in this study corresponded to the results of previous studies, such as Giao (2020) who recorded the temperature in the Hau river fluctuating from 27.1 – 32.0°C and in the Mekong river ranging from 19.9 – 32.2°C (Ongley, 2009).

The pH value of surface water in the SD system tended to be higher than in the FD system (Fig. 4a). In the dry season, there were no significant differences between the FD and SD systems ($p > 0.05$) in the pH value, with the mean

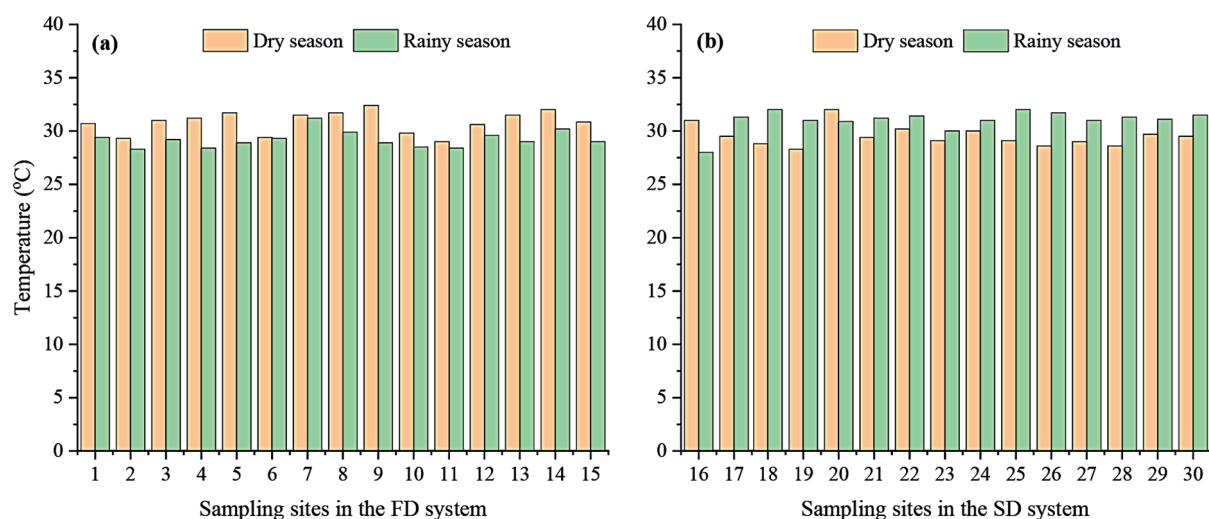


Figure 3. Temperature of surface water in the FD system (a) and the SD system (b)

value in the FD and SD system at 7.61 ± 0.28 and 7.74 ± 0.4 , respectively. However, there were significant differences ($p < 0.05$) between the FD and SD systems in the rainy season, with the pH values reaching 6.97 ± 0.34 and 7.24 ± 0.12 , respectively. According to Giao (2020), the pH value in the Tien river and Hau river fluctuated from 7.1 – 7.2 and 6.7 – 7.12, respectively. Although the pH value in the dry season tended to be higher than in the previous study, it was still suitable for development of fish as well as aquatic animals and plants, and especially for irrigation (QCVN 08:2015/BTNMT), with the pH value in the range of 6 – 8.5 (column A1) and 5.5 – 9 (column B1).

The DO concentration also shows a similar trend to the pH value (Fig. 4b). The DO concentration of surface water in the dry season was not significantly different between the FD and SD systems ($p > 0.05$; Fig. 4b).

However, the DO concentration in the rainy season was higher in the SD system than in the FD system and significantly different ($p < 0.05$). In particular, the DO concentration reached 4.27

± 1.44 mg/L and 5.73 ± 0.71 mg/L, respectively. Dissolved oxygen is an essential abiotic factor in the rice paddy field ecosystem; it could directly or indirectly affect soil nitrogen conversion and rice nitrogen absorption (Kogel-Knabner et al., 2010; Mishra and Salokhe, 2010). The decreased oxygen could reduce the absorption of ammonia in rice plants (Sasakawa and Yamamoto, 1978). Previous studies showed that the DO concentration in Hau river ranged from 4.8 – 5.5 mg/L (Lien et al., 2016) and 5.29 – 5.65 mg/L (Giao, 2020). On the other hand, the DO concentration suitable for aquatic life should be higher 5 mg/L (Ongley, 2009). However, the DO concentration in the FD system was relatively low, showing that the surface water has been organically polluted. In contrast, the DO concentration in the SD system was suitable for the previous studies. In general, the water temperature, pH and DO at the study sites were within the National technical regulations on surface water quality (QCVN 08-MT: 2015/BTNMT, column B1), with the limit value of pH (5.5 – 9) and DO (≥ 4 mg/L).

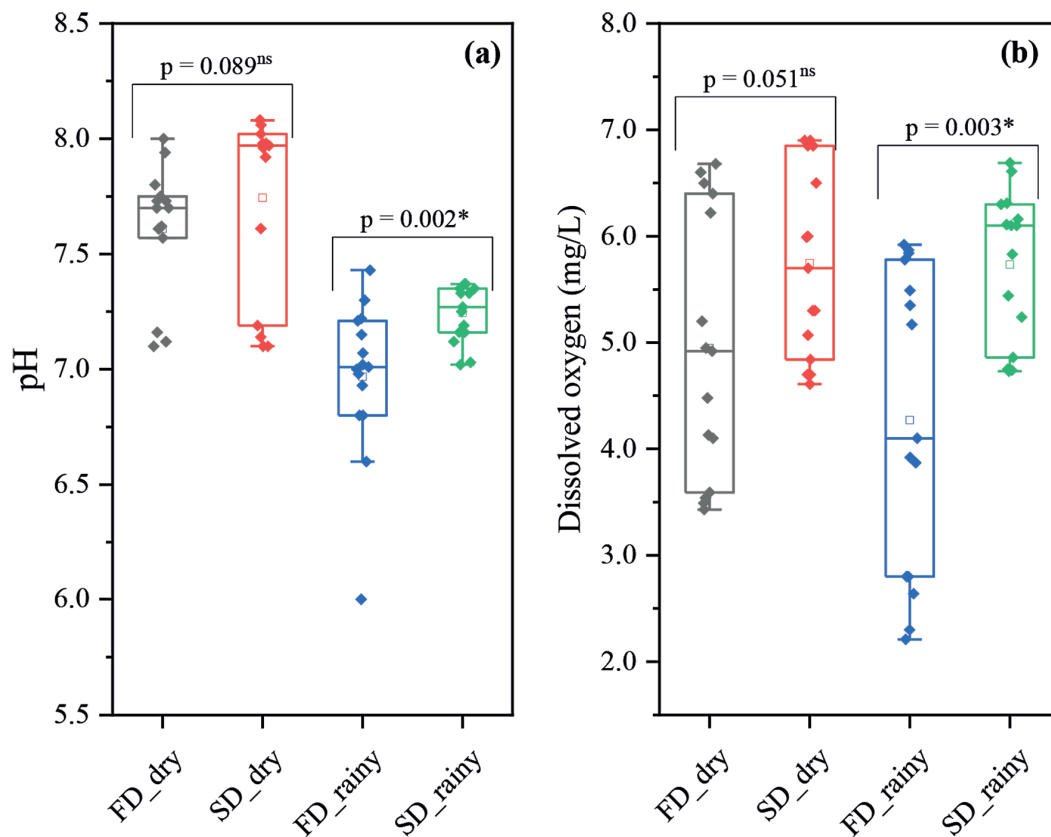


Figure 4. Summary data of discriminant parameters in the FD and SD systems in both seasons: (a) pH value and (b) DO concentration of surface water quality. The outliers of pH were found at S11, S12, S14 sites in FD-dry and S1 sites in the FD-rainy. Note: FD: full-dyke; SD: semi-dyke

The concentrations of COD, BOD and TSS parameters of the surface water samples in the FD and SD systems

Figure 5 shows the concentration of three parameters in the dry and rainy seasons. Overall, the concentration of COD, BOD₅ and TSS in the FD system were higher than in the SD system and significantly different ($p < 0.05$; Fig. 5). The COD concentration of surface water was higher in the FD system than in the SD system, and these figures were significantly different ($p < 0.05$; Fig. 5a). Specifically, the COD concentration in the FD system ranged from 23.0 – 80.6 mg/L in the dry season and from 24 – 67.2 mg/L in the rainy season. The COD value in the SD system fluctuated from 12.5 – 17.1 mg/L in the dry season and 11.2 – 17.6 mg/L in the rainy season. According to Tuyen et al. (2014), the concentration of COD was higher in the dry season than in the rainy season, and the COD value in the FD system increased higher than in the SD system. Comparison with the Vietnamese standard indicates that the average values of COD in the SD system were within the National technical regulation of surface water quality for irrigation (MONRE, 2015). However, the COD concentration in the FD system exceeded the Vietnamese standard with the mean values in the dry season (45.8 ± 19.6 mg/L) and in the rainy season (34.4 ± 12.7 mg/L).

The concentration of BOD₅ and TSS in both seasons was significantly different among the FD and SD systems ($p < 0.05$; Figs. 5b, 5c). In the dry season, the BOD₅ concentration in the FD system ranged from 7.2 – 21.5 mg/L, and it ranged from 5 – 9 mg/L in the SD system (Fig. 5b). In turn, the BOD₅ concentration in the rainy season ranged from 7.5 – 18.5 mg/L in the FD system and 4.2 – 6.9 mg/L in the SD system. The concentration in this study increased slightly compared with the study of Duyen et al. (2013), which also assessed the surface water quality in the channel of the FD system in My Luong townlet. The research recorded the BOD₅ concentration below 8.0 mg/L. Hong (2013) also found that the limited water-exchange process between inside and outside of the FD system is one of the reasons for water pollution in the FD system.

The TSS concentration in the FD system was higher than in the SD system in both seasons, and these figures were significantly different ($p < 0.05$; Fig. 5c). In the dry season, the TSS concentration in the FD and SD systems ranged from 45 – 112 mg/L and 20 – 105 mg/L, respectively. Additionally, the TSS concentration in the rainy season fluctuated from 40 – 205 mg/L in the FD system and 40 – 64 mg/L in the SD system (Fig. 5c). Boyd (1998) indicated that the amount of suspended matter, soil, sediment particles, and plankton affected the suspended solids content in water. The research by Khanh et al. (2021) found

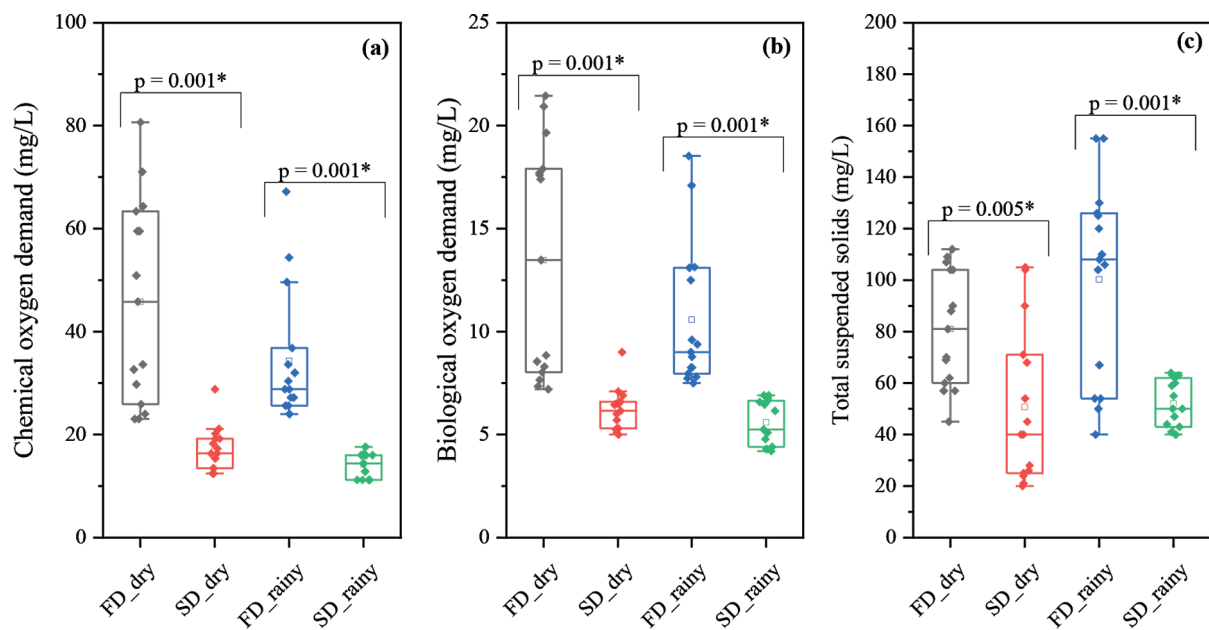


Figure 5. Summary data of discriminant parameters in the FD and SD systems in both seasons: (a) COD, (b) BOD₅ and (c) TSS concentration of surface water quality. The outliers of COD parameter were found at S1 sites in SD-dry and S8, S9 sites in the FD-rainy. The outliers of BOD parameter showed at S29 sites in the SD-dry. Note: FD: full-dyke; SD: semi-dyke

that the number of phytoplankton species in the FD system was higher than in the SD system in the Thoai Son district. The TSS concentration in this study was within the research of Hong (2013), which was carried out in the FD and SD system in the Chau Phu district. However, the TSS concentration exceeded the Vietnamese standard (< 50 mg/L), including 14/15 sites in the FD-dry, 13/15 sites in the SD-dry, 7/15 sites in the FD-rainy, and 6/15 sites in the SD-rainy.

The concentration of the NO_3^- , NH_4^+ and TKN parameters of surface water in the FD and SD systems

The NO_3^- , NH_4^+ , and TKN in surface water in both seasons were illustrated in Fig. 6. In general, the concentration of three parameters in the FD system was higher than in the SD system, and significant differences were found ($p < 0.05$), except for the NH_4^+ concentration in the dry season ($p > 0.05$; Fig. 6b). After comparing these concentrations with the Vietnamese standard (QCVN 08:2015/BTNMT, column B1), the NO_3^- concentration tended to be lower than the Vietnamese standard, but the NH_4^+ concentration was higher than the Vietnamese standard.

The NO_3^- concentration in the dry season fluctuated from 0.42 – 1.33 mg/L in the FD system and 0.32 – 0.79 mg/L in the SD system. In the rainy

season, the NO_3^- concentration in the FD system ranged from 0.52 – 2.26 mg/L and 0.41 – 0.81 mg/L in the SD system. According to Tuyen et al. (2014), the NO_3^- concentration in the FD system was also higher than in the SD system. Furthermore, previous studies have suggested that the NO_3^- concentration in the dry season was higher than in the rainy season (Minh et al., 2021; Hong, 2013).

According to the Vietnamese national technical regulation on surface water (QCVN 08:2015/BTNMT, column B1), the NH_4^+ concentration should be lower than 0.9 mg/L. However, the NH_4^+ value at all sampling sites exceeded the Vietnamese standard in the dry season, fluctuating from 1.54 – 2.66 mg/L in the FD system and 1.26–3.78 mg/L in the SD system. In the rainy season, the NH_4^+ concentration in the FD and SD systems ranged from 0.42 – 2.8 mg/L and 0.14 – 2.1 mg/L, respectively. In this study, the NH_4^+ concentration in both seasons tended to be higher than in the previous research (Minh et al., 2021; Hong, 2013). The reason might be that the FD system in Cho Moi was built more than 20 years ago. Therefore, the concentration of water quality in the FD system accumulated inside the FD system more than in the outside FD system. This point was elucidated in the research of Gai (2012), the TKN concentration in the FD system ranged from 1 – 7 years (1.83 mg/L) and 9 – 10 years (2.13 mg/L).

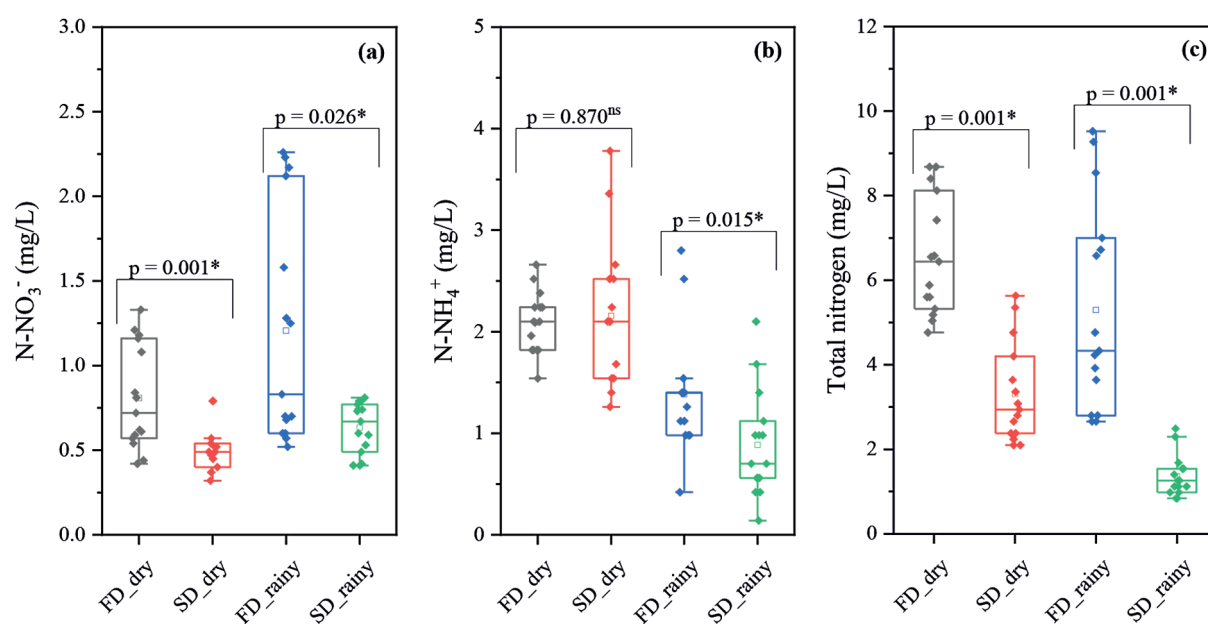


Figure 6. Summary data of discriminant parameters in the FD and SD systems in both seasons: (a) NO_3^- ; (b) NH_4^+ and (c) TKN concentration of surface water quality. The outliers of NO_3^- parameter were found at S16, S17 sites in SD-dry. The outliers of NH_4^+ parameter showed at S8, S9 sites in the FD-rainy and S21 in the SD-rainy. Note: FD: full-dyke; SD: semi-dyke

Figure 6c shows that the TKN concentration in the FD system was higher than in the SD system and significantly different ($p < 0.05$). In the dry season, the TKN concentration ranged from 4.76 – 8.68 mg/L in the FD system and 2.1 – 5.63 mg/L in the SD system. The average TKN concentration in the SD system (3.31 mg/L) was lower by half, compared with the FD system (6.55 mg/L). In the rainy season, the TKN concentration in the FD system fluctuated from 2.66 – 9.52 mg/L and 0.84 – 2.49 mg/L in the SD system (Fig. 6c). The research result was consistent with the results of the research by Duyen et al. (2015), with the TKN concentration in the FD system recorded from 5.5 – 11.8 mg/L in the dry season and from 3.6 – 5.8 mg/L in the rainy season. Besides, Duc (2014) also indicated the amount of N fertilizers used in the FD system was higher than in the SD system, with 125 kg/ha/crop and 113 kg/ha/crop, respectively. Therefore, the reason might be that the concentration of types of nitrogen in the FD system was higher than in the SD system. Besides, Nha (2006) also indicated that the amount of nitrogen fertilizer used inside the FD system was higher than in the outside FD system.

The concentrations of PO_4^{3-} and TP parameters of the surface water samples in the FD and SD systems

The PO_4^{3-} concentration in the FD system was higher than in the SD system in both seasons, with a significant difference ($p < 0.05$; Fig. 7a). In the dry season, the PO_4^{3-} concentration in the FD system fluctuated from 0.1 – 3.33 mg/L and 0.06 – 1.04 mg/L in the SD system. In the rainy season, the PO_4^{3-} concentration in the FD and SD systems ranged from 0.3 – 0.83 mg/L and 0.14 – 0.68 mg/L, respectively. According to Tuyen et al. (2014), the mean concentration of PO_4^{3-} in the SD system was lower than in the FD system, with 0.52 mg/L and 0.97 mg/L, respectively. Comparison with the Vietnamese standard (QCVN 08:2015/BTNMT, column B1) shows that the concentrations of PO_4^{3-} in the FD system tended to be a higher threshold (0.3 mg/L), but these values in the SD system were within the Vietnamese standard.

Figure 7b shows that the average concentration of TP in the SD system was lower than in the FD system, and there was a significant difference ($p < 0.05$;

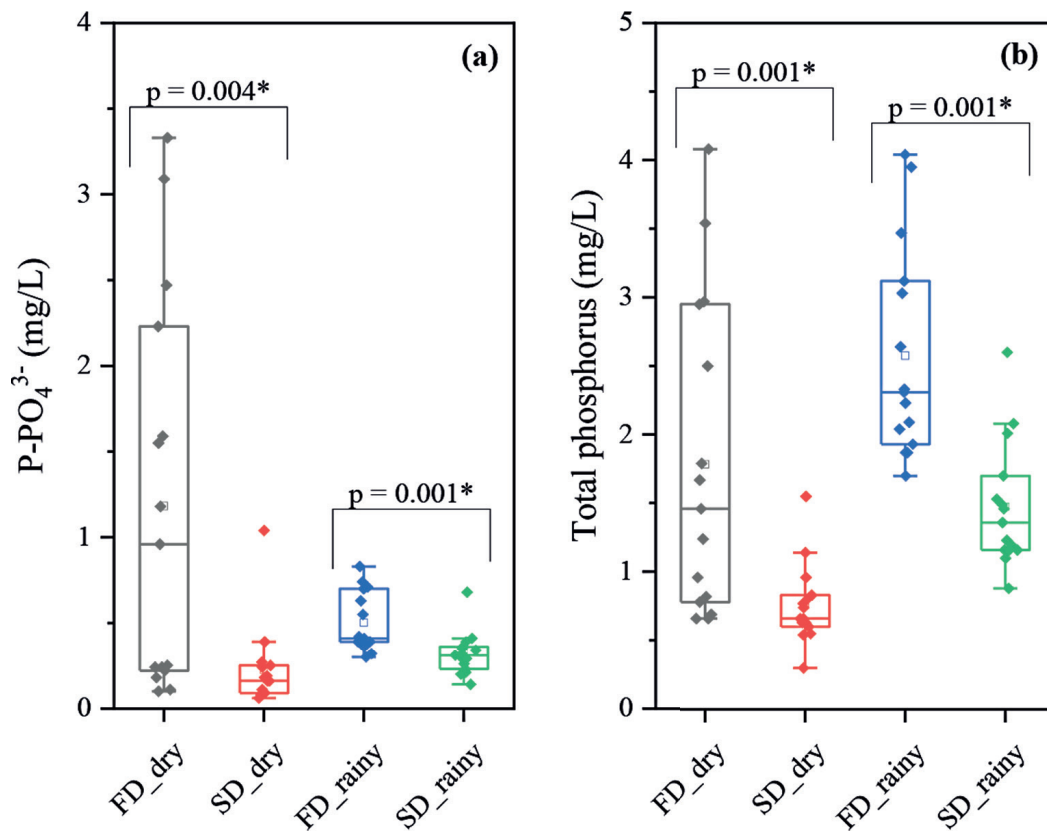


Figure 7. Summary data of discriminant parameters in the FD and SD systems in both seasons: (a) PO_4^{3-} and (b) TP concentration of surface water quality. The outliers of PO_4^{3-} parameter were found at S16 sites in SD-dry and S27 sites in the SD-rainy. The outliers of TP parameter showed at S16 sites in the SD-dry and S16 in the SD-rainy. Note: FD: full-dyke; SD: semi-dyke

Fig. 7b). Specific in the dry season, the mean values of TP in the FD system were recorded at 1.78 ± 1.15 mg/L and 0.76 ± 0.29 mg/L in the SD system. Besides, the average values of TP in the rainy season showed a similar trend to the dry season, with 2.57 ± 0.77 mg/L in the FD system and 1.47 ± 0.46 mg/L in the SD system. The values of TP in the FD system are consistent with the results of a previous study in the Cho Moi district (Duyen et al., 2015) and Chau Phu district (Hong, 2013; Gai, 2012). In addition, the amount of fertilizer in the An Giang province was applied higher inside the FD system than outside the FD system (Duc, 2013). Specifically, farmers used 90 kg P_2O_5 /ha/crop (equivalent to 270 kg/year) for rice cultivation in the FD system and 80 kg P_2O_5 /ha/crop (equivalent to 160 kg/year) in the SD system (thus, rice produced two crops per year). On the other hand, the water exchange between inside and outside of the FD system was not conducted in the long term in the FD system; therefore, it could be one of the main reasons, which made the TP concentration in the FD system become higher than in the SD system.

CONCLUSIONS

The concentration of physicochemical surface water parameters as temperature, pH, DO, COD, BOD, TSS, NO_3^- , NH_4^+ , TKN, PO_4^{3-} , and TP showed higher values in the FD system than in the SD system and significant difference was noted ($p < 0.05$), except the value of pH and DO in the dry season. The concentration of all parameters in the dry season tended to be higher than in the rainy season. The pH value was consistent with the Vietnamese standard (QCVN 08:2015/BTNMT, column B1). Other parameters, including the DO, COD, BOD, and TSS parameters in the FD system exceeded the threshold of the Vietnamese standard. However, the values of these parameters in the SD system were suitable for the Vietnamese standard. The concentration of the NO_3^- , NH_4^+ , TKN, PO_4^{3-} , and TP exceeded the threshold of the Vietnamese standard in both systems. It is expected that the government of An Giang should have essential strategies in the management of the FD system to improve the water quality inside the FD system.

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