Characterization of water pollution in drainage networks using continuous monitoring data in the Citadel area of Hue City, Vietnam

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ABSTRACT

In the Citadel area of Hue City, drainage systems that include canals and ponds are considerable sources of fecal contaminants to inundated water during the rainy season because canals and ponds receive untreated wastewater. It is important to investigate the characteristics of hydraulics and water pollution in canals and ponds. At the canals and ponds, water sampling was conducted during dry and wet weather periods in order to evaluate fecal contamination and to investigate changes in water pollution caused by runoff inflow. Inundated water was also collected from streets during heavy rainfall. At the canals and ponds, concentrations of Escherichia coli and total coliform exceeded the Vietnamese regulation values for surface water in 23 and 24 out of 27 samples (85 and 89%), respectively. The water samples were categorized based on the characteristics of water pollution using cluster analysis. In the rainy season, continuous monitoring was conducted at the canals and ponds using water depth and electrical conductivity (EC) sensors to investigate the dynamic relationship between water level and water pollution. It is suggested that in the canals, high EC meant water stagnation and low EC signified river water inflow. Therefore, EC might be a good indicator of water flow change in canals.

Key words: cluster analysis, drainage system, EC, fecal indicator, tidal effect, water quality monitoring

INTRODUCTION

In Southeast Asia, the urban population has been growing rapidly in recent years and urbanization will be more accelerated in the near future (UN 2012). In the rainy season, many people are likely to be exposed to inundation. Many studies reveal a higher incidence of waterborne disease in cases of inundation than usual. For example, Oguma et al. (2007) calculated odds ratios by incidences of waterborne disease in an inundation-affected group and a non-inundation-affected group in Ho Chi Minh City, Vietnam. The results showed that inundation caused high incidences of dermatosis and pharyngalgia. Heller et al. (2003) conducted a questionnaire survey, which found that the relative risk of diarrhea was 1.39 (95% confidence interval: 1.09–1.76) in the inundation-affected-group, which meant that inundation caused a higher incidence of diarrhea. Schwartz et al. (2006) investigated the relationship between the occurrence of inundation and the number of patients suffering from waterborne diseases caused by rotavirus and Vibrio cholerae in Dhaka, Bangladesh in 1988, 1998 and 2004. They found the number of patients increased both during and after the inundation.

In cities with combined sewer systems, inundated water is likely to be fecally contaminated. People are exposed to pathogens in these waters and suffer from waterborne disease. Veldhuis et al. (2010) measured concentrations of Escherichia coli, intestinal enterococci, Cryptosporidium, Giardia and Campylobacter in inundated water from the combined sewer system in Utrecht city, The Netherlands. They found that the concentrations of E. coli and intestinal enterococci were 1 to 3 orders of magnitude higher than the standard values for good bathing water quality according to EU Directive 2006/7/EC, while concentrations of Cryptosporidium, Giardia and Campylobacter were of the same order of magnitude as those found in crude wastewater. Quan (2009) measured concentrations of E. coli and total coliform in inundated water in Hanoi, Vietnam. The result showed that the concentrations of E. coli and total coliform
were 3 to 4 and 2 to 3 orders of magnitude higher, respectively, than the Class B2 values (E. coli: 200MPN/100 mL, total coliform: 10000MPN/100 mL) of Vietnamese national technical regulation. (QCVN08:2008/BTNMT) There are 4 classes (A1, A2, B1, B2), and Class B2 is for navigation or other uses with the lowest water quality requirement.

In the Citadel area of Hue City, Vietnam, limited drainage capacity causes severe inundation in the rainy season. Hoang Thi et al. (2011) measured the concentration of E. coli in inundated water, which varied from 1.3 \times 10^4 to 8.1 \times 10^4 CFU/100 mL, and exceeded the Vietnamese regulation values of Class B2 by 1 to 3 orders of magnitude. In the Citadel area, there is a drainage network consisting of a combined sewer system, canals and stormwater ponds. However, canals and ponds are also considerable sources of fecal contaminants because they receive untreated wastewater.

The purpose of this study was to evaluate fecal contamination and to investigate the characteristics of hydraulics and water pollution in canals and ponds. Water sampling was conducted during both dry and wet weather periods to evaluate fecal contamination and to investigate changes in water pollution caused by runoff inflow. Inundated water samples were also collected on streets during a heavy rainfall to evaluate levels of water pollution. Furthermore, in the rainy season, continuous monitoring was also conducted in canals and ponds by water depth and electrical conductivity (EC) sensors to investigate the dynamic relationship between water level and water pollution.

MATERIALS AND METHOD

Characteristics of the drainage system

The Citadel area of Hue City is located in the central part of Vietnam and about 12 km upstream of the Huong River from the sea. Figure 1 shows map of the Citadel area featuring the drainage network. The drainage network consists of more than 40 ponds, canals of around 12 km, and a combined sewer system of 52 km (Lieu et al. 2010). The canal network is connected to the ponds and the inner canal and consists of inner and outer canals, which are connected to each other. The combined sewer system receives 56% of wastewater, which is treated by septic tank; the remaining 44% is discharged directly into the canals and ponds or scattered on soil (Lieu et al. 2010). There is a distinct dry season (from January to August) and a distinct rainy season (from September to December). In a rainy season, inundation occurs several times due to limited drainage capacity. The water level of the Huong River, which is connected to the outer canal, also affects the frequency and severity of inundation. Inundation is more likely to occur when its water level is higher.

Water sampling and continuous monitoring

Water sampling was conducted on February 19–20, August 6–7, September 5 and November 17, 2012. Water sampling locations are shown in Figure 1. The water quality measured were E. coli, total coliform, chemical oxygen demand (COD), NH4-N, NO2-N, NO3-N, suspended solids (SS), PO4-P, pH, turbidity and EC. Water samples were taken at 4 to 6 points from the canals and 4 to 6 ponds in February, August and September, and at 4 points (S1–S4) on the streets during heavy rainfall in November. The sampling locations in ponds were selected according to past inundation records. Conversely, the sampling locations in the canals were selected to assess a longitudinal profile of pollution caused by wastewater inflow from the Citadel area. A 1-liter sample was taken at 0.5–1.0 m depth in canals and ponds and brought back to the laboratory of Hue University. E. coli and total coliform were incubated using an HACCP incubator (J. P. Clarus, Japan) for the February samples and a Memmert UM 500 incubator (Memmert, Germany) for the August, September and November samples, m-ColiBlue24 broth (HACH, USA) and a 37 mm monitor with a 0.45-μm filter medium (ADVANTEC, Japan) and their colonies were counted after 24 h incubation. NH4-N was determined based on the indophenol reaction with o-phenylenediamine (OPP). NO2-N, NO3-N, PO4-P, COD and SS were analyzed using the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, and WEF 1999). Turbidity was measured using H-6726 (HANNA). The pH and EC were measured using NPH 6900 (Nissin, Japan) and sensION (HACH, USA), respectively. However, in February, portable sensors (Twin pH and Twin Cond, HORIBA, Japan) were used for pH and EC measurement, respectively.

Continuous monitoring was conducted at 6 points of the canals and in 7 ponds using water depth and EC sensors during the rainy season in 2012; monitoring locations are shown in Figure 1. Since EC estimates the amount of total dissolved salts that are higher in wastewater than environment water (US EPA), EC values were taken as an indicator to detect the inflow of wastewater to canals and ponds. Knappett et al. (2011) measured E. coli, Bacteroides and EC at 43 ponds in Char Para Village, Bangladesh. They found positive correlations between E. coli, Bacteroides and EC. Accordingly, EC might also be useful as a...
representative of fecal contamination. The Citadel area is about 12 km from the sea. However, the EC of the Huong River was much lower than that of the sea water (35 μS/cm to 72 μS/cm (n = 24, average: 49 μS/cm) in 2010 and 2011 (HueWACO), which means that sea water does not intrude into the river water around the Citadel area.

RESULTS AND DISCUSSION

Characteristics of water pollution

Figure 2 shows ranges of concentration and the value of measured water quality parameters. Vietnamese regulation values were set for E. coli, total coliform, COD, NH₄-N, NO₃-N, SS, PO₄-P and pH. Concentrations of NO₃-N and pH met the regulation values (QCVN08:2008/BTNMT, Class B2: for navigation or other uses with low water quality requirement) at all the points measured. However, concentrations of E. coli, total coliform and COD exceeded the regulation values at most points. In canals and ponds, concentrations of E. coli and total coliform exceeded the regulation values in 23 and 24 out of 27 samples (85 and 89%), respectively. With regard to wet weather samples, E. coli and total coliform concentrations of 5 and 8 out of 8 samples, respectively, were higher than the regulation values. This indicates that most of the canals and ponds are fecally contaminated. Furthermore, the concentration of COD exceeded the regulation value at canals and ponds in 9 out of 18 samples (50%), whereas, concentrations of NH₄-N, PO₄-P, SS were higher than the regulation values in only 1 or 2 samples.

In inundated water samples, the concentration of E. coli exceeded the standard in 2 out of 4 samples. The inundated water was also fecally contaminated, although it was diluted by rain water. Contaminants derived from septic tanks and/or polluted canals and ponds were suspected as the source of fecal contamination in inundated water.
To understand the differences in water pollution characteristics among the sampling points, cluster analysis was applied to all the samples (except for those taken in February because COD, SS and turbidity were not measured in the February samples). Six parameters for total coliform, COD, NH$_4$-N, SS, pH and EC were selected for cluster analysis. E. coli and turbidity were excluded due to high correlations between total coliform and SS, respectively. NO$_2$-N, NO$_3$-N and PO$_4$-P were not detected at many sampling locations, so data availability was limited. Total coliform concentrations were converted to logarithmic form and the normalized Z-score for each parameter was calculated for cluster analysis.

Figure 3 shows a dendrogram of categorization of all the samples. All samples ($n = 22$) were divided into three groups. Figure 3 also shows average, minimum and maximum total coliform, COD, NH$_4$-N, SS, pH and EC values in each group. Group 3 ($n = 4$) was characterized as the highly polluted group. Concentrations of total coliform exceeded the regulation value in all the samples in Group 3. Average concentrations of NH$_4$-N, COD and EC in Group 3 were also higher than those of the other groups. P3, P7 and C2 might be more affected by wastewater inflow than other points.

Conversely, Group 1 ($n = 12$) and 2 ($n = 6$) were recognized as moderately polluted groups. However, in Group 2, the average concentration of COD exceeded the regulation...
value and the average concentration of SS was the highest of all the groups. The concentration of SS in the S₂ sample was 182 mg/L, which might separate S₂ from Group 1 that included other inundated water samples (S₁, S₃ and S₄). P₃ and P₄ are connected to each other by channels, and runoff water inflow might push the polluted P₃ water to P₄ in wet weather, so that they might be included in the same subgroup. C₁ and C₅ are end points of the inner canal. River water inflow from the outer canal during wet weather might affect both points. In addition to wastewater inflow, but connections between canals and ponds might also be an important factor for water pollution characteristics in the Citadel area.

**Cyclic change of water level and quality**

Continuous monitored data were investigated to understand the influence of connections between canals and ponds on characteristics of hydraulics and water pollution. Figure 4 shows the water level change from 6:30 am on September 17 2012 and the EC change in the inner canal during dry weather. There was a 12 h cycle change of water level at all inner canal points as well as at the outer canal points (B₁–B₃). The same cyclic change was also observed at P₄, which is connected to the inner canal. The cyclic change was caused by water level change in the Huong River, which is affected by the tidal effect. EC fluctuated inversely against the water level and varied from about 200 μS/cm to 400 μS/cm and about 100 μS/cm to 300 μS/cm at C₁ and C₅, respectively. Conversely, EC was stable and high at about 400 μS/cm to 450 μS/cm at C₂. While the inner canal water around C₂ might be stagnant and less diluted by the river water, C₁ and C₅ might be affected by river water inflow from the outer canals during high tides.

**Dynamic fluctuation of water level and quality**

Figure 5 shows water level fluctuation from 12:00 pm on October 6 2012, and EC fluctuation during wet weather.
From October 6 to 7, there was heavy rainfall with a depth of 110 mm around the Citadel area (Thua Thien Hue Province’s Steering Board of Flooding and Storm Control Search and Rescue 2012). At C1 and C2, EC decreased with rising water levels. The canal water was diluted by the increased river water inflow and runoff inflow from the Citadel area. However, there was an interesting fluctuation found at C3, where EC varied from about 200 \( \mu \)S/cm to 450 \( \mu \)S/cm before the water level reached its peak. At C3, the canal water quality might be dynamically affected by
both the polluted inner canal water and the outer canal water that originated from the Huong River. River water that inflow should be important for purification of the inner canal through its dilution effect. An intake of more river water (dredging, widening canal width) with water quality management by EC continuous monitoring might be one option to lessen water pollution in the inner canal.

CONCLUSIONS

The water quality analysis during dry and wet weather periods showed severe fecal contamination in the Citadel area of Hue City and the pollution characteristics in the drainage network. The continuous monitoring of water depth and EC showed several interesting dynamic relationships between water level and water pollution at different points of the inner canals.

(1) Most of the canals and ponds are fecally contaminated during both dry and wet weather periods. In the canal and pond samples, 23 and 24 out of 27 samples (85 and 89%) exceeded the Class B2 values of Vietnamese regulation (QCVN 08:2008 BTNMT) for E. coli and total coliform.

(2) The whole samples were categorized using cluster analysis. The highly polluted samples were included in a different group from other samples. These measurement points might be more affected by wastewater inflow than the other points. The other groups were recognized as moderately polluted groups. In Group 1, runoff water and river water inflow might affect subgroups due to connections between canals and ponds. In addition to wastewater inflow, connections might also be an important factor for water pollution characteristics.

(3) There was a 12 h cycle change of water level at all the canal points and the pond that is connected to the inner canal. The cyclic change was caused by water level changes in the Huong River, which is affected by the tidal effect. EC changed inversely against water level at the connection points of the inner canal, while a stable, high EC was observed at the middle point of the inner canal during dry weather. At the middle point of the inner canal, the canal water might be stagnant and less diluted by river water. However, during heavy rainfall, EC showed dynamic fluctuation in the inner canal due to dilution by increased river water inflow and runoff inflow from the Citadel area. Therefore, it suggests that EC is a good indicator of water pollution that is caused by water dilution and stagnation.

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