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Monitoring of land use change impact on stormwater runoff and pollutant loading estimation in Yongin watershed Korea

Sheeraz Memon, Ma. Cristina Paule, Shin-Jeong Park, Bum-Yeon Lee, Sunhae Kang, Raja Umer, Chang-Hee Lee*

Department of Environmental Engineering and Biotechnology, Myongji University, San 38-2, Namdong, Yongin, Gyeonggi Province, Korea
Email: changhee@mju.ac.kr

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ABSTRACT

This study investigates the preliminary assessment of land use changes and their specific effects on hydrological characteristics and stormwater quality in Yongin watershed. Two experimental catchment sites comprising of mix land uses including urban and construction areas were monitored and tested for major stormwater quality parameters. It was observed that dry field, paddy field, forest, and ground cover were changed to bare land about 61, 96, 13, and 9%, respectively, at Site 1 from June 2011 to December 2011 due to construction activities for new development. The findings indicate that increase in bare soil resulted in reduction of stormwater runoff. Overall pollutograph shape for the entire stormwater events for most of the water quality parameters showed multiple peaks of equivalent magnitude, reflecting the rainfall intensity distribution. A wide range of Event mean concentrations (EMCs) for individual runoff event was measured for each water quality constituent based on the flow rate and concentration data. These wide EMC distributions did not show relationship with antecedent dry period, rainfall intensity, and runoff duration due to continuous modifications in monitoring sites. Pollutant loading at Site 2 was higher as compared to Site 1 because of the urban area impact and the difference of catchment area.

Keywords: Land use; Event mean concentration (EMC); Pollutant load; Stormwater

1. Introduction

Stormwater runoff pollution is considered as a leading source for water quality impairment and degradation in Korea. The sources include runoff from agriculture, urban, forest, construction site and anywhere water moves freely from contaminated surfaces. Stormwater source contamination significantly depends on local factors, whose effects are difficult to analyze. Assessment of water quality from land development requires information on the way land use affects stormwater quantity and quality [1]. Land development usually involves major earthworks;

*Corresponding author.

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potentially resulting in significant contamination of stormwater in waterbodies by eroding soils [2]. Construction activity is an important contributor to stormwater pollution source in urbanizing areas [3]. Land use change impact from vegetation and forest cover to urban development disturbs the natural water environment and aquatic ecosystem severely.

Replacement of ground cover of any catchment area affects in water quality, runoff volume, and flow characteristics within the watershed. In a construction site, daily activities and materials transportation makes stormwater runoff difficult to manage but their impacts are transient and can be mitigated through good planning and best management practices implementation [4]. When analyzing the quantity and temporal variations of stormwater flow, many contributing factors exist including geology of the land, topography, geography, rainfall intensity, rainfall pattern and the land use type [5]. Depending on the type of land use and the activities carried out on the land, the volume of runoff and the amount of pollutant it carries vary [6]. In addition, the intensity and duration of rainfall and the time, since the last storm event will also affect the quantity and transport of pollutants generated [7]. Urban development causes stormwater infiltration reduction, increase in runoff volume, and strongly affect on hydrological cycle due to expansion in impervious cover [8]. In an urban surface runoff, location of sampling site is selected according to specific sources such as highway runoff, industrial, commercial, residential and others, whereas in mix land use system with new development and construction activities, it is difficult to identify the specific pollutant source to be sampled. To effectively manage stormwater runoff, managers need to gain a deeper understanding of factors that affect stormwater quality. In particular, managers need to understand the sources, processes, and mechanisms that affect runoff and associated constituent holding [9].

In this study, variations in surface runoff with the passage of time, and stormwater quality for new development considering onsite activities were monitored for two sampling sites. Furthermore, this study also summarizes the understanding of stormwater discharge pattern with increase of land disturbance and bare soil cover, investigates the pollutant concentration behavior, determines the trends for problem parameters and evaluates the impact of watershed development on stormwater pollutant loads.

2. Materials and methods

2.1. Description of site

Two sites were selected to evaluate and characterize the stormwater runoff quantity and quality for event based monitoring within Yongin watershed as shown in Fig. 1. Stormwater drainage layout map was provided by Yongin administrative office for the illustration of locations of each drain and associated pipe network within the catchment area. Site 1 covers an area of 0.634 km^2 and is mainly a construction site. It also includes forest, agriculture, and ground cover. However, Site 2 is the drainage outlet towards the Geum-Hak stream and it covers an area of 1.398 km^2. This site is the catchment area for discharge from Site 1, surrounding residential, commercial, and roadways. The red line shows the boundary of Site 2, pink is the

Fig. 1. Monitoring sites location.

dividing line between Sites 1 and 2, and yellow line represents the drainage network, whereas green line signifies the new development area within the watershed. At Site 2, during dry period, some of the wastewater from sewage system leakage was observed. These sites were best representative for monitoring of new development and were selected on the basis of defined runoff area, ease of access, site safety, and access to the flow stream.

2.2. Sampling methodology

In sampling, weather forecasting is an essential factor. It is important to find out the most reliable source for forecast to avoid storms that do not occur. In this study, sampling strategy was made to provide complete coverage of the storm and to reflect the pollutant load in all flow. Sampling time and frequency were thus based on qualitative assessment of weather forecast and flow data in order to capture important parts of the storm hydrographs. Manual grab sampling was carried out in both monitoring sites for all of the stormwater events. Samples were taken for 6 and 8 rainfall events from Sites 1 and 2 during the period from June to December 2011. Events in November and December could not generate enough runoff at Site 1. Sampling was started immediately after the flow was observed at the discharge points. Generally, the sampling interval time was 15–30 min at the initial 2 h rainfall runoff period and then interval of 1–2 h for the receding flow stage. This strategy sufficiently characterized the initial runoff but was inadequate to characterize later runoff for Site 1 in few of the rainfall events as it was observed for the 29 September event. Therefore, rainfall intensity and runoff patterns were also considered with a lengthy period of light rainfall to set the stormwater sampling interval time. Samples were transported immediately to the laboratory for the water quality parameters analysis.

2.3. Rainfall and flow rate analysis

In the study area, most of the rain occurs from June to September, accounting for approximately 80% of the annual rainfall. Rainfall data were measured after installing the automated rainfall gauge (HB 3207-09) in an open area of monitoring site during rainfall events. At Site 1, flow rate data were measured manually using the current meter velocity and flow area of the channel, whereas at Site 2, automatic flow meter was installed at the outlet of the catchment area, and discharge was calculated based on velocity, depth of water, and width of the channel.

2.4. Monthly change in land use patterns

Geographic information system (GIS) applications were used to develop the land development alteration maps in monitoring sites. Monthly field visits data, maps, and documents from local administration office were used to validate and update the mapping criteria. The land use cover was classified according to Korean unit load classification that includes, dry field, paddy field, forest, ground, and other (bare land, grassland, etc.) categories.

2.5. Water quality parameters analysis

Surface runoff carries several constituents including sediments, nutrients, organics, metals, etc. Mix land use sites such as urbanization and construction activities may increase concentration levels in water bodies. Two liters of water samples were collected in polyethylene bottles and fixed at 4℃ until transferred to laboratory. Water parameters, including temperature, pH and turbidity, conductivity, were measured on-site using U-50 Multi-Probe. On the other hand, suspended solids (SS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), chloride (Cl^-), and heavy metals (Cd, Cr, Cu, and Pb) were analyzed in laboratory according to Korean standard methods.

2.6. Total pollutant effects and load estimation

Event mean concentration (EMCs) and load of pollutants were estimated to evaluate the stormwater runoff quantity and quality characteristics of the monitored events. EMC is appropriate for evaluating the effects of stormwater runoff on receiving waters and is often used as a single index to characterize concentrations [10]. The generated load mechanism of watershed development was estimated by using the EMCs criteria, which requires flow rate, pollutant concentration, and time data. This methodology was adopted based on a previous comparison of different methods for load estimation [11]. EMC is a flow-weighted average concentration of constituents and is expressed in mg/L units. Total constituent mass release can be obtained as the product of EMC by total volume of storm runoff [12]. Mathematically, it can be written as follows:

$$\text{Event mean concentration (mg/L)} = \frac{\text{Total pollutant mass (Kg)}}{\text{Volume (m}^3\text{)}}$$

$$\mathrm{EMC} = \frac{\int_0^T C(t) \times Q(t)dt}{\int_0^T Q(t)dt}$$

where $C(t)$ is pollutant concentration at time t and $Q(t)$ is stormwater discharge at time t.

Pollution load varies with the intensity and duration of the precipitation event, the extent of the watershed, and the use and occupancy of the watershed [13]. Thus complete hydrological, stormwater, and site characteristics data are required to estimate pollutant loading accurately.

3. Results and discussion

3.1. Rainfall-runoff features

Fig. 2 represents the individual stormwater event data. During the monitoring period, antecedent dry days (ADD), average rainfall intensity, runoff length, and rainfall depth were ranged from 0.8 to 9 days, 0.33 to 10.6 mm/h, 180 to 500 min, and 1.0 to 55 mm, at Site 1 and 0.8 to 14 days, 0.33 to 10.05 mm/h, 180 to 700 min, and 1.0 to 55 mm at Site 2, respectively. Antecedent dry conditions were 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.

3.2. Change in land use patterns

In this study, land use/land cover maps were produced using GIS and on-site field investigations based on new land development activities as shown in Fig. 3. In the month of July, cutting of trees and clearing of some parts at Site 1 were observed which resulted change in bare land. Further cutting of trees

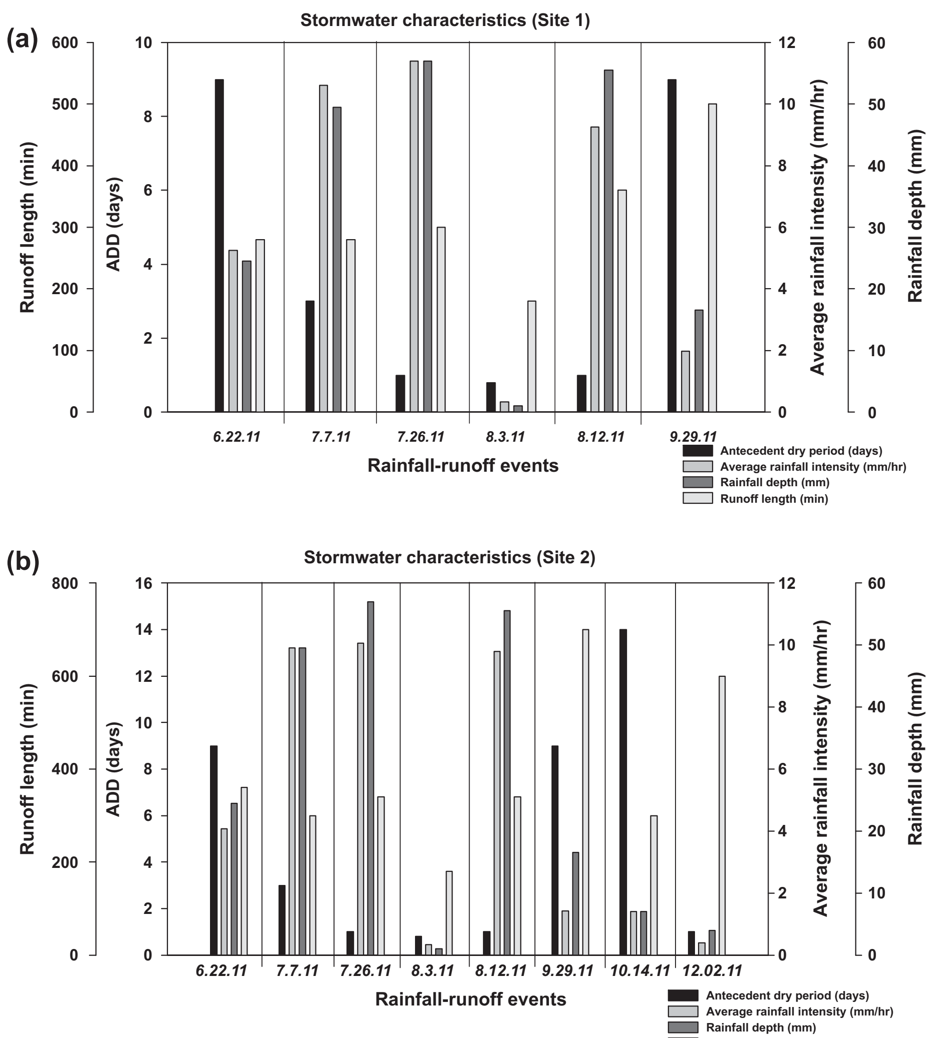

Fig. 2. Rainfall-runoff characteristics.

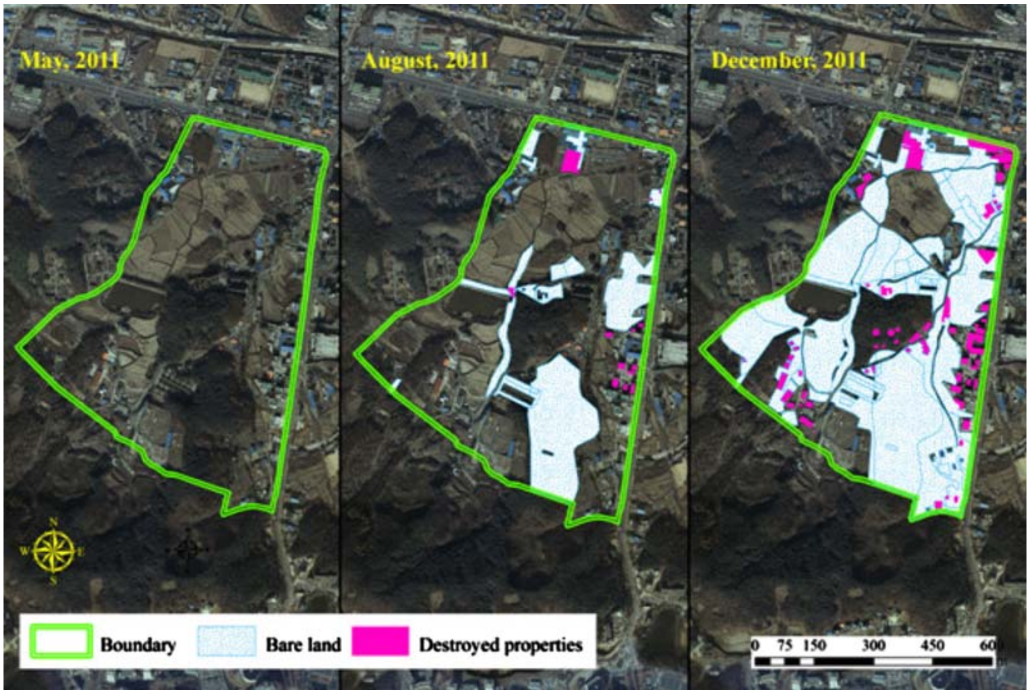

Fig. 3. Alteration of land use modification in monitoring sites.

from forest area and digging at mountain area were observed in the month of August. The soil from some parts of mountain at Site 1 was also transferred in low down elevation areas. In the month of September destruction of properties (e.g. burial in mountain, house, and commercial building) were started and major portion of paddy fields changed to bare land. The fields and residential buildings were almost transformed to clear ground soil cover in the month of December.

Fig. 4 shows the monthly percentage in land use change due to construction activities at Site 1. It was observed that dry field, paddy field, forest, and ground cover land uses were converted to bare land

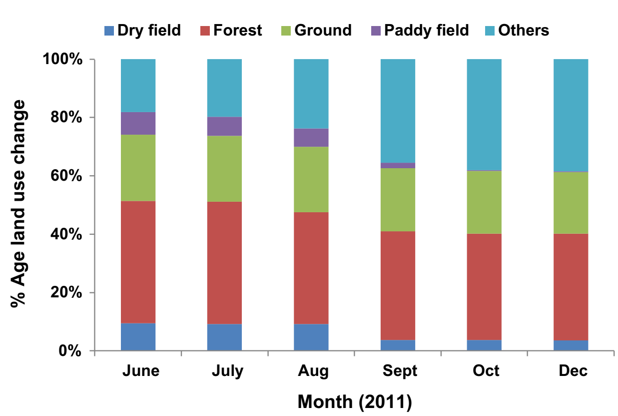

Fig. 4. Monthly percentage land use change.

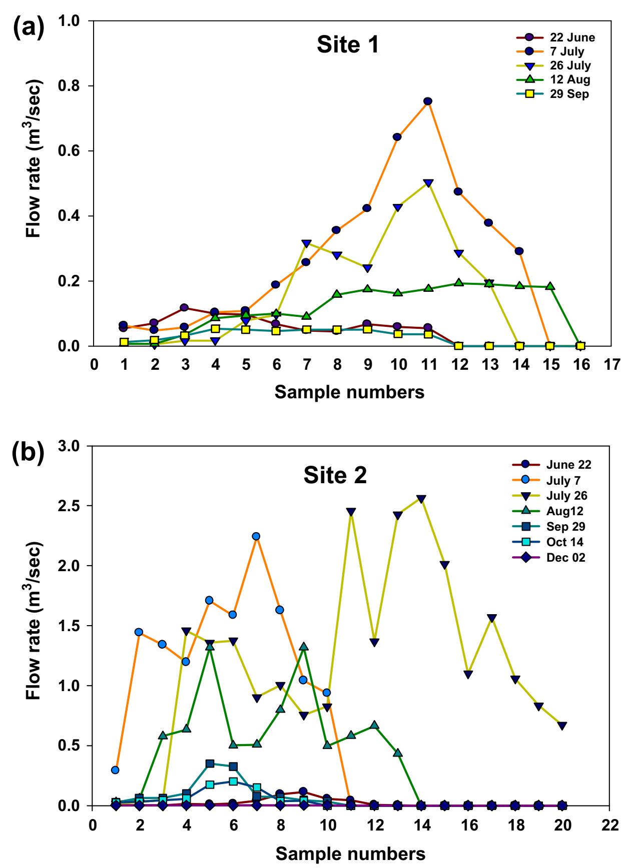

Fig. 5. Flow pattern of stormwater events.

approximately 61, 96, 13, and 9% respectively from July to December 2011. In the month of August, maximum land use modification scenario was observed specifically for forest and paddy field. This analysis was conducted by using field visits data, on site mapping, photos, and GIS techniques.

3.3. Flow pattern change analysis

Flow rate change pattern was observed that varied with time, land disturbing activities, ground cover change, and stormwater characteristics. Fig. 5 shows variations in the flow pattern with the ground cover change due to cutting of trees, excavation, digging, clearing, grading and other construction activities.

It was observed that Site 1 showed peak flow rate in the later period of rainfall event except for 22 June event, whereas velocity of stormwater flow was reduced in the month of September due to increase in infiltration capacity, and percolation of soil after removal of vegetation cover, change of ground surface and land development disturbance. Site 2 showed multiple peaks of flow rate due to the surrounding urban runoff at first and then the discharge from construction site in the later period of rainfall event except for September and December events. This may be due to the hydraulic and site change characteristics in Site 1. All of these hydrologic changes resulted in less stormwater runoff reaching to the discharge points of monitoring sites.

3.4. Pollutograph analysis

In this study, concentration profiles showed that time of peak flow rate did not correlate with peak concentration time. It was observed that pollutant concentrations in most of the stormwater events were variant with respect to runoff and flow rate. Site 2 showed maximum variation of the pollutant concentrations during stormwater event. Peak concentration preceded or lagged the peak flow rate in stormwater events but gradual decrease in concentration was not observed. Apparently, the existence of first flush phenomenon is difficult to describe. Ranjan [14] showed that highest peak occurred at the beginning of storm event and referred as first flush event from different land use areas.

Overall pollutograph shape for the entire stormwater events for most of the water quality parameters had multiple peaks of equivalent magnitude, reflect-

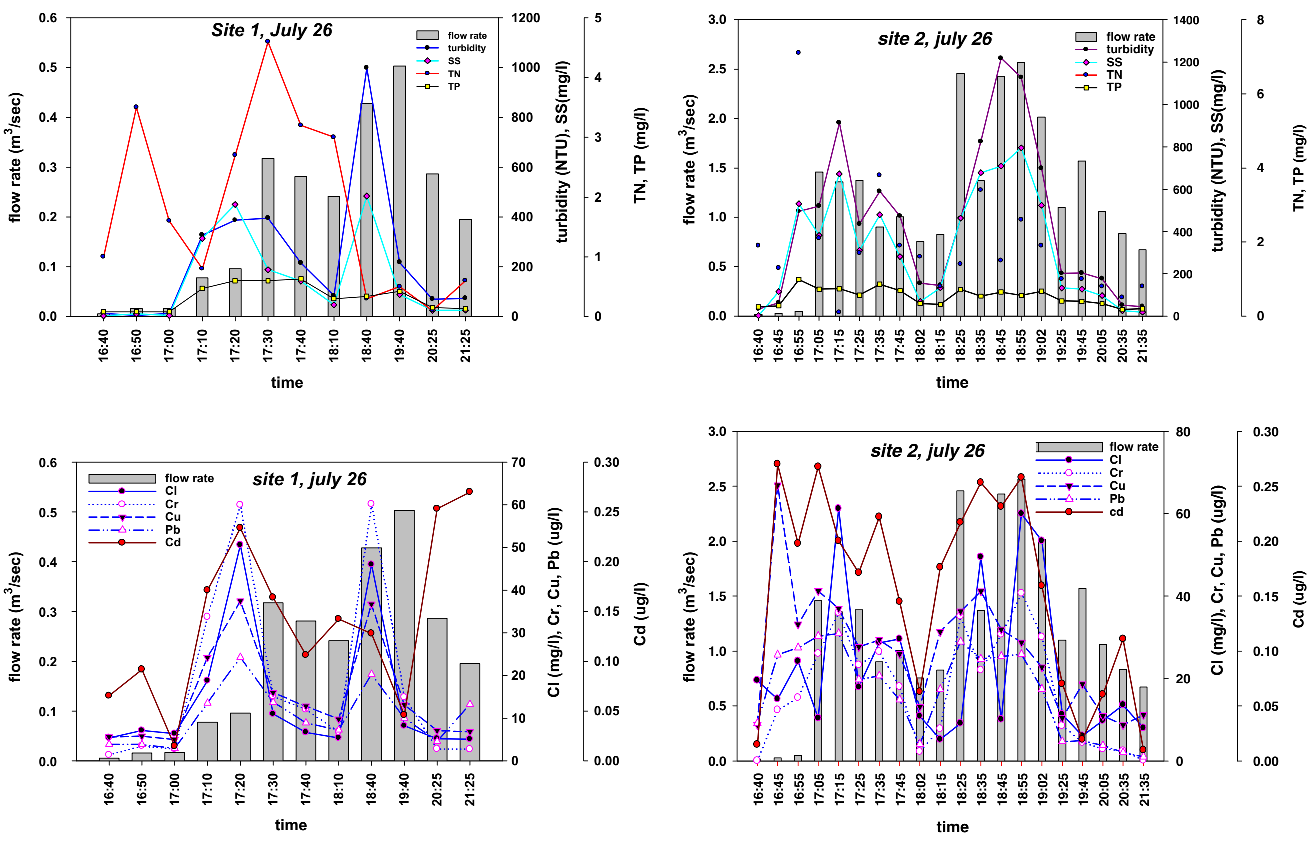

Fig. 6. Pollutographs of storm event in monitoring sites.

Table 1
EMCs at monitoring Site 1

Storm event	ADD (days)	Rainfall (mm)	SS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TN (mg/L)	TP (mg/L)	Cl^- (mg/L)	Cr (μg/L)	Cu (μg/L)	Cd (μg/L)	Pb (μg/L)
22 June 2011	9.00	24.50	72.26	7.73	30.94	4.16	0.51	NA	10.27	12.73	0.74	7.51
7 July 2011	3.00	49.50	72.10	1.08	23.45	4.01	0.33	12.25	15.83	7.62	0.03	4.34
26 July 2011	1.00	57.00	179.39	1.14	58.42	1.63	0.39	16.04	21.44	17.19	0.15	12.07
3 August 2011	0.80	1.00	187.63	4.35	31.27	2.59	0.87	20.80	37.76	11.40	0.00	11.81
12 August 2011	1.00	55.50	74.47	15.85	19.03	1.68	0.35	3.91	3.28	7.91	0.68	21.63
29 September 2011	9.00	16.50	68.20	6.14	13.28	1.46	0.68	4.83	NT	NT	NT	NT
Mean	–	–	109.01	6.05	29.40	2.59	0.52	11.56	17.72	11.37	0.32	11.47
Minimum	–	–	68.20	1.08	13.28	1.46	0.33	3.91	3.28	7.62	0.00	4.34
Maximum	–	–	187.63	15.85	58.42	4.16	0.87	20.80	37.76	17.19	0.74	21.63

Table 2
EMCs at monitoring Site 2

Storm event	ADD (days)	Rainfall (mm)	SS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TN (mg/L)	TP (mg/L)	Cl^- (mg/L)	Cr (μg/L)	Cu (μg/L)	Cd (μg/L)	Pb (μg/L)
22 June 2011	9	24.5	223.49	68.25	207.31	12.87	1.33	NA	12.95	69.03	1.05	16.64
7 July 2011	3	49.5	213.31	3.81	28.30	3.88	0.54	18.91	20.37	26.74	0.29	11.43
26 July 2011	1	57	426.58	1.80	55.74	1.69	0.57	25.93	22.95	27.27	0.17	19.03
3 August 2011	0.8	1	416.28	5.52	34.32	3.39	1.47	121.26	54.18	19.71	0.00	22.39
12 August 2011	1	55.5	227.42	17.61	25.05	2.96	0.80	3.37	42.93	24.27	0.18	23.88
29 September 2011	9	16.5	60.56	7.15	19.94	1.61	0.80	5.92	5.93	17.21	0.18	6.66
14 October 2011	14	2.5	395.32	18.91	303.67	5.40	1.78	4.89	NT	63.41	NT	41.77
2 December 2011	1	4	43.73	7.98	30.13	3.69	2.20	16.62	NT	NT	NT	NT
Mean	–	–	250.84	16.38	88.06	4.44	1.19	28.13	26.55	35.38	0.31	20.26
Minimum	–	–	43.73	1.80	19.94	1.61	0.54	3.37	5.93	17.21	0.00	6.66
Maximum	–	–	426.58	68.25	303.67	12.87	2.20	121.26	54.18	69.03	1.05	41.77

ing the rainfall intensity distribution as shown in Fig. 6. This kind of flow pattern influenced the interval time between the pollution level and flow rate.

In previous studies peak pollutant concentration appeared in the start of rainfall event and decreased gradually from impervious cover but pollutant concentration from pervious areas such as Zoo site and agriculture increased with the increase in rainfall depth because the removal of pollutants from pervious surface depends on rainfall pattern [15,16]. In this study, the results showed different kind of pollutograph pattern because continuous land development activities occurred in monitoring sites.

3.5. Total pollutant effects and load estimation

EMCs distribution is widely dependent on total rainfall, ADD, and rainfall intensity due to the dilution effect during a rainfall storm [17]. Among stormwater characteristics, ADD is considered as well correlated variable with pollutants concentration specifically for SS because more pollutants accumulation exhibit in longer ADD. In this study, EMC levels for monitoring sites varied by each constituent and no single hydrological and site characteristic was responsible for contributing the high levels of measured constituents measured as shown in Tables 1 and 2. In previous study, similar results for EMCs and rainfall variables without correlation were observed [18]. In case of SS, maximum EMC values were found in 26 July and 3 August events with minimum ADD period in both monitoring sites. It may be because of heavy rainfall, smaller rainfall duration, and continuous land disturbance activities. In case of nutrients, EMCs of TN was found high for 22 June in both monitoring sites due to the agricultural land use before the start of construction activities. EMC for Cl^- was high in 3 August among the other events. Due to the lower rainfall and smaller runoff duration in that event, the effect of stagnant water and surrounding activities was obvious at Site 1, whereas the influence of urban discharge was apparent at Site 2. In case of heavy metals, EMCs values were not detected in 29 September event in Site 1, and 2 December event in Site 2. Overall Site 2 contributed 2–3 times higher values of EMC compared to the Site 1.

Mass transport calculations were also made for the stormwater pollutants and were expressed in kg/day as shown in Fig. 7. Stormwater events in monitoring sites with high rainfall intensity resulted in high values of pollutant loadings for most of the parameters as can be seen for 7 July and 26 July, events. In 29

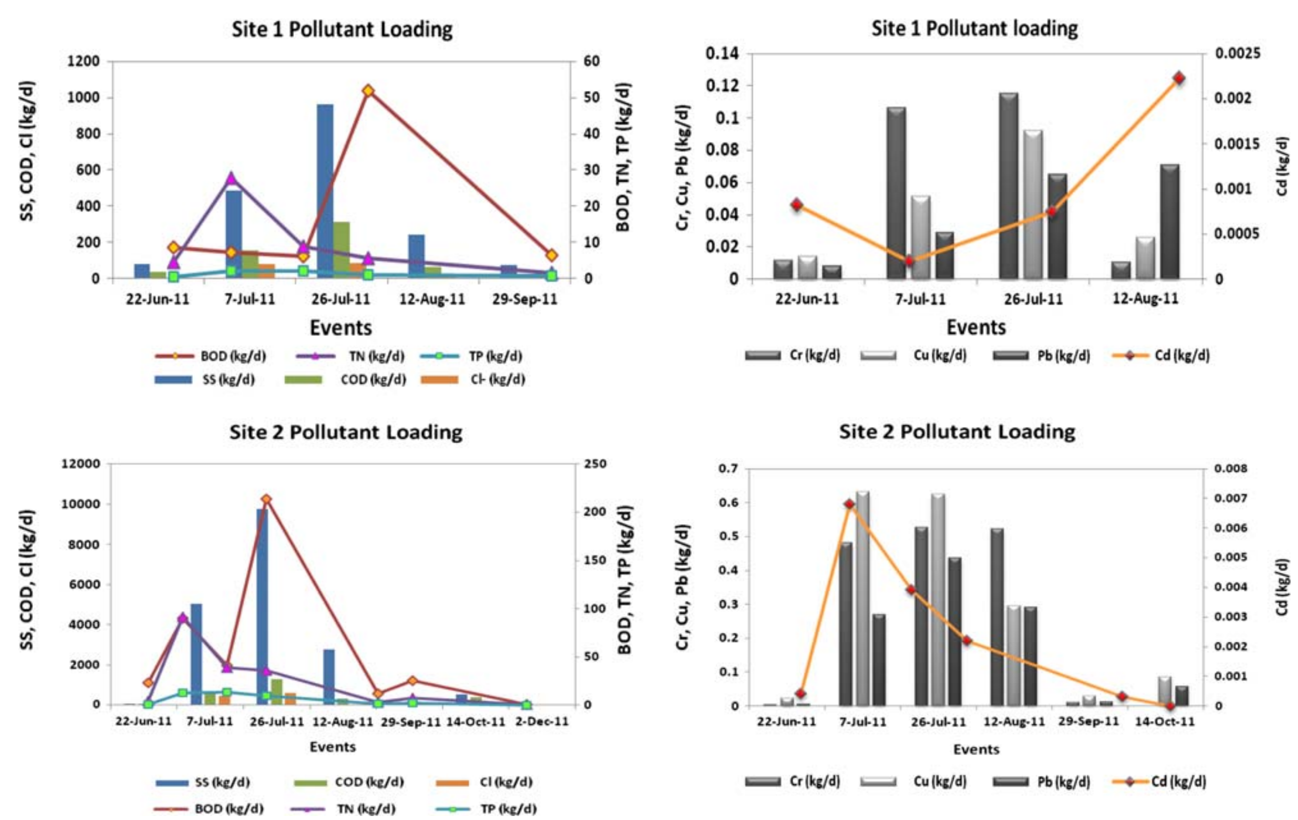

Fig. 7. Pollutant mass computations for Sites 1 and 2.

September and 2 December stormwater events, most of the parameters showed lowest pollutant loading trend in both monitoring sites because these events contain lowest rainfall amongst all events. Maniquiz [19] stated that pollutant loading is the function of flow rate that could be dependent on rainfall and runoff in particular and similar results were also found in this study. Overall, the pollutant loading values comparison indicates that average daily loading of pollutants was high at Site 2 as compared to Site 1 due to the urban land use impact, and larger catchment area.

4. Conclusions

Information derived from this study is useful as a basis of monitoring strategy for stormwater management in complex land use watershed. In this study, quantitative and qualitative characteristics of stormwater were investigated through continuous flow monitoring and discrete rainfall events sampling. The findings concluded that new development activities and change in ground cover within a watershed reduces the velocity of flow. It was also observed that areas for dry field, paddy field, forest, and ground cover land uses were destroyed approximately 61, 96, 13, and 9% respectively. Pollutograph showed that peak concentration preceded or lagged the peak flow rate in stormwater events but gradual decrease in concentration was not observed, and therefore, concentration profile trend is difficult to describe. Results of EMC for organic compounds, nutrients, and heavy metals were found higher at Site 2 and did not show any relation with rainfall runoff characteristics. The pollutant loading values were also found higher with heavily rainfall events for most of the parameters. These results can be used to develop, and assist future land use planning and for sustainable stormwater management strategies.

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References

[1] J.C. Randall, M.E. Barrett, Evaluation of methods for estimating stormwater pollutant load, Water Environ. Res. 70 (1998) 1295–1302.
[2] Environmental Protection Agency (EPA), State and Regional Coastal Management Plans Queensland's Coastal Policy, Guideline, EPA Best Practice Urban Stormwater Management Erosion and Sediment Control, 2008.
[3] V. Novotny, H. Olem, Water Quality: Prevention, Identification and Management of Diffuse Pollution, Van Nostrand Reinhold, New York, NY, 1994.
[4] R. Charbonneau, G.M. Kondolf, Land use change in California, USA: Nonpoint source water quality impacts, Environ. Manage. 17 (1993) 453–460.
[5] D. Niehoff, U. Fritsch, A. Bronstert, Land-use impacts on storm-runoff generation: Scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW Germany, J. Hydrol. 267 (2002) 80–93.
[6] C. Ho, D.J. Kumar, Water Quality from a Mixed Land-Use Catchment in Miri, Sarawak, WASET, 2011, p. 60.
[7] Z. Christopher, Review of urban stormwater models, Environ. Model. Softw. 16 (2001) 195–231.
[8] J.M. Lee, K.H. Hyun, J.S. Choi, Y.J. Yoon, F.K. Geronimo, Flood reduction analysis on watershed of LID design demonstration district using SWMM5, Desalin. Water Treat. 38 (2012) 255–261.
[9] E.D. Stein, L.L. Tiefenthaler, K.C. SchiffRandall, Comparison of stormwater pollutant loading by land use type, Southern California Coastal Water Research Project 2008 Annual Report, 2008, 15–27.
[10] J.J. Sansalone, S.G. Buchberger, Partitioning and first flush of metals in urban roadway stormwater, J. Environ. Eng. 123 (1997) 134–143.
[11] H. Li, Basic characteristics of nonpoint source pollution in Hong Kong, Proceedings of the International Conference on Estuaries and Coasts, November 9-11, Hangzhou (2003) 655–622.
[12] W.C. Huber, Contaminant transport in surface water, in: D.R. Maidment (Ed.), Handbook of Hydrology, McGraw-Hill, New York, NY, 1993 (Chapter 14), 14.1–14.50.
[13] O.A. Patrik, L.J. Boccia J, Impact Assessment of Non-Point Source Pollution with the L-THIA Model, Proceedings of the World Environmental and Water Resources Congress, Bearing Knowledge for Sustainability (2011) 732–741.
[14] J. Ranjan, P. Shane, G. Dinushi, Evaluation of the impacts of land use on stormwater quality: Case study from Western Australia, Int. J. Environ. Sci. Dev. 3 (2012) 20–26.
[15] V.J.W. Zhao, B.Q. Shan, C.Q. Yin, Pollutant loads of surface runo in Wuhan City zoo, an urban tourist area, J. Environ. Sci. 19 (2007) 464–468.
[16] G.W. Characklis, M.R. Wiesner, Particles, metals, and water quality in runoff from large urban watershed, J. Environ. Eng. 123 (1997) 753–759.
[17] H. Luo, M. Li, R. Xu, X. Fu, G. Huang, X. Huan X, Pollution characteristics of urban surface runoff in a street community, Sustainable Environ. Res. 22 (2012) 61–68.
[18] M.C. Maniquiz, S. Lee, K.S. Min, J.H. Kim, H.L. Kim, Stormwater runoff monitoring in a deciduous and coniferous forest, Desalin. Water Treat. 38 (2012) 316–322.
[19] M.C. Maniquiz, S. Lee, H.L. Kim, Multiple linear regression models of urban runoff pollutant load and event mean concentration considering rainfall variables, J. Environ. Sci. 22 (2010) 946–952.