Analysis of Urban Imperviousness Impacts on Runoff Process by Hydrological Simulation

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1. INTRODUCTION

Urbanization have increased storm water runoff volume, flow rates and peak flows and decreases flow time and low flows (Shuster et al,2005). The increase of impervious surfaces and the utilization of efficient drainage systems are generally considered as the main driver of the hydrological changes. Imperviousness, which is a direct viewing and easily measured index, has been widely regarded as a key predictor of urbanization impacts on rainfall-runoff processes. Traditionally the most generally used imperviousness index is total impervious area (TIA), which means the whole fraction of impervious area in a catchment. Recent study found that EIA (effective impervious area), the impervious area that is hydraulically connected to the drainage system, should be a better indicator of runoff in urbanized areas (Mejia et al, 2009; Ravagnani et al, 2009; EPA, 2014; Krebs et al, 2014;). In this study, we use TIA and EIA as indicators for predicting rainfall runoff process and thus provide effective indicators for runoff management of small urbanized catchments in cities.

2. MATERIAL AND METHOD

2.1 Study site

We chose the Kunimigaoka Area in Sendai City, Japan for the case study (Fig.1(a)). KA is located in the north-western part of the uptown of Sendai City, which covers approximately 50 hector with a medium gradient slope topography. KA is featured with a temperate monsoon climate and the annual average rainfall and temperature are 1254 mm and 12.4C, respectively. KA is an old uptown where urbanization degree is rather complete and the land use shows little change after 2000. The urban land use accounts for over 90% of the total in this region. The storm water was firstly drained to a regulating pond and then to a downstream river. The drainage system of KA can be divided into two parts, one being the sewer network in the Northern part of KA which accounted for most of the drainage areas; the other is a located in the southern part beside the regulating pond.

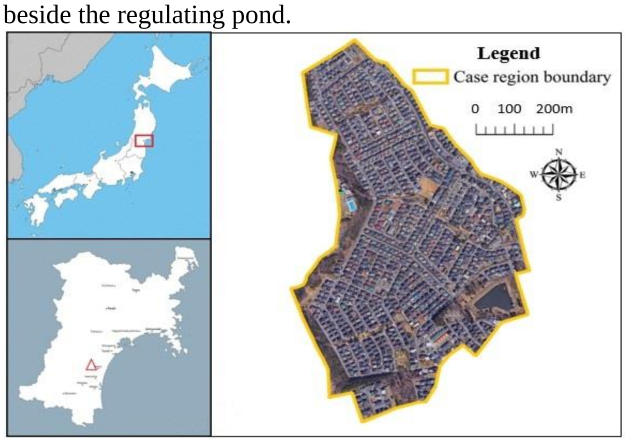

Fig.1. Watershed of Kunimigaoka Area

2.2 Data and preparation

The DEM of KA was available in the form of a high-resolution (5x5m) elevation data set, which was provided and quality controlled by the Land and Resources Department of Japan. In order to represent the blockage effect of buildings on surface flows, the building profiles were distinguished using the planar graph and Google satellite image. The underground pipeline data were obtained from Sewer Administration Office of Sendai City which contained geographic and geometric information of more than 400 pipelines and manholes. Most of the pipes are circular with diameters ranging from 0.3 to 2.4 m, while some pipes are rectangular whose widths and heights vary from 0.4 to 0.8 m. The pipe slopes show a wide range, varying from 0.5 to 38%.

2.3 Hydrological simulation design

The EPA Storm Water Management Model (SWMM) was selected for this study, as it provides all features required to meet the aims of this research. SWMM is widely used for single- or long-term event simulation of runoff quantity and quality in urban areas (Zoppou, 2001; Rossman, 2010). The spatially explicit character of SWMM allowed us to build high-resolution model to characterize the complicated overland flow routing and to examine the potential influence of TIA/EIA on rainfall–runoff. The core process in SWMM delineates the targeted catchment into a collection of sub-catchments that receive rainfall and generate runoff, then transport excess storm water from sub-catchments to assigned outlets through sewer networks (Rossman, 2010). General runoff routing described in the SWMM model was generated from upstream disconnected impervious sub-catchments and flowed through down-stream pervious sub-catchments. It was then transferred to the EIA sub-catchments and finally drained to the storm water inlet of the drainage network. Accordingly, a total of 149 sub-catchment were delineated as basic study units. Fig 2 showed the TIA/EIA and land

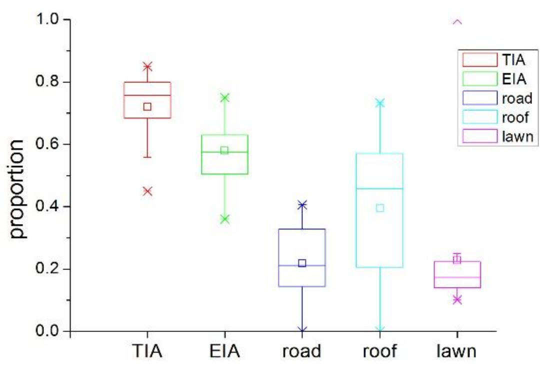

Fig.2. Imperviousness and land cover proportions within sub-catchments

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cover within the sub-catchments of study area.

To analyze the relationship between rainfall and runoff, over 80 rainfall events with varying depth and duration recorded during the 2016 and 2017 are randomly selected and simulated using the model parameterization for the P-R regression analysis. Also, the rainfall event of entire 2016 and 2017 was simulated to assessing the imperviousness effect for long series simulation.

3. RESULT AND DISCUSSION

80 selected rainfall event were simulated in our model. The runoff precipitation relationship was plotted and a linear regression analysis was conducted (see fig.3). From the result of the analysis we can see that the rainfall were comprised by two part: a compact and mild first part and a relative looser and steeper second part. The slope of the first and the second part were 0.467 and 0.715 respectively, which were close to the EIA value (0.56) and TIA value (0.75). This phenomenon well reflected the rainfall-runoff processes in the reality. When the rainfall amount were small, the water on EIA surface would generate runoff and flowed directly to the sewer. When the rainfall was large enough to exceed the infiltration capacity of the pervious area, the runoff from all the impervious area would become runoff. Therefore, for rainfalls which overwhelmed the infiltration, the general runoff ratio was close to TIA.

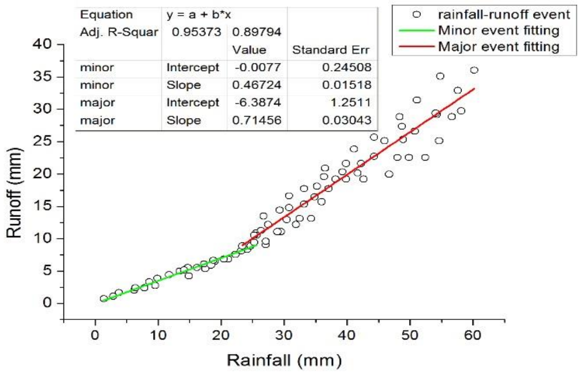

Fig.3 rainfall and runoff for the simulated minor and major event

The rainfalls could be divided to two groups: major and minor. In this case, the threshold value was 23.6mm. This value was dependent on the interception and infiltration capacities of the catchment. These capacities were represented by the intercept of the two lines in fig.3. In the aspect of all the rainfall, the average runoff-precipitation ratio was around 0.61 (fig.4). This value was quite close to EIA. This was mainly because of the minor rainfalls had a larger proportion among rainfalls of entire years. Thus, EIA should be regarded as a better and more objective indicator. The long series simulation showed similar results as well. In the view of different land surface (fig.4(b)), EIA surface had a largest r-p ratio, and then TIA, pervious surface smallest. This meant that majority of the runoff was generated from EIA surface. Thus EIA is a key indicator for runoff and pollutant controlling.

4. CONCLUSIONS

From the above explanation, we can conclude as follows:

1. In urban catchment, there is a threshold effect that can divide the rainfall to two group: the major and the minor. These two groups of rainfall had a linear relationship respectively and had different runoff rainfall ratios. The threshold value was affected by the infiltration and interception capacities of the catchment.
2. In the condition of major rainfalls, TIA was a good indicator for rainfall-runoff process. While for minor rainfalls and annual scale, EIA performed as a better and objective indicator.

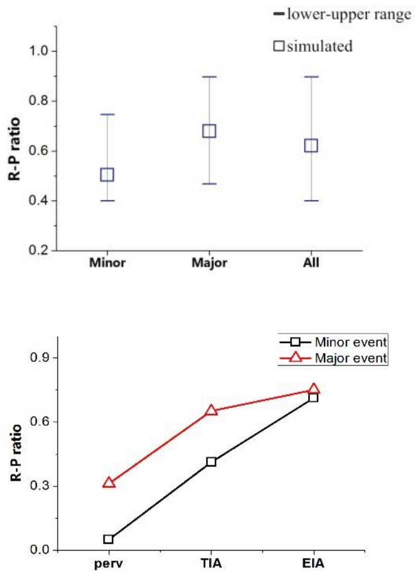

Fig.4 R-P ratio for different (a) rainfall events, (b) surface

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