Evaluation of the impact of landfill on floodplain water quality in a tropical monsoon region

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Abstract:

Nowadays, a deterioration of floodplain water quality in the Lower Mekong River Basin in Cambodia is expected because of urbanization/industrialization by landfilling. This study aimed to evaluate the impact of floodplain landfilling on basin water quality. Field observations of total phosphorus (TP), chemical oxygen demand and heavy metals were conducted in the Mekong River Basin in Cambodia and the Chao Phraya River Basin in Thailand. In the Mekong River Basin, TP was 2.05 mg/L in the floodplain where large-scale landfill was carried out using waste, with iron (Fe) at the factory site 6.54 mg/L. In comparison, in the Chao Phraya River Basin, TP and Fe concentrations were low. A degree of floodplain water quality management commensurate to the level of economic development was confirmed from water quality conservation efforts, among others, in Thailand.

KEYWORDS: reclamation; land use; river basin management; water quality; wetlands

INTRODUCTION

Floodplains play important roles in supplying water for agriculture, fisheries, groundwater replenishment, and water purification, making them important for the environment and people (Schilling et al., 2015; Isaac et al., 2016; Yu and Rhoads, 2018; Wang et al., 2019). In the Mekong River Basin where large-scale flooding occurs during the rainy season, floodplains are of great importance (Adamson et al., 2009; Campbel, 2016). Flood inundation risks include infrastructure and property destruction (Hirsch, 2016), as well as the spread of infectious diseases (Kazama et al., 2012) and other issues. However, flood inundation also provides agricultural benefits, such as the deposition of fertile sediments on the floodplains (Tong, 2017; Dang et al., 2018b). Especially in Cambodia, flooding has been utilized in agriculture as water and nutrient resources (Kazama et al., 2007; Douven and Buurman, 2013). In addition, the floodplain also plays an important role in the fishery industry, which is fundamental for the livelihood and food security of large population groups in Cambodia (Roos et al., 2007; Orr et al., 2012; Hecht et al., 2019). The further importance of the floodplain in the Mekong River Basin has been discussed from various perspectives, such as its relationship with net primary production (Hiraga et al., 2017a), agricultural benefits and damage during maximum flooding (Kazama et al., 2009), flood water resource benefits (Kazama et al., 2003), groundwater resources (Shrestha et al., 2016; Ha et al., 2018), and management strategy in light of changing sediment budgets (Kondolf et al., 2018).

This valuable floodplain is, however, facing an existential crisis under the pressure of watershed development (Arias et al., 2014; Dang et al., 2018a; Arias et al., 2019), with further watershed development expected in Cambodia (Hiraga et al., 2017b; Hoang et al., 2019). In Cambodia, since the floodplain of the Mekong River accounts for the majority of national land, most basin development means urbanization by landfilling floodplains (Hiraga et al., 2018). A rapid decrease in the floodplain area may cause issues such as an increase in flooding risk due to the loss of water retention functions and a decrease in base discharge (Hiraga et al., 2018). There are also many concerns in terms of environmental issues, such as a decrease in fish spawning grounds, water pollution, and the loss of purification function (Minh et al., 2007; Nguyen and Ye, 2015). It has been confirmed that water pollutants are discharged to the surroundings due to floodplain landfilling (Figure S1). Additionally, large-scale contamination of river sand landfill with waste has been confirmed to occur (Figure S2). Thus, a deterioration of floodplain water quality is expected. For this reason, clarification of the influence of floodplain landfill on the basin environment – especially its influence on water quality of the floodplain – is an important consideration during watershed development.

Based on the above, this study aimed to evaluate the impact of floodplain landfilling on basin water quality in a tropical monsoon region. To achieve this objective, we conducted local water quality observations in the Mekong River Basin in Cambodia to evaluate the impact of landfill on floodplain water quality. In addition, we conducted the same local water quality observations in the Chao Phraya River Basin in Thailand, which is also located in a tropical monsoon region, to evaluate how differences in the level of economic development affect water quality in developed areas. Moreover, we investigated the factors affecting water quality.
floodplain water quality, such as surrounding land use or seasonal factors. Finally, the results of the observations at both Mekong River and Chao Phraya River Basins were compared in light of their economic differences.

METHODS

Field observation sites

In the Mekong River Basin in Cambodia, we conducted observations in Kandal Province in the vicinity of Phnom Penh. In the Chao Phraya River Basin in Thailand, observations were conducted near Ayutthaya Province and Don Mueang International Airport in Pathum Thani Province. Compared with the Mekong River Basin, the expansion of industrial and urban areas into the floodplain has occurred at much larger scale in Thailand.

In the Mekong River Basin, while landfilled areas were identified based on satellite images from Landsat-TM and Landsat-OLI composites, observation sites were selected in light of surrounding land uses and the number of years that had passed since the beginning of landfill. To examine the influence of land use, factory areas, luxury resort/residential areas (well maintained), village/living areas (less maintained), sandy areas where landfill is still in progress, agricultural areas, and non-landfilled areas were identified. We estimated the number of years that have passed since the beginning of landfill at each site by comparing Landsat images for the past 30 years (1987–2017). A total of 17 sites were selected: 9 sites (P-1 to P-9) in the vicinity of Phnom Penh and 8 sites (K-1 to K-8) in the areas surrounding Kandal (Figure 1). For the Chao Phraya River Basin, observation sites were also selected using the same procedure as above. Nine sites (D-1 to D-9) around Don Mueang Airport in the basin and 4 sites (A-1 to A-4) from Ayutthaya (Figure 2) for a total of 13 sites were selected.

Field observation period

Observations of water quality in the Mekong River Basin were carried out a total of three times in October 2015, January 2016, and October 2016. Observations were conducted twice in the Chao Phraya River Basin in September 2016 and January 2017. In the tropical monsoon region to which the two countries belong, the rainy season extends from May to October, while the dry season is from November to April. To observe seasonal changes in floodplain water quality, September and October were selected as representative of the rainy season, and January was selected as representative of the dry season.

Water quality measurement method

Samples were analyzed to determine total phosphorus (TP), chemical oxygen demand (COD), and heavy metal content (cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn)). TP was measured using a BLTEC Auto Analyzer II after decomposing the sample using a potassium peroxydisulfate decomposition method. COD was measured using a 100°C potassium permanganate method. Heavy metals were thermally decomposed with nitric acid and measured using inductively coupled plasma-optical emission spectroscopy (ICP-OES). The water samples were taken from surface water to reduce the influence of resuspended bottom sediments. Three 100-ml samples were collected from each site.
RESULTS AND DISCUSSION

Mekong River Basin in Cambodia

Observations from the Mekong River Basin are summarized in Figure 3, 4, and S3-S7. In these figures, black bars indicate dry season values and white bars the rainy season values. Data for periods when observations were not carried out are not shown. In addition, the land use type after landfill and the number of years elapsed since landfill began are noted on the figures. “Factory” represents a factory area, “Luxury” represents a luxury resort/residential area (well maintained), “Village” represents a village/living area (less maintained), “Sandy” is a sandy area that is formed when landfill is in progress, “Agricultural” is an agricultural area, and “Non-landfilled” is a non-landfilled area (natural floodplains). The tables shown in Figures 3, S3, S6, and S7 are surface freshwater quality standards defined by the United Nations Economic Commission for Europe (UNECE standard). These standards represent 5

| UNECE Water quality standard | Total phosphorus (UNECE, 1994) |
|-----------------------------|--------------------------------|
| Class I                     | < 0.01 mg/L                    |
| Class II                    | 0.01 – 0.025 mg/L              |
| Class III                   | 0.025 – 0.05 mg/L              |
| Class IV                    | 0.05 – 0.125 mg/L              |
| Class V                     | > 0.125 mg/L                   |

Figure 3. Total phosphorus in floodplain water in Phnom Penh, Cambodia. The $p$ values are significance levels according to Welch’s t-test comparing the dry and rainy season values

Figure 4. Fe in floodplain water in Phnom Penh, Cambodia. The $p$ values are significance levels according to Welch’s t-test comparing the dry and rainy season values.
levels of water quality based on habitat quality for aquatic life (Class I to Class V) (UNECE, 1994). The black lines in Figures 4 and S4 are the drinking water standard value of 0.3 mg/L determined by the World Health Organization (WHO, 2011). The p-values (p) according to Welch’s t-test for the dry season values and the rainy season values are shown at each site where observations were carried out in both seasons.

Total Phosphorus (TP)

TP concentrations in floodplain water around Phnom Penh are shown in Figure 3 while those for Kandal Province are shown in Figure S3. Regarding TP in floodplain water, many sites were classified as Class V (exceeding 0.125 mg/L) according to the UNECE standard, with a high value evident for the floodplain overall (UNECE, 1994).

As shown in Figure 3, TP was significantly high for sandy area sites P-6 and P-9 (2.05 mg/L and 1.40 mg/L, respectively). Among all observation for Cambodia, TP at site P-6 was the highest. A large-scale dumped waste landfill was confirmed at site P-6. Additionally, water accumulated in the floodplain was siphoned off by drainage hoses (Figure S2). A large amount of phosphorus may flow into the floodplain from this landfill waste, whereupon it is concentrated due to the reduction in the amount of water, leading to increased TP.

High TP was also evident for the village/living areas P-2, P-3 and P-7, potentially due to the influence of domestic wastewater inflow. The average TP value of the village/living area was about 1.61 mg/L higher than the luxury resort/residential areas in the dry season and the p-value according to Welch’s t-test for both land use values was less than 0.01.

TP concentrations were lower in the rainy season than in the dry season at sites P-2 and P-3 (p < 0.01, p < 0.05). Regarding the decrease in TP in the rainy season, it seems likely that TP is diluted by the increase in floodplain water volume due to rainfall. At P-1, however, TP concentration in the dry season was slightly higher than in the rainy season. Further studies are necessary to discuss the seasonal effect on the water quality in light of the characteristics of each area.

Heavy metals (Fe)

Concerning heavy metals, excluding Fe, in floodplain water, the concentration of Cd, Cu, Pb, and Zn from the field observation samples was lower than that of WHO water quality guidelines (WHO, 2011). Thus, only Fe measurements are shown, with Figure 4 showing Phnom Penh and Figure S4 Kandal Province.

As shown in Figure 4, apart from the dry season value at site P-3, all observations exceeded the WHO standard value, indicating high Fe concentrations as a whole. In addition, relatively high Fe concentrations were evident at sandy sites P-6 and P-9. These sites were affected by waste landfill as mentioned above. At sites K-1 and K-4, which are sandy sites unaffected by waste landfill, the average Fe concentration was about 1.85 mg/L lower than that of P-6 and P-9 affected by domestic waste landfill, confirming the magnitude of the influence of waste landfill on the deterioration of water quality with respect to heavy metals. The p-value according to Welch’s t-test for both sandy sites affected and unaffected by waste landfill was less than 0.01. In addition, Fe concentration was significantly higher at P-1 site. In fact, factory construction supported by landfill was occurring at the time of observation time, which was possibly the source of contamination (Figure S5).

Chemical Oxygen Demand (COD)

The observation of COD in the floodplain water around Phnom Penh are shown in Figure 6 and those in Kandal Province are shown in Figure S7. The values at site P-3 and P-6 were judged to be Class V, the worst classification of surface freshwater quality (UNECE, 1994). At these sites, TP and Fe were also high. Overall, COD values became higher at the sites where waste landfill was found or around the village/living area, showing a similar tendency to TP.

Chao Phraya River Basin in Thailand

Observations for the Chao Phraya River Basin are shown in Figure 5, 6, and S8. In the figures, “Chao Phraya River” represents the area where the river water was collected.

Total Phosphorus (TP)

Regarding TP in floodplain water, many sites were classified as Class V (exceeding 0.125 mg/L) according to the UNECE standard, especially in the dry season (Figure 5) (UNECE, 1994). TP was relatively high for dry season measurements at factory sites A-4, D-8 and D-4, with dry season TP particularly high at site A-4 (1.84 mg/L). The floodplain at site A-4 was in a large-scale factory belt. It was surrounded by factories and concentrated influx of factory wastewater was confirmed.

In contrast, TP in the luxury resort/residential areas was relatively low. The average TP value of the luxury resort/residential area is 0.68 mg/L lower in the dry season and 0.29 mg/L lower in the rainy season than factory areas, which is possibly due to water quality preservation measures such as regulations on waste disposal and drainage in the luxury resort/residential areas. The p-values according to Welch’s t-test for both land use values were less than 0.01 both in the dry and rainy seasons. In Thailand, when developing resort or hotel projects at sites considered to affect neighboring environments, application for an Environmental Impact Assessment (EIA) stipulated by the environmental protection laws of the country is often required (Suwanteep et al., 2016; Faircloth et al., 2019). Likewise, approval via EIA is required for residential land construction. Thus, it can be considered that the TP was lowered by implementing environmental conservation measures in the luxury residential/resort areas.

Additionally, among the sites showing a relatively high TP of 0.2 mg/L or greater, the TP in the dry season tended to be higher than in the rainy season at all sites other than site A-2. In particular, at site A-4, the TP in the rainy season was approximately 1/6th that of the dry season (p < 0.01). Regarding such a decrease in TP during the rainy season, TP was possibly diluted by increasing floodplain water volumes due to rainfall, resulting in a lower measured concentration.

Heavy metals (Fe)

Concerning heavy metals, excluding Fe, in floodplain water, the concentration of Cd, Cu, Pb, and Zn from the field observation samples was lower than that of WHO water quality guidelines (WHO, 2011). The measurement results for Fe are shown in Figure 6. The black line in the figure is the drinking water quality standard of 0.3 mg/L.
Overall, as the Fe values at factory sites were relatively high, it was found that the WHO standard value was exceeded at all factory sites and no other land use sites. Thus, it is conceivable that water pollution due to industrial wastewater influences the Fe concentration, as was evident in Cambodia. At the time of the field observations, different types of factories were confirmed at each factory site. For example, a factory assumed to be a chemical factory was confirmed at site A-2, and a factory assumed to be a food factory was confirmed at site A-3. Since there was also a difference in the Fe concentration values at sites A-2 and A-3, a deeper investigation of the relationship between the values would be possible in the future by quantitatively measuring the heavy metal emissions from each type of factory.

It is also interesting that the rainy season values were higher than the dry season values at every site, which does not match the tendency observed in Cambodia, although significant differences were not found at some sites (D-3, D-5, D-8, and A-3). Further studies are necessary to discuss the effect of seasonality.

Chemical Oxygen Demand (COD)

In Figure S8, COD exceeded 10 mg/L at all sites other than the Chao Phraya River water. Sites D-2 and A-3 showed values that were more than twice the COD value for Class V (30 mg/L), the worst in the UNECE standard (UNECE, 1994). At site D-2, there were many residential and living facilities in the surrounding area. In fact, a large amount of blue-green algae was confirmed in the observed floodplain area. Additionally, COD values in the rainy season were lower than dry season values at all sites, apart from D-2 and A-3.
from site A-4, which can be considered a dilution effect.

Comparison of field observation results in both regions

Several sites with TP concentrations exceeding 1.5 mg/L were village/living sites and sites with waste landfill (P-2, P-3, P-6 and P-7) in Cambodia. In contrast, the highest value in Thailand was 0.48 mg/L at a village/living site (A-1) and the TP concentration as a whole was low. At the observation sites in Thailand, the installation of aeration circulation equipment was confirmed at several sites on the floodplain (Figure S8). Such water purification equipment was not confirmed at any site in Cambodia, suggesting a difference in the approach to environmental issues between the two countries. Additionally, in comparison to Cambodia, the amount of dumped waste around the floodplain was very small not only at luxury resort areas but across all survey sites in Thailand. Based on these observations, concern for environmental protection seems to be relatively high, not only at the level of government and private enterprise but also among local residents in Thailand.

Further, Fe concentrations at the factory site in Thailand were all within the range of 0 mg/L to 0.9 mg/L. The Fe concentration in Thailand as a whole was also over one order of magnitude lower in comparison to the 10.79 mg/L observed at the factory site in Cambodia (site K-2). This can likely be attributed to the environmental standards stipulated for industrial parks in Thailand and water quality conservation efforts including EIAs (JBIC, 2012). Furthermore, in the floodplains around factory sites in Thailand there was almost no dumping of waste, and signs promoting environmental consideration were displayed. Differences in awareness of environmental issues was evident between the two countries, which also have different levels of economic development.

These findings suggest that improvement in floodplain water quality may be expected by taking appropriate water quality conservation measures in Cambodia, such as tightened regulation of waste dumping and landfilling or the installation of aeration circulation equipment. Considering the current situation where floodplains play an important role, it is desirable to implement measures without delay.

CONCLUSION

This study aimed to evaluate the impact of floodplain landfilling on basin water quality in a tropical monsoon region. It was clarified that waste landfill and the form of land use after floodplain landfill had a large influence on the surrounding water quality in both basins. This trend was confirmed where environmental standards were greatly exceeded at floodplain sites developed as sandy areas with waste landfill or village/living areas. In addition, the tendency for Fe concentrations to be higher at factory sites was confirmed. Although the decreasing trend in concentration was confirmed in the rainy season when the amount of water increases leading to dilution at some sites, further studies are necessary to clarify the effect of seasonality on water quality in light of each land use characteristic. Meanwhile, Cambodia demonstrated more instances of water quality issues than Thailand. A degree of floodplain water quality management commensurate to the level of economic development was confirmed. These findings bring us forward regarding the impact of landfilling of floodplains on basin water quality and provide valuable data for basin water quality management.

In the future, it will be necessary to investigate TP concentrations in inflow from surrounding areas during the rainy season to understand the balance of TP in the floodplain. Furthermore, a deeper investigation of the difference in concentrations between the dry season and rainy season, by measuring the TP of both the floodplain bottom and soil, should be implemented. In addition, regarding the fluctuation of phosphorus and inflow/outflow, factors of biological origin should also be considered. Such further studies will provide important information in terms of the deterministic factors of water quality in these floodplains.

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SUPPLEMENTS

Figure S1. Discharge of polluted water to the flood plain (October 2016 in Phnom Penh)
Figure S2. Large-scale landfilling of waste with river sand (October 2016 in Phnom Penh)
Figure S3. Total phosphorus in floodplain water in Kandal Province, Cambodia
Figure S4. Fe in floodplain water in Kandal Province, Cambodia
Figure S5. Factory construction at landfilled area (site P-1) in Cambodia
Figure S6. Chemical oxygen demand in floodplain water in Kandal Province, Cambodia
Figure S7. Chemical oxygen demand in floodplain water in Phnom Penh, Cambodia
Figure S8. Chemical oxygen demand value in floodplain water in Phnom Penh
Figure S9. Installation of aeration circulation equipment in Thailand (site D-2)

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