

Quantifying the deposited sedimentation during flooding in semi-dyke protected area: A case study in the Plain of Reeds, Mekong Delta, Vietnam

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ABSTRACT

Sedimentation supplemented by flood is an essential source of soil nutrition in the lower Mekong River basin. This study evaluated the sediment deposited on fields during the 2022 flood season at the Plain of Reeds (PoR), Vietnam. The PoR is a region of soil with heavy acid sulfate. The selected research area was two provinces in PoR, Long An and Tien Giang. The dike system in this region comprises the complete-dyke and semi-dyke. This study uses a new sediment trapping design to measure deposited sediment with particle sizes $> 50 \mu\text{m}$ during the whole flooding season of 2022. Three location types were selected for measurement, including internal canal (InC), flat field (FF), and the raising bed (RB). We selected these three location types based on agricultural practices in this region. The deposited sediment in one flood season was at a mean of $1242.3 \pm 1102.6 \text{ g/m}^2$. There were observed differences between location types, in which the highest was found at the flat field upstream ($2941.5 \pm 500.8 \text{ g/m}^2$), to the flat field downstream ($1621.3 \pm 141.2 \text{ g/m}^2$), to the internal canal ($987.5 \pm 929.43 \text{ g/m}^2$), and lowest at raising bed ($119.2 \pm 9.43 \text{ g/m}^2$). Significant differences were found between the flat field upstream and the other three location types within the study area. Total N and P content of sediment were found at a mean of $9.08 \pm 5.05 \text{ mg/g}$ dry weight (dw) and $0.62 \pm 0.21 \text{ mg/g}$ dw, respectively. The data showed a significant amount of sediment, and its nutrient contents can be trapped during the flooding season in this semi-dyke system.

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1. Introduction

The Plain of Reeds (PoR) is one of the four acid-sulfate soil regions in the Mekong Delta, Vietnam. The Vietnamese government has implemented a program to build a canal system for irrigation and renovation of soil quality, supporting agricultural development in this region from 1980 to the present. The process of building dykes and canals in the Mekong Delta has significantly contributed to improving the alum soil and facilitating agricultural cultivation in the heavy alum region of the Plain of Reeds. PoR has an area of 6,711.3 km² (Nguyen, 2020), including 3 provinces (Long An, Tien Giang, Dong Thap). The area of acid sulfate soil in the region is 696,946 ha. Building a hydraulic structure system for irrigation and land improvement began in 1980 and was gradually completed. To date, the complete dyke system accounts for 3,150 km, the remaining is the semi-dyke system accounting for 6,880 km (Nguyen, 2018). In the Region's development strategy, the state will continue to invest in building a complete dike system to help farmers be more proactive in agricultural cultivation (Nguyen, 2018).

In the PoR, during the flood season from late July to November, floodwaters overflow the banks, carrying alluvial sediment to fields, regenerating the river ecosystem, and helping farmers increase their income thanks to the farming model of flood-based agriculture (WB, 2021). However, the Mekong Delta region, in general, and the PoR, in particular, are facing new challenges that can seriously affect agricultural cultivation, including a decline in water resources due to excessive water use and climate change.

The amount of water in the lower Mekong Delta has been recorded as having experienced a severe decline since 2020, causing the amount of flood water to decrease during the rainy season, and saltwater intrusion to deepen during the dry season (Luong, 2023). Water resources challenges are expected to worsen due to the

impact of climate change (Cosslett et al., 2014). Agricultural cultivation in this region needs to be considered and adapted to current and upcoming developments in water resources. Especially, farming on heavy alum soils is strongly affected by the efficiency of alum soil washing and irrigation. The dependence on chemical fertilizers, combined with the intensive soil utilization thanks to the protected dyke systems, poses a further risk to agricultural farming in this region. Sedimentation is an essential source of soil nutrition in the lower Mekong River basin. However, there were limited studies that measured the flood-deposited sedimentation in the dyke protected systems, thereby supporting the design and operation of irrigation systems in the region. Two studies measured sediment deposition in the paddy field in the PoR (Manh et al., 2013; Hung et al., 2014). Other studies assessed the sedimentation in the Mekong River by modelling (Manh et al., 2014; Thanh et al., 2020). Manh et al. (2013) and Hung et al. (2014) used pan traps and plastic turf traps to collect sediment samples. However, Manh et al. (2013) reported a significant uncertainty in data collection due to their trap's design. Therefore, this study aims to quantify sediment mass and nutrient content (total N and P) in semi-dyke area to support irrigation system design and operation in this region. The trap used in this study was designed to improve the accuracy for long-term placement in the field.

2. Materials and Methods

2.1. Study area

The study area of this study was shown in Figure 1. This area belongs to the PoR's heavy acid sulfate soil. The dike system has been invested in this region since 1980 and will continue to be completed. The study area comprised Thanh Hoa district (Long An province) and Tan Phuoc District (Tien Giang province), two provinces in the PoR. These two districts are located in the

heavy acid sulfate soil and are used for growing pineapple and yam in the raising bed farming. The study area has a system of irrigation and drainage canals connected to the Vam Co Tay river. The study area has two types of dykes, complete-dyke and semi-dyke systems. In regions with complete-dyke, farmers can fully control the watering and usually cultivate full-time throughout the year, leaving no time for the soil to rest. In the semi-dyke area, farmers leave

the land to relax during the flood period and start farming after the flood season ends. This study monitored the sedimentation in the PoR, focusing on a case study in the semi-dyke area in the heavy acid sulfate soil region in the PoR, including Tan Phuoc and Thanh Hoa districts of Tien Giang and Long An province (Figure 1). Locations for installing sediment traps were also shown in Figure 1.

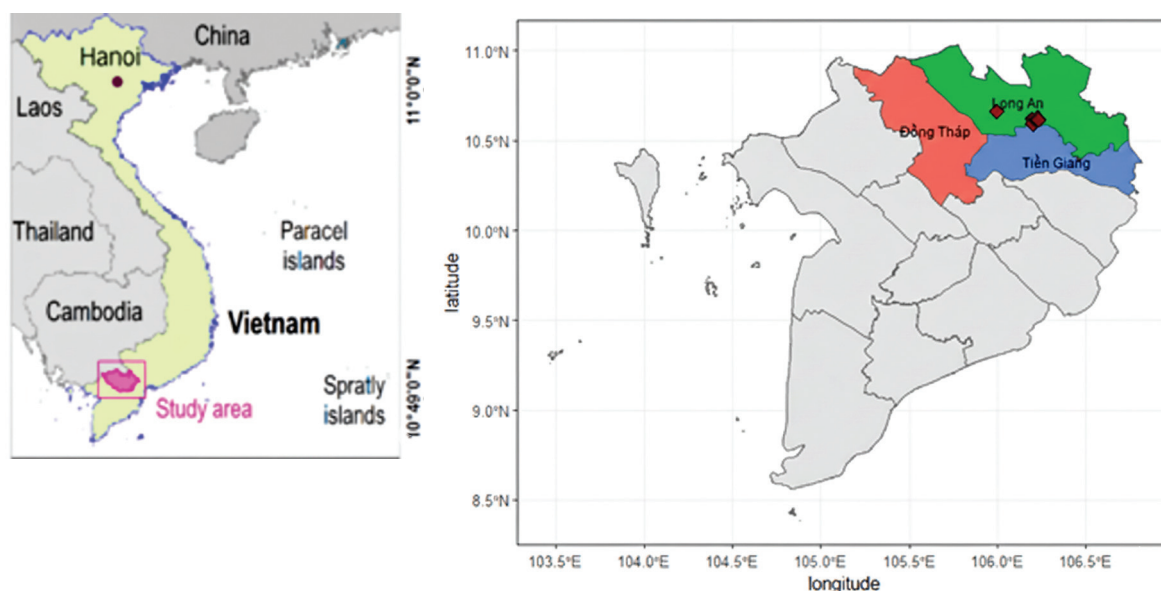


Figure 1. Study area and locations of seven sediment trapping sites (marked in red).

2.2. Sediment trapping

This study evaluated sediment deposits in the fields during the 2022 flood season. The study was conducted from September to November, corresponding to the beginning to the end of the 2022 flood. The flood in 2022 came later than in the previous years. In addition, the studied area is located far from the Mekong River mainstream, so floods reached this area later than the areas upstream. Selected locations for placing sediment traps include upstream locations supplying water to the study area and locations in flooded fields inside the research area. A map of sediment trap locations was shown in Figure 1. Traps were placed in seven fields, including one field upstream (rice

field) and six fields in the study area (one rice field and five yam fields). Three traps were placed at each field, making up twenty-one traps.

The sediment trap was designed to stably place the trap in the field during the installation period of about 1.5 to 2 months, be convenient to install and collect at the end of the flood season, and be capable of keeping sediment with high performance. The polypropylene (PP) filter cloth (pore size of 50 μm , weight of 380 g/m^2 , thickness of 2.3 mm, Miennam TEC Co.) was sewn onto a plastic basket (size of length $\times$ width $\times$ height = 28 $\times$ 39 $\times$ 8 cm) (Figure 2). The pore size of 50 μm used in this study was based on the average grain size of inundated sediment into the floodplain of

Tam Nong district, Dong Thap province, which was in the range of < 2 to $100\ \mu\text{m}$ (Hung et al., 2014). From our preliminary test in the laboratory, this pore size, combined with the rough surface and large thickness of the filter cloth, allows water to gradually filter through, while trapping and stabilizing sediment inside the trap. The bottom of the basket is reinforced with nails to stabilize the basket at the trap location. The basket is made of a steel wire frame with a height of 1.5 m to place and pull the trap on the field surface conveniently. After being placed, traps were marked with multi-colored flags so that farmers could identify and avoid impacting the traps during the entire flood season, while also helping to find the exact locations of the traps at the end of the flood season. This prevented the disturbing and loss of the trap, thereby increasing trap recovery. Traps collected at the end of the flood season were dried at $50 - 60^\circ\text{C}$ until completely dry; the sediment was removed from the filter cloth to weigh for calculating the mass trapped, and analyzing nutrient contents, including total N and P. Pretreatment of sediment samples before analysis followed the TCVN 6647:2007 method. Total N was analyzed using the TCVN 6498:1999, and total P was analyzed using the TCVN 8940:2011 method. Sample digestion was conducted in the digestion unit (DK20) described in the TCVN method for total N and P analysis. Each measurement was triplicated. In the results section, data for nutritional contents (total N and P) showed the means of triplicate measurements.

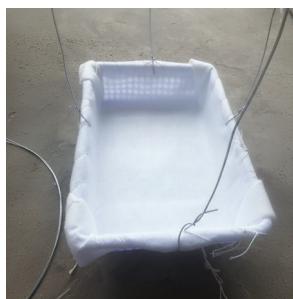


Figure 2. The sediment trap design used in this study.

2.3. Statistical analysis

Statistical analysis was conducted using JMP Pro 17 software. An independent sample T-test was used to compare means. The P value < 0.05 indicated a statistically significant mean difference between groups.

3. Results and Discussion

3.1. Deposited sediment accumulation

There were three sediment traps placed at each location. The total number of traps set was twenty-one. The total number of undisturbed traps collected after the flooding season was sixteen, reaching a recovery rate of 76%. The number of undisturbed traps in each field varied from two to three, providing reliable data for each field. A loss rate of 24% included three loss-traps and two disturbed-traps. The mass of deposited sediment (g/m^2) was shown in Figure 3. Mass varied in a range of 112.54 to $3295.60\ \text{g}/\text{m}^2$. Lowest mass was found on the rising bed ($119.20 \pm 9.43\ \text{g}/\text{m}^2$). The highest accumulation was found in the flat fields upstream ($2941.48 \pm 500.81\ \text{g}/\text{m}^2$). There was a significant difference between the flat field upstream and the other three location types (Table 1). The deposited sediment's mass range found in this study was significantly lower than the range reported by Manh et al. (2013) (ranged from 2.2 to $60\ \text{kg}/\text{m}^2$ for the larger Mekong Delta) and Hung et al. (2014) ($6.86\ \text{kg}/\text{m}^2$ for Dong Thap floodplain). In the study of Manh et al. (2013), one sampling site was also located in our study area. In the low dike compartment, the sedimentation rate was reported as 2.0 to $3.5\ \text{kg}/\text{m}^2$ (Manh et al., 2013), which was higher than the range found in our study, even though their plastic turf trap could result in more loss of the deposited sediment than our trap. This result raised the problem of sedimentation reduction in the lower Mekong Delta over time. Sediment was projected to reduce by 67 to 97% in 2020 and

2040 (MRC, 2024). Manh et al. (2015) reported that the median changes of the combined drivers in the Mekong Delta could decrease the overall floodplain sedimentation by approximately 40% in 2050 - 2060.

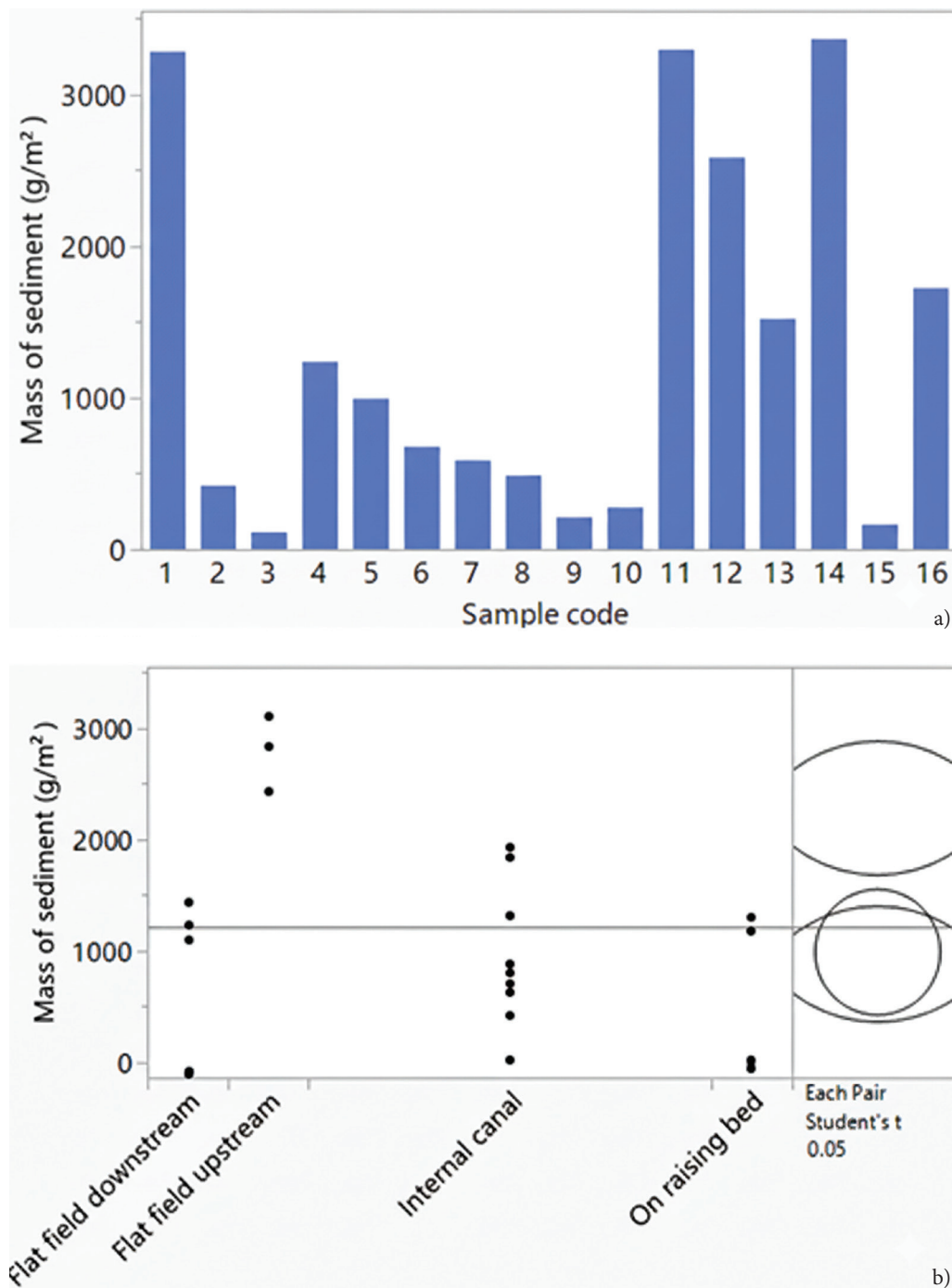


Figure 3. a) The mass of sediment trapped in all locations; b) The mass of sediment group for each location type was compared by each pair of students' T-test ($\alpha = 0.05$).

Table 1. Deposited sediment mass (mean and standard deviation)

Location type	Deposited sediment mass (mg/m ²)*
Internal canal	987.51 ± 929.43 (A)
On raising bed	119.20 ± 9.43 (A)
Flat field downstream	1621.32 ± 141.18 (AB)
Flat field upstream	2941.48 ± 500.81 (B)

*Letters in the mean column were calculated by comparing the mean with each pair of students' T-tests ($\alpha = 0.05$). Different letters indicated significant mean differences between groups ($P < 0.05$).

3.2. Total N and P of inundated sediment

Total N concentrations in fourteen samples varied in the range of 4.71 to 22.52 mg/g dry weight (dw) (mean of 9.08 ± 5.05 mg/g dw) (Figure 4), and total P varied in the range of 0.35 to 1.18 mg/g dw (mean of 0.62 ± 0.21 mg/g dw) (Figure 5). The highest nutritional contents were found for the sample collected on the raising bed (20.46 ± 2.41 mg/g dw for total N and 1.00 ± 0.31 mg/g dw for total P), the lowest was found in flat field samples. There was no difference in total N and P between the internal canal and flat fields (the mean values range of 6.10 to 8.32 mg/g dw and 0.41 to 0.68 mg/g dw for total N and P, respectively). However, there was a significantly higher total N and P contents for the sample on the raising bed (mean of 22.52 mg/g for total N and 1.00 mg/g dw for total P) (Table 2). The nutritional content in this study differed from the data reported by Manh et al. (2013) for a similar study area. Manh et al. (2013) obtained the lower total N content (at 3.60 mg/g) and higher total P content (at 1.37 mg/g). These results show

potential variation in nutritional contents in flood-deposited sediment between studies. However, these differences were insignificant compared to the variation between location types. Our results showed that flood could supplement from 10.82 to 267.1 kg/ha of total N and from 0.74 to 18.24 kg/ha of total P, depending on the locations in this region. Consider the fertilizers used by yam growers in this region, which were 275.06 kg N/ha crop season and 97.15 kg P/ha crop season (our unpublished data), nutrient supplements from flood-sediment would contribute from 4 to 97% of N and from 0.8 to 18.8% of P for the yam cropping season. The lower level is applied to the raising bed, and the upper level to the field upstream. This data showed that the semi-dyke system allowed nutrients to be supplemented to the soil and plants. Therefore, we suggest that the operation of dyke systems should be flexible to capture sediment from floods to supplement nutrients to the soil for both semi-dyke and complete-dyke systems.

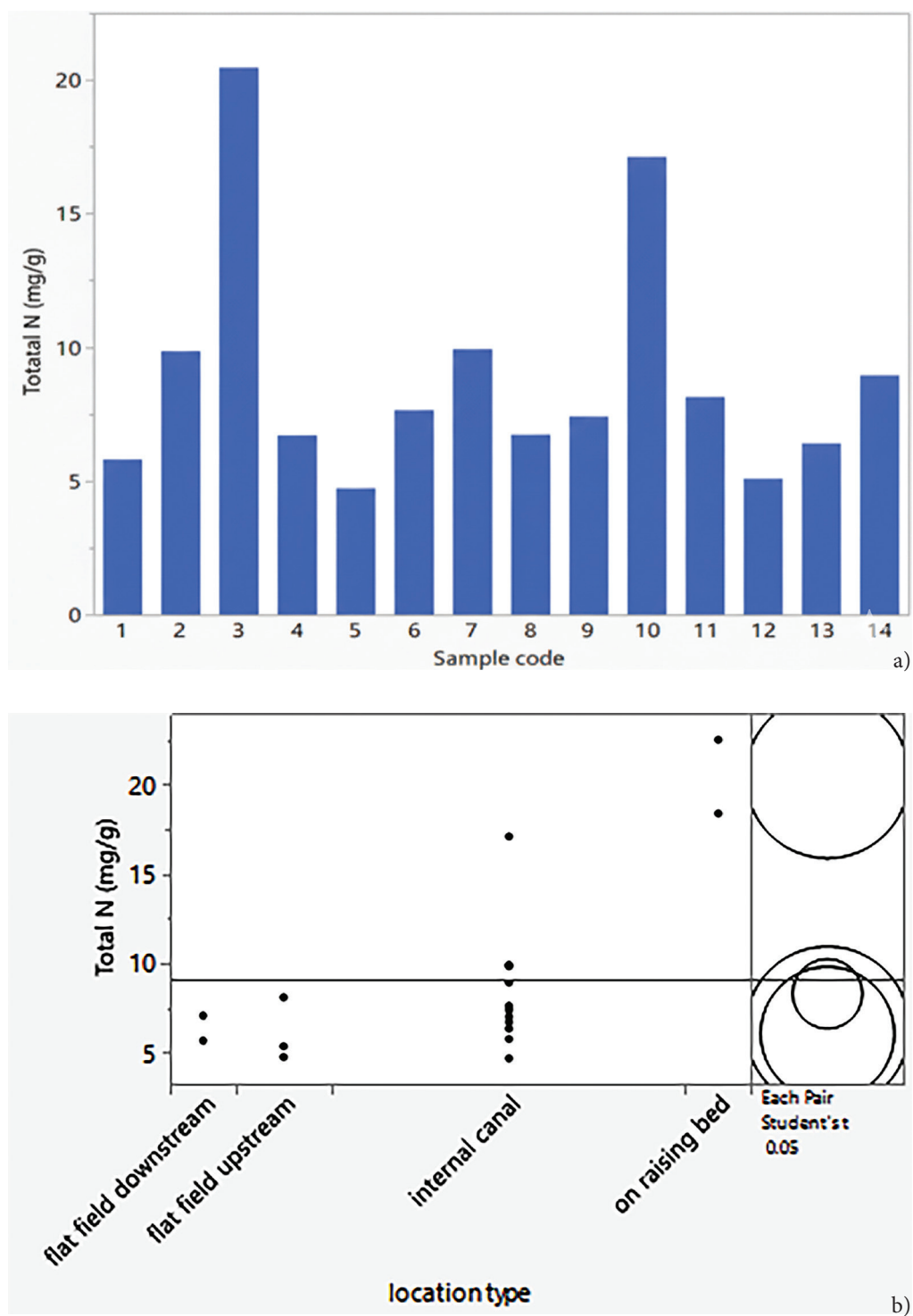


Figure 4. Nitrogen nutrient content in the deposited sediment. a) Total N for each location; b) Total N for each group of location types. Compare the means by each pair of students' T-test ($\alpha = 0.05$) shown in the right picture.

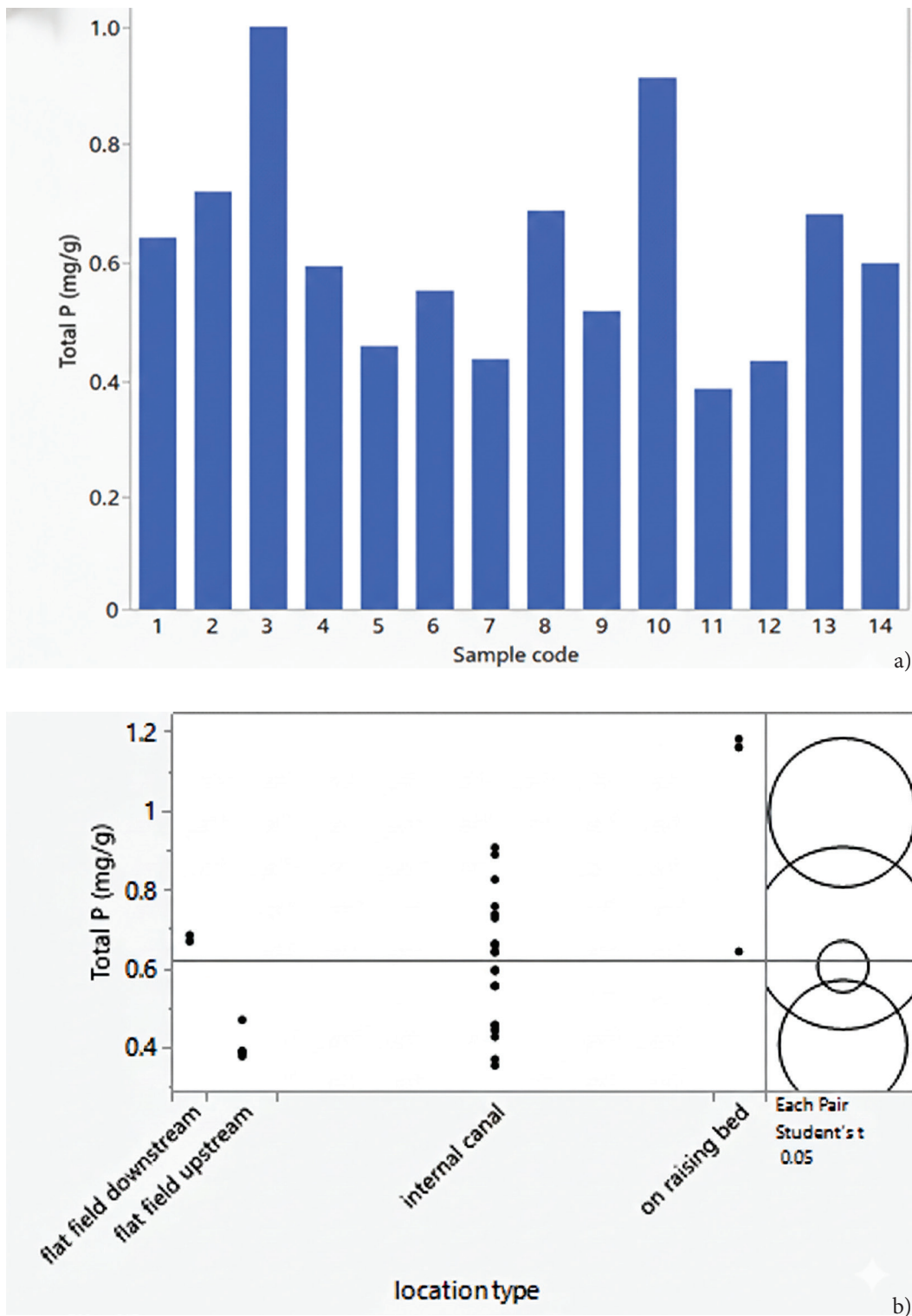


Figure 5. Phosphorus nutrient content in the deposited sediment. a) Total P for each location; b) Total P for each group of location types. Compare the means by each pair of students' T-test ($\alpha = 0.05$) shown in the right picture.

Table 2. Nutrient contents of deposited sediment

Location type	Mean of total N $\pm$ Standard deviation (mg/g)*	Mean of total P $\pm$ Standard deviation (mg/g)*
Internal canal	8.32 $\pm$ 3.34 ^A	0.60 $\pm$ 0.16 ^b
On raising bed	20.46 $\pm$ 2.91 ^B	1.00 $\pm$ 0.31 ^a
Flat field downstream	6.40 $\pm$ 0.99 ^A	0.68 $\pm$ 0.01 ^{bc}
Flat field upstream	6.10 $\pm$ 1.78 ^A	0.41 $\pm$ 0.04 ^c

*Letters in the mean columns were calculated by comparing the mean with each pair of students' T-tests ($\alpha = 0.05$). The different letters showed a significant difference in means between groups. The capital letters compare the means of total N between groups, and the lowercase letters compare the means of total P between groups.

4. Conclusions

This study evaluated the inundated sedimentation content in the semi-dyke protected area in the study area in the PoR, Mekong Delta, Vietnam. Using a novel portable and scalable sediment trap design, we could quantify the deposited sediment from different location types. The data showed a significant amount of sediment, and its nutrient contents can be trapped during the flooding season in this semi-dyke system. This information also estimated the potential loss of nutrients in the complete protected dyke system in this region if inundation is allowed in the fields. The design and flexible operation of the dyke systems allow flood inundation of paddy fields, which could supplement a significant amount of nutrients for crops, and support sustainable agriculture in this region.

Conflict of interest

All authors declare that we have no conflicts of interest.

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