Stormwater runoff quality in correlation to land use and land cover development in Yongin, South Korea


ABSTRACT

Stormwater runoff quality is sensitive to land use and land cover (LULC) change. It is difficult to understand their relationship in predicting the pollution potential and developing watershed management practices to eliminate or reduce the pollution risk. In this study, the relationship between LULC change and stormwater runoff quality in two separate monitoring sites comprising a construction area (Site 1) and mixed land use (Site 2) was analyzed using geographic information system (GIS), event mean concentration (EMC), and correlation analysis. It was detected that bare land area increased, while other land use areas such as agriculture, commercial, forest, grassland, parking lot, residential, and road reduced. Based on the analyses performed, high maximum range and average EMCs were found in Site 2 for most of the water pollutants. Also, urban areas and increased conversion of LULC into bare land corresponded to degradation of stormwater quality. Correlation analysis between LULC and stormwater quality showed the influence of different factors such as farming practices, geographical location, and amount of precipitation, vegetation loss, and anthropogenic activities in monitoring sites. This research found that GIS application was an efficient tool for monthly monitoring, validation and statistical analysis of LULC change in the study area.

Key words | event mean concentration, geographic information system, land use/land cover, stormwater

INTRODUCTION

Stormwater runoff pollution is considered as a leading source for water quality impairment and degradation in Korea (Memon et al. 2013). Land development typically involves the removal of vegetation, soil grading and compaction, construction of impervious surfaces, and hydraulic conveyance systems (Emerson & Traver 2008). This process alters the watershed hydrology, reducing the vegetative interception of rainfall, infiltration, and groundwater recharge, with contaminant increases in surface water runoff (Li et al. 2009). As stormwater flows in on-going land development areas, it also picks up natural and man-made contaminants that are accumulated on the surface during dry days and transports them to receiving water bodies. The significance of the relationship between land development and stormwater runoff quality needs a deeper understanding due to increased recognition that non-point source (NPS) pollution has become a major environmental concern in Korea. Numerous studies have been performed to find the relationships between the water quality and stormwater runoff (Zampella et al. 2007; Li et al. 2008; Lee et al. 2010; Chu et al. 2013). However, these studies have focused on suspended solids (SS) and nutrients. NPS pollution monitoring presents a great challenge because of the dispersed origin and loss of pollutants in response to hydrological processes and land use patterns. Also, a large set of data is required for the NPS pollution characterization contrary to point source pollution (Mishra et al. 2010). Consequently, geographic information system (GIS) and water quality models are used for the assessment and management of NPS pollution.

In recent years, when Korea initiated its economic reform and open-door policy, rapid urbanization and economic expansion have resulted in massive land alteration and environmental degradation. Urbanization is considered as the major source of NPS pollution in the form of land use change impact on catchment morphological features and hydrological behavior, which completely disturbs the mechanisms of source, process and sink of urban NPS pollution.
Land use modifications associated with urbanization result in changes in stormwater runoff characteristics such as increase in runoff volume and peak flow rate. In this research, therefore, land use and land cover (LULC) change GIS data and stormwater runoff quality data from 2011 to 2012 were collected and analyzed: (1) to monitor the LULC change and its impact on runoff quality; (2) to determine the correlation factor for event mean concentration (EMC) of stormwater pollutants from different land use sites; and (3) to obtain baseline data for stormwater management and water quality modeling.

MATERIAL AND METHODS

Site description

The study was conducted within Geum-Hak watershed in Yongin City, Gyeonggi Province, which is located at the north-western part of South Korea (Figure 1). Two representative monitoring sites were selected on the basis of site-specific and hydrological characteristics to investigate the impacts of LULC development on stormwater runoff quality. Site 1 (area 0.634 km²) is an outlet of a sedimentation pond and it was considered as a groundwork activities area due to on-going conversion of LULC for developing a residential complex. The LULC in this site includes land alteration (conversion of forest, agricultural, or commercial to bare land), forest, and agricultural land. Site 2 (area 1.398 km²), which includes Site 1 and the additional downstream catchment area, is the outlet of the Geum-Hak stream that eventually flows into Paldang reservoir, the major source of drinking water for the Seoul Metropolitan area and nearby provinces. This site is categorized as a mixed catchment because it covers the land alteration, forest, agriculture, and urban area.

Methods

The overall procedure used in this study is shown in Figure 2, which includes: (1) stormwater runoff monitoring, water quality and water quantity data analysis; (2) monthly monitoring of LULC change; (3) calculation of EMC; and (4) analysis of the relationship between LULC and water quality data using Pearson’s correlation.

Monitoring and analysis

Fifteen storm events from June 2011 to December 2012 were monitored and a total of 398 grab samples (n = 9–20 samples in each site) were collected. Samples were analyzed for typical water quality pollutants including SS, chemical oxygen demand (COD), 5-day biological oxygen demand (BOD₅), total nitrogen (TN), and total phosphorus (TP) using the standard methods (APHA 1998). Hydrologic
data gathered from each event included antecedent dry days (ADD), event rainfall, runoff duration, average rainfall intensity, and runoff rate. ADD is the number of dry days before a rain event, whereas rainfall intensity is a measure of the amount of rain that falls over time.

**LULC change pattern**

Land use maps from the Korean Ministry of Environment Republic of Korea (MOE) and Ministry of Agriculture and Forestry Republic of Korea (MAF) in raster format with 4 m resolution were used to measure the LULC composition in the study area. The land use types in the MAF maps were classified from Landsat TM images (30 m resolution). Monthly field visits were done to update and validate the LULC alteration within the study area. The original MOE land use map was classified into 23 land use types. However in this study, the LULC was reclassified into nine categories: agriculture, bare land (soil digging, soil filling, gravels, bare ground, and bare rocks), commercial, ditch/water (drainage system and settling pond), forest, grassland, parking lot, residential, and road. GIS was used to calculate the area of each land use and update and validate the LULC change within the monitoring areas.

**Event mean concentration**

Typically, the concentration of a pollutant in stormwater runoff is described based on the EMC, due to the large fluctuation during rainfall events. The EMC can be defined as the total mass pollutant load yielded from a site during a storm event divided by the total runoff water volume discharged during the storm (Lang et al. 2015). It can be calculated as:

\[
EMC = \frac{M}{V} = \frac{\sum C_t Q_t \Delta t}{\sum Q_t \Delta t}
\]

where the EMC is the event mean concentration (mg/L); \( M \) is the total mass of pollutant over the entire event duration (g); \( V \) is total volume flow over entire storm event duration (m\(^3\)); \( t \) is the time (min); \( C_t \) is the time variable concentration (mg/L); \( Q_t \) is the time variable flow (m\(^3\)/min); and \( \Delta t \) is the discrete time interval (min).
Correlation analysis

Pearson’s (parametric) correlation coefficient matrix was adopted to perform bivariate analysis of storm water quality parameters and landscape pattern indices in the multivariate statistical analysis software SPSS 12.0. Correlations between EMC and rainfall variables and between EMC and LULC change pattern were determined. The two-sided test method was chosen for significant level of P-value at <0.05.

RESULTS AND DISCUSSION

Rainfall and runoff characteristics

All events above a minimum rainfall (generally ≥1.0 mm rainfall) were monitored. A summary of event details are shown in Table 1, which includes event date, ADD, rainfall, average rainfall intensity, and runoff duration. The event rainfall varies from 1.0 to 74 mm; ADD varies from 0.8 to 31 days and; average rainfall intensity varies from 0.33 to 10.6 mm/hr. The runoff duration during the monitoring period ranged from 180 to 850 min in Site 1 and 180 to 960 min in Site 2. Hydrological variables were analyzed by using rainfall gauge data at monitoring sites, local meteorological data, and flow rate data.

LULC change pattern

LULC change in this study was classified into several distinct patterns, such as agriculture, bare land, commercial, ditch/water, forest, grassland, parking lot, residential, and road using the GIS technique.

Figure 3 shows the LULC composition before groundwork (Phase I) and during groundwork activities between 2011 (Phase II) and 2012 (Phase III) in the construction area. Under Phase I, the LULC of agriculture, bare land, commercial, ditch/water, forest, grassland, parking lot, residential, and road accounted for 17.16, 4.79, 2.07, 0.98, 41.86, 12.45, 8.99, 5.47, and 6.23% of the total study area, respectively, but it changed rapidly due to groundwork activities during Phases II and III period, as presented in Table 2. Results revealed that bare land increased exponentially about 615.72% and ditch/water increased about 35.61% from Phases I to III period. However, other land uses such as agriculture (78.82%), commercial (44.16%), forest (15.44%), grassland (15.61%), parking lot (50.12%), residential (25.61%), and road (17.51%) reduced in spatial extent from Phases I to III.

Event mean concentration

Table 3 presents the statistics of EMC for some constituents measured during Phases II and III in both monitoring sites. The range of and average EMC values were found to be higher in Site 2 than in Site 1 for most of the pollutants. This could be because Site 2 covers a larger catchment area and collects discharge from Site 1 and surrounding urban areas, whereas the sedimentation pond at Site 1 caused removal of SS. Also, it was observed that Phase III generally had higher range and mean EMC values for all parameters possibly because construction of a settling pond, soil alteration (e.g. soil digging and soil filling), rapid increase of bare land, and vegetation loss were the major groundwork activities, contributing to the change in pollutant concentration in the study area. In similar studies, it was found that such conditions may affect soil erosion and
sediment delivery, which caused increase of SS concentration in stormwater runoff (Chu et al. 2013). To determine the potential impact of rainfall variables in estimating the EMC of pollutant concerns, correlations were investigated for Phases II and III in both monitoring sites (Table 4). From the correlation analysis, the ADD was weakly and negatively correlated to all EMC pollutants (the highest was TN in Phase III, \( r = 0.456 \)). Average rainfall intensity appears to be negatively correlated with all pollutants; \( r \) values ranged from \(-0.501 \) (TP in Phase III) to...
Runoff length and runoff depth showed positive correlation to pollutants but some coefficient were low. BOD, COD, TN, and TP were positively correlated to runoff length than to rainfall depth; however, SS was more positively correlated with rainfall depth than with runoff length. Due to weak correlation between EMC and rainfall variables during both phases, it was hypothesized that not only the rainfall variables contributed to the EMCs; other factors should be considered.

### Relationship between land use and land cover change and water quality

Table 5 shows the Pearson correlation coefficients between individual LULC and stormwater quality variables. Correlations significant at $P < 0.05$ are expressed in bold text.

Agricultural land use showed positive correlation for TN and TP. Although it was less than 15% of total area (Figure 3), it may have contributed to an increase of nutrient concentration in stormwater runoff due to possibly the effect of fertilizer used in rice paddy fields within the study area. In this study, it was hypothesized that the farming practices and geographical location were factors that affect the correlation between agricultural land and nutrients. A similar case in a previous study (Lee et al. 2009) found that the rice paddies in Korea received intensive application of fertilizers during spring and fall, in the seasons during which the water quality parameters were monitored. Also, the farmers keep paddies flooded after the application of fertilizer to

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**Table 3** Summary of EMC at each monitoring site in Phases II and III (unit: mg/L)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Site 1 Range</th>
<th>Mean</th>
<th>SD</th>
<th>Site 2 Range</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>68.2–187.63</td>
<td>109</td>
<td>57.81</td>
<td>43.74–426.58</td>
<td>250.8</td>
<td>151.63</td>
</tr>
<tr>
<td>BOD&lt;sub&gt;5&lt;/sub&gt;</td>
<td>1.08–15.85</td>
<td>6.05</td>
<td>5.49</td>
<td>1.80–68.24</td>
<td>16.38</td>
<td>21.85</td>
</tr>
<tr>
<td>COD</td>
<td>13.28–58.42</td>
<td>29.40</td>
<td>15.82</td>
<td>19.94–303.67</td>
<td>88.06</td>
<td>107.02</td>
</tr>
<tr>
<td>TN</td>
<td>1.46–4.16</td>
<td>2.59</td>
<td>1.23</td>
<td>1.61–12.87</td>
<td>4.44</td>
<td>3.62</td>
</tr>
<tr>
<td>TP</td>
<td>0.33–0.87</td>
<td>0.52</td>
<td>0.21</td>
<td>0.54–2.20</td>
<td>1.19</td>
<td>0.61</td>
</tr>
</tbody>
</table>

SD: standard deviation.

**Table 4** Correlation analysis results between EMCs and rainfall variables for Phase II (first row) and Phase III (second row)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SS</th>
<th>BOD&lt;sub&gt;5&lt;/sub&gt;</th>
<th>COD</th>
<th>TN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADD</td>
<td>-0.051</td>
<td>0.385</td>
<td>0.336</td>
<td>0.352</td>
<td>0.251</td>
</tr>
<tr>
<td>Average rainfall intensity</td>
<td>-0.351</td>
<td>-0.387</td>
<td>-0.264</td>
<td>-0.214</td>
<td>-0.487</td>
</tr>
<tr>
<td>Runoff length</td>
<td>0.501</td>
<td>0.351</td>
<td>0.415</td>
<td>0.456</td>
<td>0.413</td>
</tr>
<tr>
<td>Rainfall depth</td>
<td>0.562</td>
<td>0.321</td>
<td>0.291</td>
<td>0.247</td>
<td>0.376</td>
</tr>
</tbody>
</table>

**Table 5** Pearson correlation coefficients for LULC change pattern and EMC for Phase II (first row) and Phase III (second row)

<table>
<thead>
<tr>
<th>Water quality variables</th>
<th>Land use types</th>
<th>SS</th>
<th>BOD&lt;sub&gt;5&lt;/sub&gt;</th>
<th>COD</th>
<th>TN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>-0.201</td>
<td>0.284</td>
<td>-0.095</td>
<td>0.601</td>
<td>0.653</td>
<td></td>
</tr>
<tr>
<td>Bare land</td>
<td>-0.130</td>
<td>0.252</td>
<td>-0.076</td>
<td>0.707</td>
<td>0.698</td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>0.912</td>
<td>0.680</td>
<td>0.658</td>
<td>0.639</td>
<td>0.675</td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>0.714</td>
<td>0.757</td>
<td>0.603</td>
<td>0.680</td>
<td>0.634</td>
<td></td>
</tr>
<tr>
<td>Grassland</td>
<td>-0.350</td>
<td>0.618</td>
<td>-0.342</td>
<td>-0.282</td>
<td>-0.276</td>
<td></td>
</tr>
<tr>
<td>Parking lot</td>
<td>-0.249</td>
<td>0.574</td>
<td>-0.276</td>
<td>-0.261</td>
<td>-0.246</td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>0.567</td>
<td>0.597</td>
<td>0.638</td>
<td>0.547</td>
<td>0.533</td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>0.531</td>
<td>0.558</td>
<td>0.602</td>
<td>0.558</td>
<td>0.625</td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>0.638</td>
<td>0.591</td>
<td>0.657</td>
<td>0.523</td>
<td>0.576</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>0.729</td>
<td>0.608</td>
<td>0.656</td>
<td>0.692</td>
<td>0.590</td>
<td></td>
</tr>
</tbody>
</table>

Pollutants are in mg/L; all $P$-values are less than 0.05.
allow increase of nutrient uptake by the rice plants. However, large amounts of precipitation can cause fertilized paddies to overflow through drainage weirs and more negatively affect water quality (Lee et al. 2009).

Forest and grassland were negatively correlated with SS, COD, TN, and TP and were positively correlated with BOD. This result is similar to other research in which it was observed that increases in forest and grassland area will reduce the concentration of SS, COD, TP, and TN, increase the concentration of BOD, and consequently improve the water quality (Fu et al. 1998; Amiri & Nakane 2009).

Urban land use corresponding to commercial, residential, parking lot, and road had positive correlation with all water quality parameters. This was obvious due to the high impervious cover within the catchment area, and a direct relation between imperviousness and surface runoff. The result is consistent with the findings from other research, which indicate that higher percentages of urban land use types had a profound influence on the quality of stormwater runoff owing to the introduction of pollutants of physical, chemical, and biological origin resulting from various anthropogenic activities common to urban areas (Goonetilleke et al. 2004). Typically, human land uses in watersheds result in fragmented natural areas with numerous negative ecological and environmental effects (Lee et al. 2009).

Bare land and SS concentration have a positive relationship. A high degree of soil digging and transferring of soil from forest to elevated area was observed during Phase III. Therefore, bare land use was a source of soil erosion and sediment delivery to downstream receiving waters. It was found in previous studies that vegetation loss, soil disturbance, increased soil exposure, and heavy rainfall storms will lead to an increase in the potential for soil erosion (Chu et al. 2013) and subsequently degradation of water quality. The positive relationship between bare land use and TN could be explained in the same manner as mentioned in a previous study whereby weathering of bare rocks and gravel during urban development activities could lead to increase in TN concentration (Li et al. 2008). The concentrations of BOD and COD were positively correlated with bare land, indicating that the increase of bare land area has resulted in discharge of a large amount of organic pollutants into the river, severely affecting water quality.

Overall, the water quality variables were degraded from 2011 to 2012 where the bare land areas were dramatically increased and their impact was observed. Also, the built-up areas (commercial, parking lot, residential, and road) have a positive relationship with the water quality variables. So, it was clear that the main cause of deteriorating water quality in the study area was bare land and built-up areas, which have the potential to generate a large amount of NPS pollution from stormwater runoff.

**CONCLUSION**

Various studies have conducted investigations of the relationship between the LULC change and water quality in stormwater runoff. However, in explaining the relationship between LULC change and water quality, many studies have emphasized specific land uses such as urban and agricultural land. In this study, an integrated approach, involving stormwater runoff data, GIS, and EMC analysis, was used to conduct a study on the impact of the on-going construction activities and mixed land use on stormwater runoff. The result suggest that the concentration of most of the pollutants was found to be higher in Site 2, which consisted of the discharge from Site 1 (the construction zone) and surrounding urban areas. Rapid groundwork activities led to an increase in bare land use percentage and a decrease in built-up areas, which resulted in degradation of water quality in the study area specifically during Phase III.

The EMCs for pollutants were mostly negatively or marginally correlated with all rainfall variables, which suggests that the runoff EMC is highly variable due to site and event characteristics. The agricultural land had positive correlation with nutrients. Farming practices, geographical location and amount of precipitation were the suggested factors for the nutrient correlation. The forest and grassland were negatively correlated to SS, COD, TN, and TP and were positively correlated to BOD. Bare land and SS had a positive relationship due to vegetation loss, soil disturbance, and increased soil exposure. The urban land use types showed positive correlation to all water quality parameters owing to their direct relation with imperviousness.

The results indicate that application of GIS (monthly monitoring, updating, and validating the LULC change) to integrate EMC and correlation analysis can develop a decision-making support system to manage the land development and control the NPS impact at the watershed scale. This study provides scientific reference for local land use optimization and water pollution control and assists the formulation of policies for coordinating water resource exploitation and protection. In the future work, this study may refine the method and indicators to deeply reveal the reasons causing water quality change within the study area.
ACKNOWLEDGEMENT

This research was supported by the Korea Environmental Technology and Industrial Institute, Next Generation Eco Innovation Project (No. 413-111-003).

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First received 5 December 2013; accepted in revised form 15 April 2014. Available online 3 May 2014