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Fecal contamination in Yongin watershed: association to land use and land cover and stormwater quality

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ABSTRACT

Fecal contaminants in stormwater runoff have a potential threat to impairment and degradation of water and have a negative impact on public health. Stormwater runoff is increasing in amount and rate of discharge due to loss of vegetated landscape and increasing urbanization. The aim of this study was to investigate the association of fecal contaminants on four monitoring sites and on stormwater quality in Yongin watershed, South Korea. The four experimental catchment sites comprising of construction areas, mixed land use, agricultural, and urban. It was observed that mixed catchment and urban area have higher fecal contaminants among other land use and land cover. The results indicate that an increase in human activities in a particular area may indicate a high contribution in the increased fecal levels, however, it does not necessarily mean that majority of human-related activities may bring the increase of human source of fecal contamination. Overall, the obtained most probable number values for all fecal tests suggested that the water samples are not fit for either safe drinking, washing, or bathing as they may cause some serious illnesses to human.

Keywords: Fecal contaminants; Land use and land cover; Stormwater; Watershed

1. Introduction

Stormwater runoff, one of the most common forms of non-point source (NPS) pollution, has been identified as a potential threat to impairment and degradation of water quality due to high levels of chemical and biological contaminants [1]. During precipitation, stormwater runoff picks up natural and human-made contaminants that are accumulated on the surface during dry days and transports it to receiving water bodies. The forms and concentrations of contaminants from stormwater runoff are closely related to various types of land use and land cover (LULC) such as agriculture, commercial, construction sites, and forest use [2]. For instance, urban, agricultural, and forestry stormwater runoff have been shown to contain large quantities of fecal microbes contributing to surface

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water quality impairments [3–5]. Microbes are affected by numerous physical, chemical, and biological factors. Moisture, temperature, sunlight exposure, nutrient availability, adsorption/desorption processes, hydrologic processes, and predation are factors that influence the microbial fate and transport [6]. The watershed characteristics including topography and geology can influence the stormwater quality [7]. Also, the alteration of LULC, associated with anthropogenic activities and natural factors [8], may one or more affect the stormwater quality parameters. For instance, the conversion of agricultural, forest, commercial, and road use into bare lands due to construction activities may affect the stormwater quality, runoff volume, and flow characteristics [9]. The construction activities make difficult to manage but their impacts on water quality are transient and can be mitigate through implementing good planning and best management practices [10]. Therefore, the importance of association to LULC change and water quality contaminants specifically the fecal contamination need deeper understanding due to the increasing recognition over the past two decades that NPS pollution has come into being the major environmental concern. Few studies have addressed the effects and management of water pollution resulting from rainfall and runoff in East Asia, including Korea. Nutrients have been focusing on their relationships with stormwater runoff [7,11,12]. However, monitoring and controlling the NPS pollution presents great challenges [13] because of their dispersed origins and the fact that they vary with the season and the weather, in addition to the fact that non-point inputs are often overlooked by human beings [14]. At the same time, there is increasing availability of geographic information system (GIS) and statistical analysis allowed the researchers to investigate the association of LULC, stormwater quality on fecal contaminants. In recent years, when Korea has initiated her economic reform and open-door policy, rapid urbanization and economic expansion has resulted in massive land alteration. However, people only focus on the economic growth, and always neglect this factor that economy grows at the expense of the environmental destruction. In this study, therefore, we used four different monitoring sites with varied LULC in Yongin watershed, South Korea to: (1) evaluate the concentration of stormwater fecal contaminants; (2) develop an understanding of the variability of fecal count in surface water during storm event (initial, peak, and final sampling); (3) determine the influence of LULC, hydrological characteristics, discharge, chemical oxygen demand (COD), and nutrients on the fecal count; and (4) obtain baseline data for stormwater management and microbial modeling.

2. Materials and Methods

2.1. Site description

Data were collected in Yongin watershed, Gyeonggi, Republic of Korea (Fig. 1). Yongin watershed directly drains in Geumhak stream; one of the tributary of Paldang reservoir (source of drinking water for 23 million residents in Seoul and Gyeonggi Province). Also, it drains in a different LULC with variable population densities. Four different monitoring areas in the watershed were monitored. The monitoring areas are the following: construction area (Site 1), mixed catchment (Site 2), agriculture (Site 3), and urban (Site 4) (Fig. 2). Monitoring sites varied in area, LULC, and imperviousness allowing an analysis of fecal contaminants. The characteristics of the monitoring sites are presented in Table 1.

2.2. Water sampling and insitu measurement

From June to December 2012, stormwater samples were gathered from a total of seven storm events. Rainfall data and runoff flow were measured during all the time of sampling. Two sites (Site 1 and Site 3), flow rate were measured using the current meter velocity and flow area channel, whereas other sites (Site 2 and Site 4), automatic flow meter was installed and discharged were calculated based on velocity, depth of water, and width of the channel. The amount of rainfall during each runoff event was measured with a rain gauge (HB 3207-09) in an open area of monitoring sites. Grab sampling ($n = 10–20$ samples in each site) was done at 15–20 min intervals when the flow is rising and then at 30–60 min intervals for receding. Field measurements included pH and conductivity, measured with a U-50 Multi-Probe. Once sampling was completed for a runoff event, samples were transported to the laboratory and analyzed within 6–8 h of collection. COD, total nitrogen (TN), and total phosphorus (TP) were measured according to the standard methods [15,16].

2.3. LULC analysis

GIS applications and Korean Land Cover 2010 data-set were used to develop the LULC alteration maps in monitoring sites. Monthly field visit, maps, and documentation from local administration were used to update and validate the LULC mapping criteria. The LULC categories according to Korean unit load classification include: (1) agriculture, including paddy field and dry land; (2) bare land, including gravels, bare ground, and bare rocks; (3) commercial;

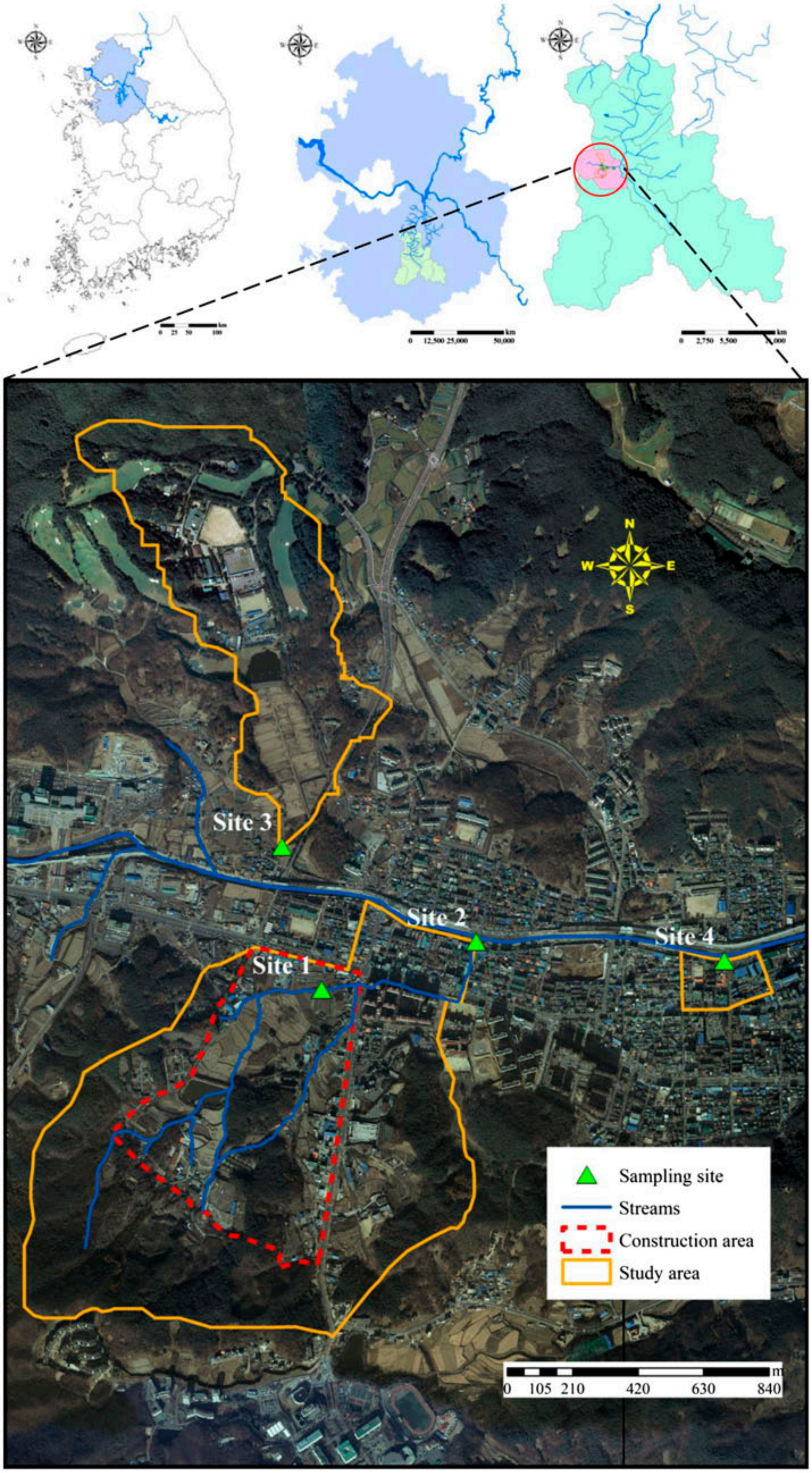

Fig. 1. Study area and locations of monitoring stations.

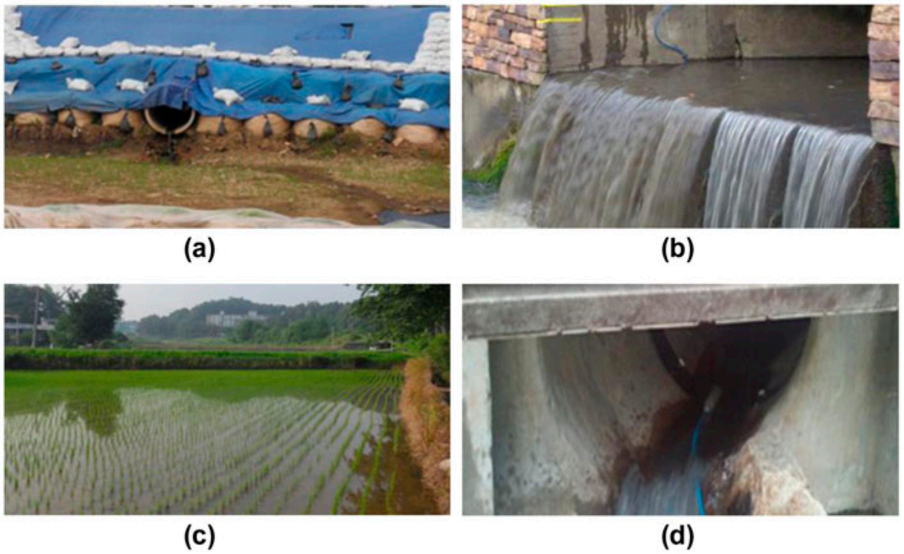

Fig. 2. Monitoring site: (a) construction; (b) mixed catchment; (c) agriculture; and (d) urban area.

Table 1
General characteristics of monitoring sites

Site	Monitoring area	Land use/land cover	Area (km^2)	Imperviousness (%)	Possible source of pollution
1	Construction site	Agriculture, bare land, commercial, forest, and residential	0.469	4.6	Soil, domesticated and wildlife, birds leakage from sewer and septic systems (due to land conversion), and human
2	Mixed catchment	Agriculture, bare land, commercial, forest, parking lot, residential, and road	1.399	18.71	Soil, domesticated and wildlife, birds leakage from sewer and septic systems, and human
3	Agriculture	Paddy field and residential	0.576	13.01	Wildlife, birds, soil, and humans
4	Urban	Commercial, parking lot, residential, and road	0.052	96.69	Soil, leakage from sewer and septic systems, and human

(4) forest, deciduous forest, mixed coniferous, and broad-leaved forest; (5) grassland; (6) parking lot; (7) residential; (8) road; and (9) water.

2.4. Analyses of fecal contaminants

Measurement of fecal indicator bacteria (FIB): Fecal coliform (FC, ES 04701.2) and fecal streptococcus (FS, ES 05706.1a) were determined using the National Institute of Environmental Research at Incheon, Korea, which modified from the original version of the American standard methods for the examination of water and wastewater [15,16]. To characterize the intra-event variability of FIB in Yongin watershed, the following variables were obtained for each event at each site: the event initial concentration, two event peak concentrations, and the final sample. The initial pollutant concentration was represented by the first stormwater runoff, in which generally the samples were taken between 5 and 120 min depending on the site; event peak of FIB and water quality were found, and the ratio between the pollutant maximum and the flow rate maximum was used to determine whether the pollutant peak occurred or after the flow peak for each event and; the final sample is the sample taken at the end of storm event.

2.5. Statistical analysis

SPSS version 12 was used for all statistical analyses. The confidence interval was set at 95% or α of 0.05. Fecal concentration, rainfall, discharge, and other stormwater characteristics were log transformed prior to statistical analysis.

3. Results and discussion

3.1. Rainfall and runoff events characteristics

Fig. 3(a)–(d) shows the characteristics of rainfall and runoff during each of the monitored events. It was observed, antecedent dry days (ADD), average rainfall intensity, rainfall depth, and runoff length ranged from 3 to 31 d, 2.24 to 5.69 mm/h, 28.5 to 74 mm, and 280 to 855 min at Site 1; 3 to 31 d, 0.940 to 5.69 mm/h, 7.5 to 74 mm, and 400 to 960 min at Site 2; 3 to 31 d, 2.24 to 5.69 mm/h, 28.5 to 74.0 mm, and 145 to 585 min at Site 3; and 3 to 31 d, 2.24 to 5.69 mm/h, 11 to 74 mm, and 180 to 1440 min at Site 4, respectively. ADD condition is determined as the number of days following the ending of measurable rain. Rainfall intensity is a measure of the amount of rain that falls over time [10].

3.2. Land use and land cover

Forest land was the dominant land cover type in the watershed and it covered from 0.03 km^2 (Site 1) to

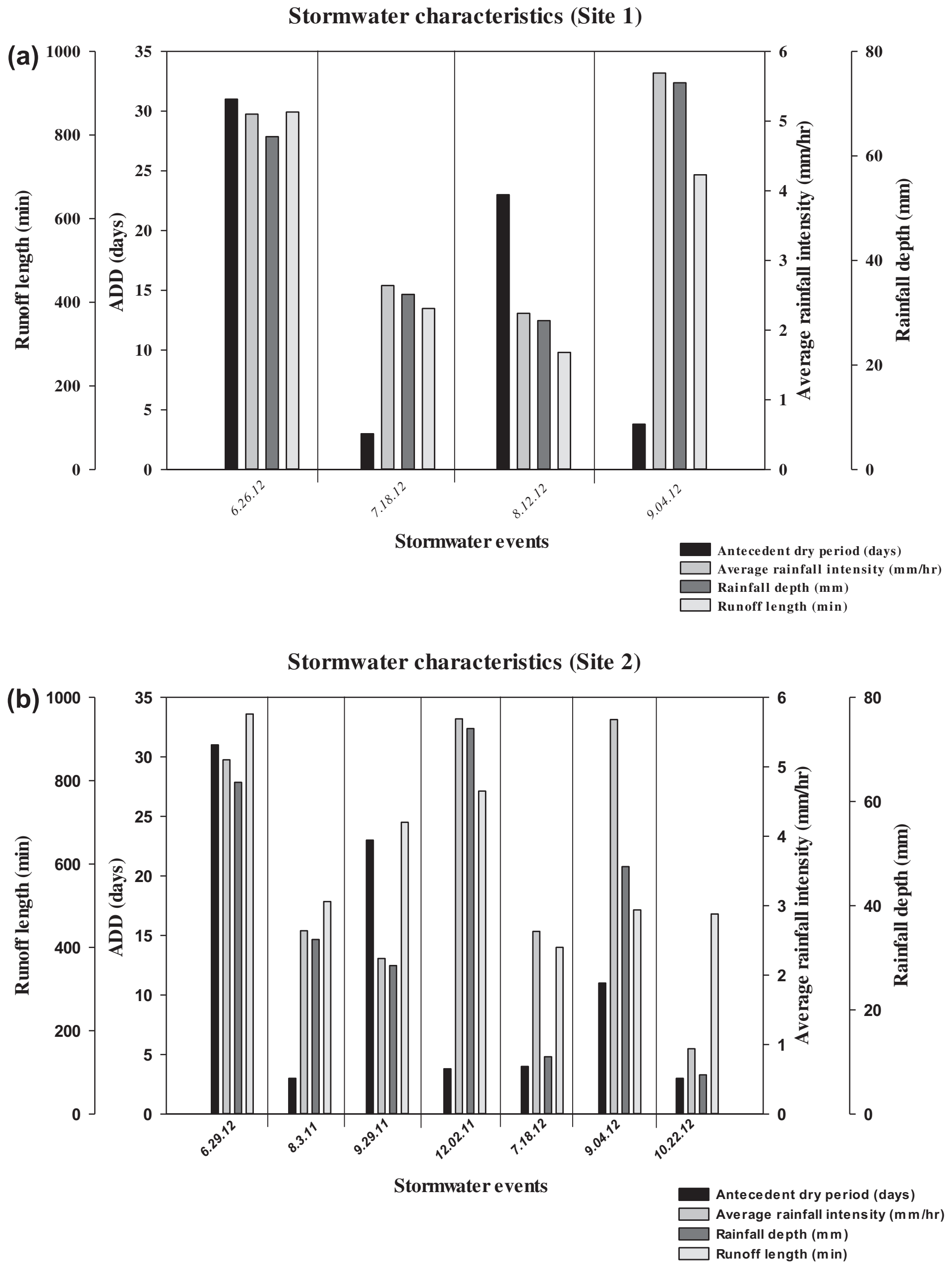

Fig. 3. Rainfall-runoff characteristics.

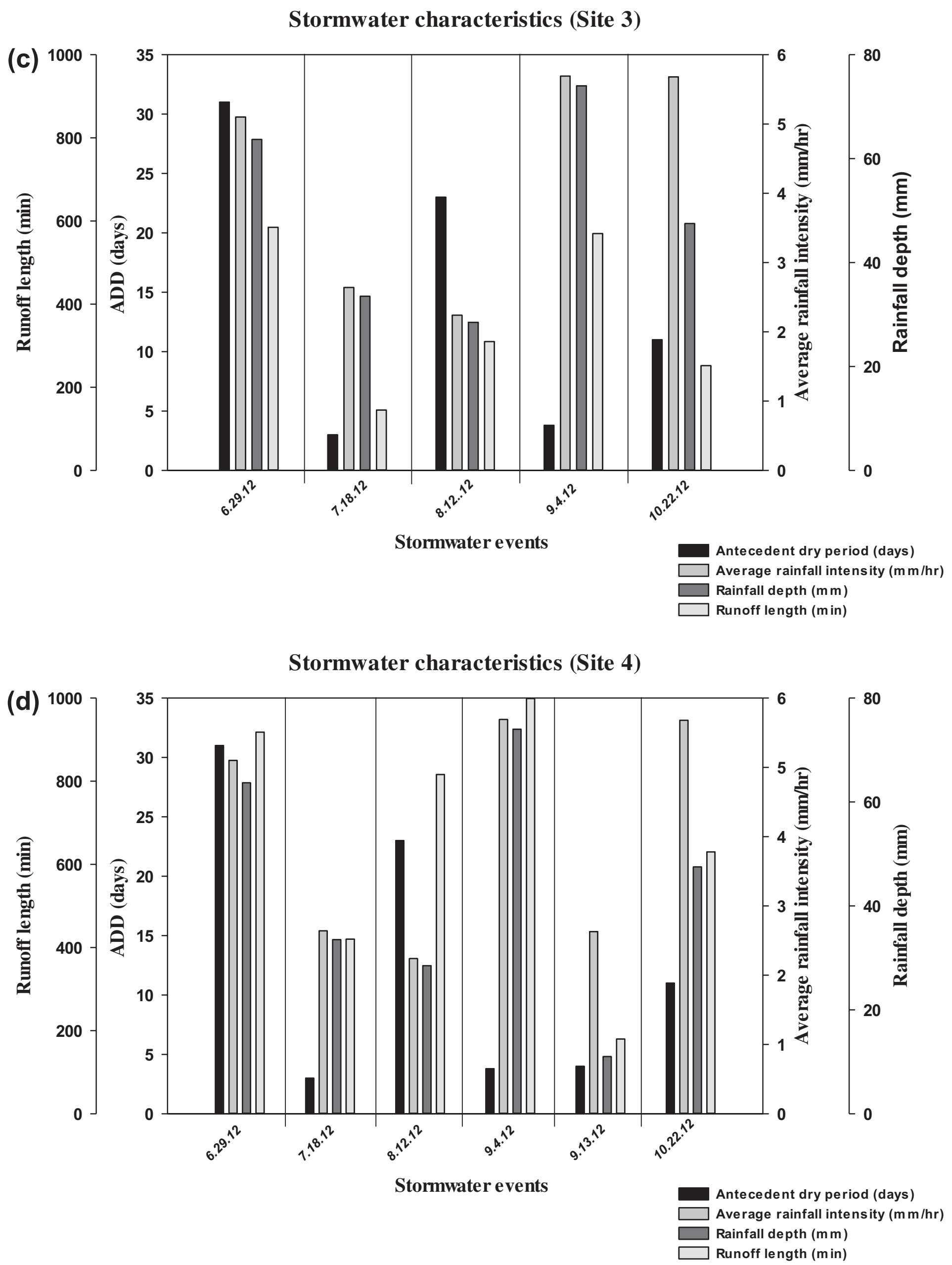

Fig. 3. (*Continued*).

0.51 km^2 (Site 2) of its respective land area (Fig. 4). Although agricultural land cover type is widely distributed across the watershed, it is mainly concentrated in Site 3, comprising 0.07 km^2 of its land area. Commercial (0.015 km^2), parking lot (0.015 km^2), and road (0.012 km^2) were the major LULC in Site 4. Bare land had higher area in Site 1 and Site 2 with 0.40 and 0.45 km^2, respectively.

In terms of LULC change, Site 1 and Site 2 had rapid change over the study period (Fig. 5). Whereas Site 3 and in Site 4 had no change in their spatial extents. The LULC change detection reveals that one LULC increased over the study period while seven had reduction in their spatial extents (Table 2). Barren land increased exponentially between 2010 and 2012 in Site 1 (2932.71%) and in Site 2 (582.80%). Agricultural land decreased by 99.99% (Site 1) and 78.95%, while residential land use decrease by 100% (Site 1) and 22.54% (Site 2). Developed/open space which encompasses commercial, parking, and road also increased over the study period.

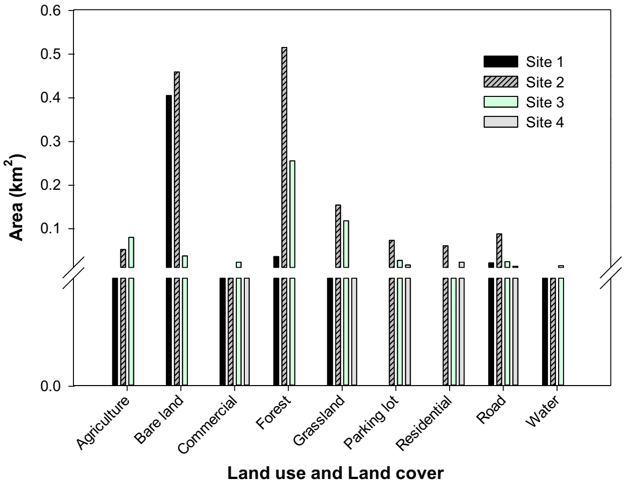

Fig. 4. The LULC compositions in the study area.

3.3. Monitoring fecal levels

3.3.1. Construction area

Based on Fig. 6 the highest FC and FS were recorded on 4 September approximately 400 and 650×10^3 MPN/100 mL, respectively. While almost negligible concentration was accounted for the other months.

The FC/FS ratios were also determined (Fig. 7(a)) in order to compare the dominant source of fecal contaminant. Although the FC/FS parameter was still been questioned because of the variable rates of survival of FS group upon exposure to aquatic environment or disinfected wastewater, the stormwater is a type of untreated water which is not impounded for longer periods of time because of the constant runoff especially during rainy season. As shown in Fig. 6(a), the increased fecal level on 29 June demonstrated that the fecal contamination was directly associated to human, while the succeeding months showed that both human and non-human contaminations coexisted.

The increased fecal level on June and September indicated that either the discharge ($p = 0.001189$) or rainfall data ($p = 0.007125$) (Fig. 7(b)) were directly related based on ANOVA results ($\alpha = 0.05$). The highest discharge recorded was at 200 L/s with rainfall of 74 mm on 4 September.

COD, TN, and TP data were also compared to the FC and FS concentrations of all the samples collected on this site. Fig. 8 shows that 12 August and 4 September were the highest recorded concentrations for the COD, TN, and TP. To assess the relation of these selected characterizations, ANOVA and paired *t*-Test were conducted. Accordingly from the ANOVA result, the COD, TN, and TP compared to the FC and FS levels were related to each other. This meant that these characteristics imply direct relationship of the level of the fecal contaminant of the stormwater. Analysis using paired *t*-Test also gave parameter values below the set confidence interval level. Thus, the following characterization can express an estimation of the fecal concentration on the stormwater sample if further investigation is to be carried out.

3.3.2. Mixed catchment

Site 2 is the combination of both construction and urban areas. In this site, the highest concentration of FC and FS were found in the months of August and September (Fig. 9). FC value went as high as 2.5×10^6 MPN/100 mL (Fig. 9(a)) while FS almost reached 1.2×10^6 MPN/100 mL (Fig. 9(b)). Although, comparable at the highest fecal concentration, the distribution pattern of fecal levels among the sampling periods were relatively higher than Site 1. The high fecal concentration could be due to the stormwater mixing from urban and developing areas. The urban stormwater has been perceived to have high concentrations of both fecal and chemical contaminants because of higher human activities around that area.

The FC/FS ratio was a mixed human and non-human fecal contamination (Fig. 10(a)), but the human fecal contamination demonstrated higher types of contamination around Site 2. On 29 June, human contamination dominated because the FC/FS value was more than 300. This indicated that during this event period, human source of fecal contamination may greatly exist. As can be seen further, Fig. 9(a) shows that a high concentration of FC was observed on 29 July compared to FS (Fig. 9(b)) which had a higher FC/FS ratio. In connection to the discharge and rainfall data (Fig. 10(b)), the discharge had shown to be not totally related to the most probable number (MPN) value of FC and FS ($p = 0.089$) while the rainfall data were directly related to the fecal MPN value ($p = 0.002$). Thus, discharge data may or cannot be a good indicator of the increase or decrease of fecal concentration of stormwater on Site 2 during the sampling events.

In comparison to the highest COD, TN, and TP values of Site 2 (Fig. 11) on different sampling events, it was found that these parameters were directly proportional to the same mid/peak fecal concentration of FC and FS. The *p*-values of COD, TN, and TP compared to FC and FS were in the range of 10^{-2}–10^{-5}, respectively. Thus, it could infer that the additional characterization may provide significant information on the fecal level of Site 2.

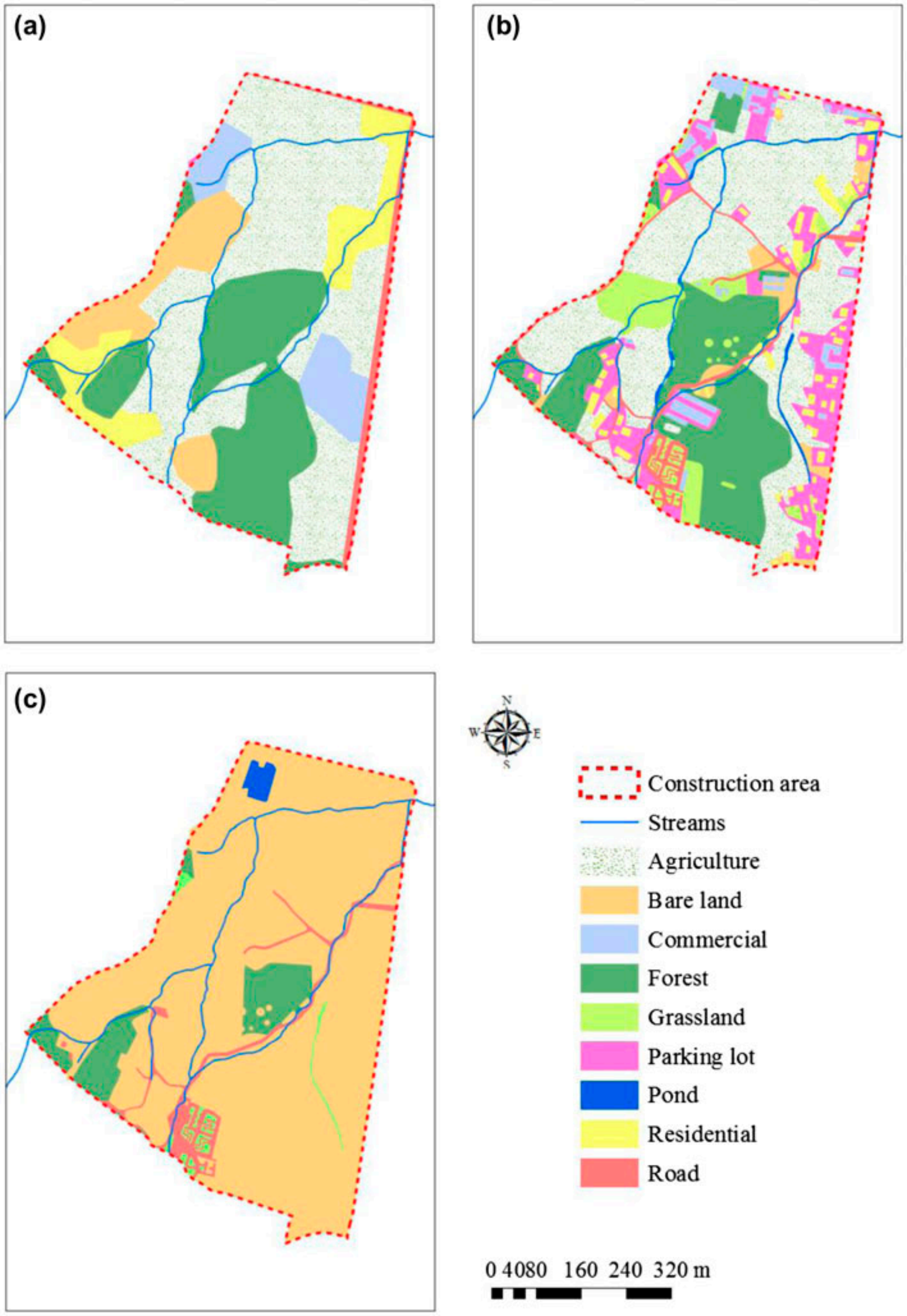

Fig. 5. LULC patterns in the study area: (a) 2010, (b) July 2012, and (c) December 2012.

3.3.3. Agricultural area

As observed in this site, a low MPN value of FC and FS were obtained (Fig. 12). Fecal levels of the previous sites may increase as high as 10^6 MPN/100 mL, however, this site just went down at 10^3 MPN/100 mL. In particular, the highest MPN values of FC and FS were at approximately 250×10^3 MPN/100 mL (Fig. 12(a)) and 110×10^3 MPN/100 mL (Fig. 12(b)), respectively. This was about 10 times lower FC and two to seven times lower FS compared to Sites 1 and 2. The highest fecal counts were observed to be on August and September.

Site 3 FC/FS ratio may not be dominated by human fecal contamination because of the diversity of the observed ratio (Fig.13(a)). June and August may indicate the domination of human fecal contamination;

Table 2
Percentage of land use/land cover change

	Site 1			Site 1		
Land use	2010 (km^2)	2012 (km^2)	Change (%)	2010 (km^2)	2012 (km^2)	Change (%)
Agriculture	0.1905	1.61×10^{-6}	−99.9915	0.2414	0.0508	−78.9357
Bare land	0.0133	0.4035	*2932.7180*	0.0670	0.4575	*582.801*
Commercial	0.0142	0.0014	−90.4064	0.0177	0.0025	−85.6655
Forest	0.1063	0.0347	−67.3680	0.5854	0.5137	−12.2390
Grassland	0.0358	0.0060	−83.1793	0.1826	0.1529	−16.2972
Parking lot	0.0649	0.0000	−100.0000	0.1370	0.0718	−47.5676
Residential	0.0196	0.0000	−100.0000	0.0765	0.0592	−22.5414
Road	0.0208	0.0203	−2.4029	0.0871	0.0866	−0.5735

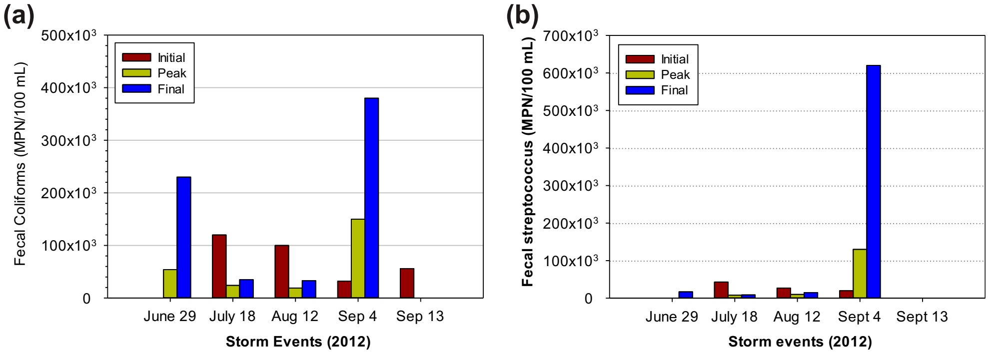

Fig. 6. (a) Fecal coliforms and (b) fecal streptococcus concentrations in the construction area.

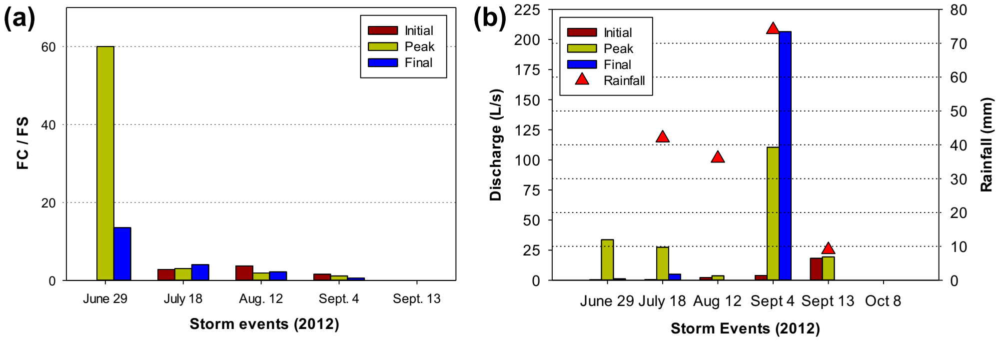

Fig. 7. (a) FC/FS ratio and (b) water discharge, and rainfall data in the construction area.

however, other sampling events indicated that both types of sources of fecal contamination co-existed. To confirm if discharge and rainfall data (Fig. 13(b)) were related to the FC and FS MPN value, a statistical analysis was conducted. Based on the ANOVA of the discharge vs. fecal levels (FC and FS), the p-value was 0.0969, which was higher than the set α of 0.05. This suggests that the discharge was not an indicative of direct fecal levels on Site 3. However, the rainfall statistical data had shown relevance of fecal levels because of the p-value lower than 0.05 ($p = 0.0288$). Likewise, rainfall data were more direct in comparison to fecal data than the discharge data as were also observed on Site 2.

To compare the relationship of fecal concentration to the selected stormwater characterization using both the peak value of these parameters, ANOVA and paired t-Test were also conducted. As observed from

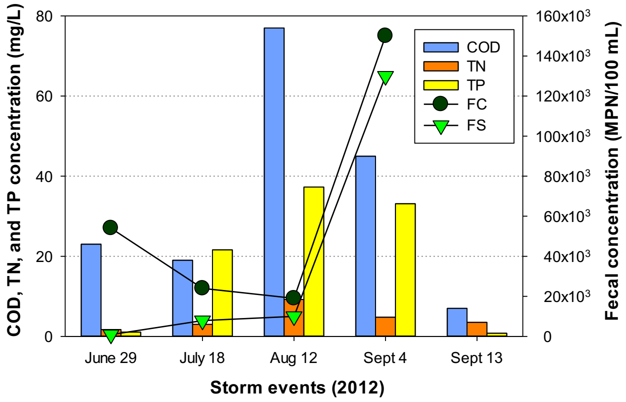

Fig. 8. COD, TN, and TP vs. fecal data during the peak/mid-sampling periods of construction area.

the calculation, the COD, TN, and TP values were also related to the fecal levels during the peak sampling events of Site 3. *p*-Values obtained were lower than the set *α* value of 0.05 in both one-way ANOVA and paired *t*-Test. As shown in Fig. 14, the concentration of COD, TN, and TP were almost to the increase or decrease in value of fecal levels in Fig. 11.

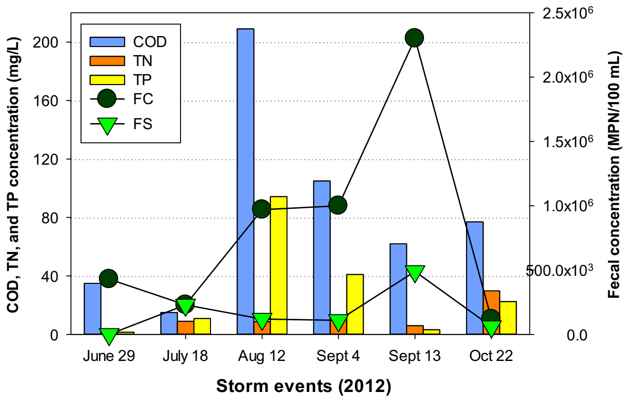

Fig. 11. COD, TN, and TP vs. fecal data during the peak/mid-sampling periods of mixed catchment.

3.3.4. Urban area

Urban area located nearby the vicinity of market place. This site was known to be having the highest concentration of both fecal and chemical contaminants because of the dense human activity and population in this area. Obviously, the highest FC and FS concentrations of Site 7 (Fig. 15) were about 7 times and 17

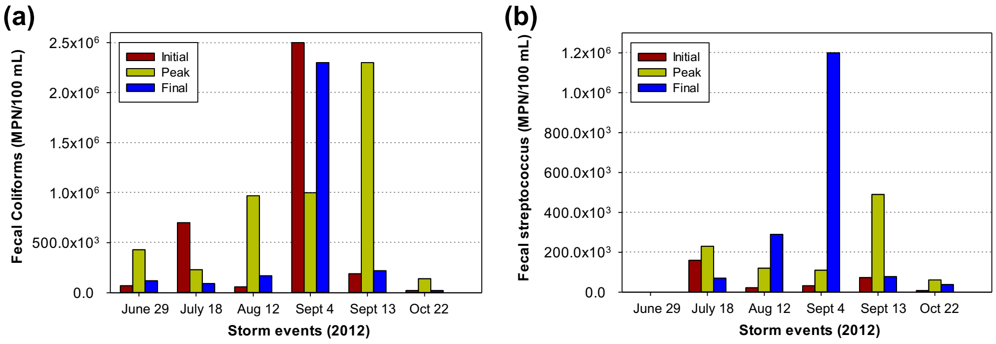

Fig. 9. (a) Fecal coliforms and (b) fecal streptococcus concentration in mixed catchment.

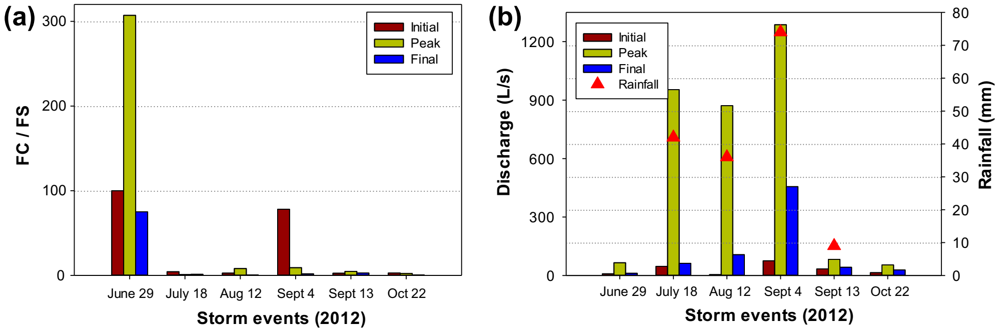

Fig. 10. (a) FC/FS ratio and (b) water discharge, and rainfall data in mixed catchment.

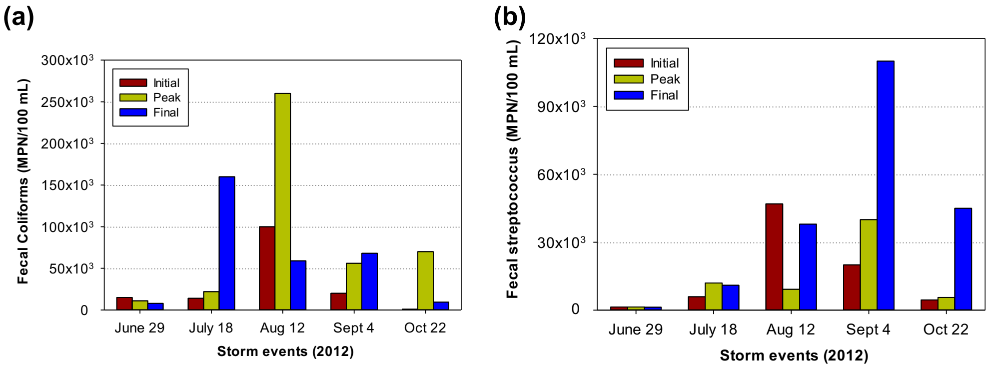

Fig. 12. (a) Fecal coliforms and (b) fecal streptococcus concentration in agriculture area.

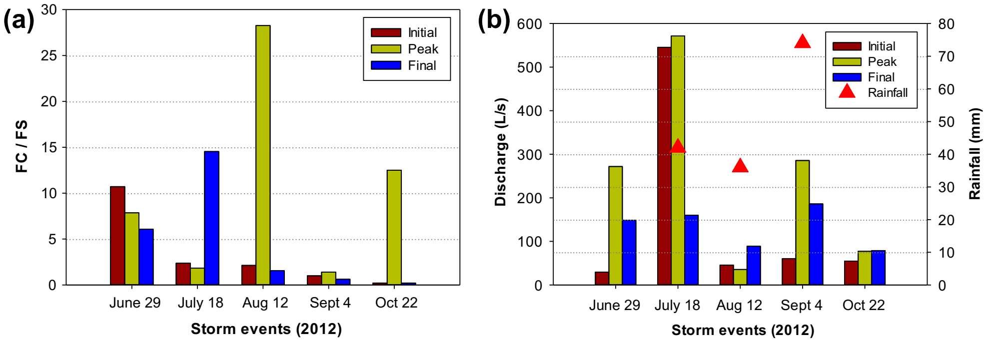

Fig. 13. (a) FC/FS ratio and (b) water discharge, and rainfall data of agriculture area.

times higher than Site 1, respectively (Fig. 6). FS concentration reached as high as 24 × 10^6 MPN/100 mL (Fig. 15(a)) while the FS concentration was about half of this value (Fig. 15(b)). The high concentration was also directly proportional to the discharge and rainfall values (Fig. 16). And by the ANOVA analysis, these parameters were significantly related to the fecal levels of Site 4. The high FC value was observed on 4 September while the highest FS was observed on 22 October. The high FS concentration on 22 October might be attributed to the lower rainfall or discharge value which was usually perceived when high FS levels were accounted. Although, a high FS value was obtained on 22 October, other sampling events did not transform the FC/FS ratio. In this site, it could be observed that most of the contaminants directly involved human type of fecal contamination (Fig. 16(a)).

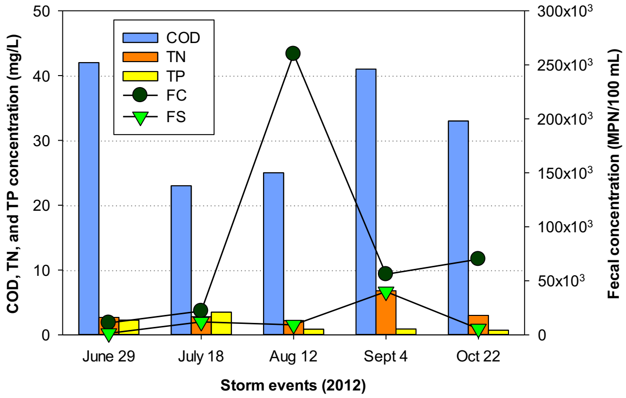

Fig. 14. COD, TN, and TP vs. fecal data during the peak/mid-sampling periods of agriculture area.

Although fecal levels were highly increased, the concentrations of COD, TN, and TP at peak sampling events were almost similar to Site 2 range of values (Fig. 9). Thus, this was subjected to statistical analysis, to determine if these parameters were directly related to the fecal levels of Site 4 stormwater samples. As presented from the ANOVA and paired *t*-Test, the following chemical characterization was significantly related to the fecal concentrations of Site 4 because of the *p*-value of 10^{-4}–10^{-7} in both statistical analyses. The values of COD, TN, and TP, therefore can be used to estimate the concentration of FC and FS in the stormwater samples (Fig. 17).

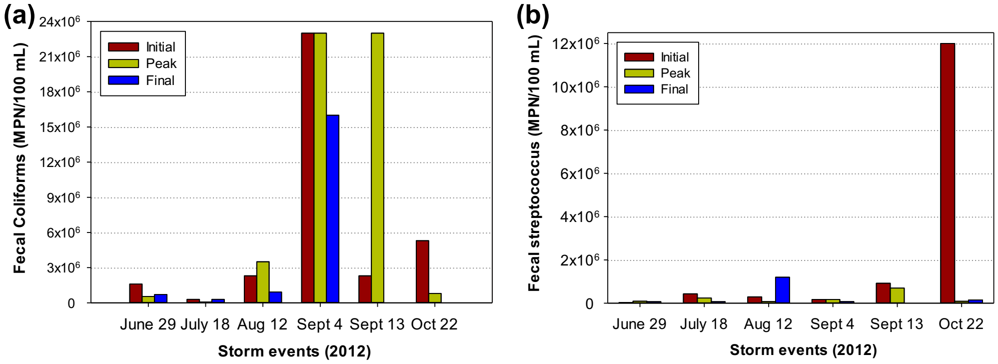

Fig. 15. (a) Fecal coliforms and (b) fecal streptococcus data of urban area.

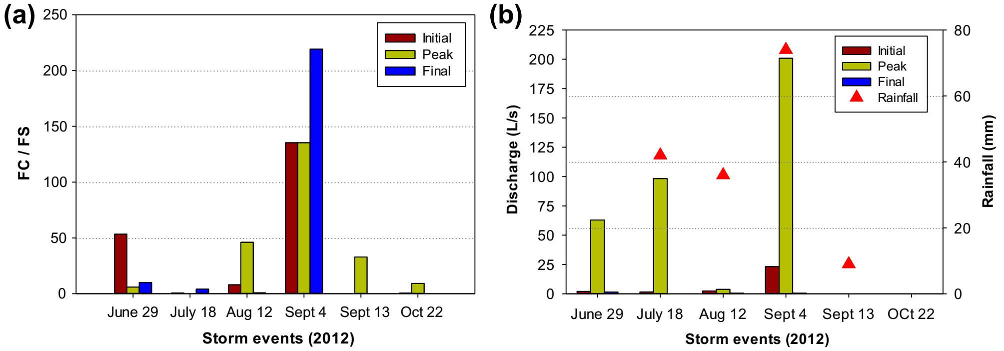

Fig. 16. (a) FC/FS ratio and (b) water discharge, and rainfall data of urban area.

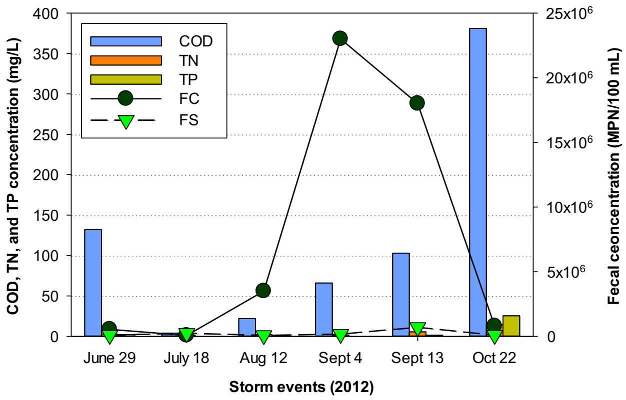

Fig. 17. COD, TN, and TP vs. fecal data during the peak/mid-sampling period of urban area.

4. Conclusion

The variability of fecal contaminants in four monitoring sites was examined. Monitoring sites varied in size, LULC, imperviousness, and possible source of contaminants allowing a robust analysis of variability of numerous intra-event characteristics and their relationship to discharge, rainfall, COD, TN, and TP. From this, the following conclusions were made: (1) the highest FC and FS values were observed in the following site order: Sites 3 < 1 < 4 < 7. Highest FC values ranged from 250×10^3 MPN/100 mL (Site 1) to 24×10^6 MPN/100 mL (Site 4), while in FS value ranged from 110×10^3 MPN/100 (Site 1) to 12×10^6 MPN/100 mL (Site 4). These high fecal values were obtained on the months of August, September, and October; (2) based on the FC/FS ratio, human fecal contamination almost dominated in every event specifically in mixed catchment and urban areas; (3) numerous factors affects bacterial water quality, however, the rainfall data and chemical characterization significantly infer a direct relationship to the level of fecal contaminants on the stormwater sample; (4) regression analysis can be employed to establish the relationship of fecal levels to the chemical characterization or rainfall data of the stormwater sample; (5) human activities in a particular area may indicate a high contribution in the increased fecal levels, however, it does not necessarily mean that majority of human-related activities may bring the increase of human source of fecal contamination; (6) FC was not properly distinguished because of the similarity in the MPN values, therefore this should be subjected to amendment for better quantification on the difference of both microbial analyses; and (7) The obtained MPN values for all fecal tests suggested that the water samples are not fit for either safe drinking, washing, or bathing as they may cause some serious illnesses to human.

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