Change detection of runoff-urban growth relationship in urbanised watershed

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Abstract. Urban growth has negative environmental impacts that create water-based disasters such as flash floods and storm runoff causing billions of dollars worth of damage each year. Due to serious flash floods in urbanised areas of Malaysia, water resource management is a vital issue. This paper reports on a study that has been carried out using remote sensing techniques and hydrological modelling for examining the spatial patterns changes of urban areas and its impacts on surface runoff. The estimation of surface runoff based on the Soil Conservation Service Curve Number (SCS CN) method was performed by integrating both remote sensing and Geographic Information System (GIS) techniques. Remote sensing is a data sources for monitoring urban growth by quantifying the changes of urban area and its environmental impact are then analysed by using a GIS-based hydrological model. By linking the integrated approach of remote sensing and GIS, the relationship of runoff with urban expansion are further examined. Hence, the changes in runoff due to urbanisation are analysed. This methodology is applied to the central region of Malaysia in Kuala Lumpur, where rapid urban growth has occurred over the last decade. The results showed that there was a significant between spatial patterns of urban growth and estimated runoff depth. The increase in runoff from year 2000, 2006 and 2010 are estimated about five percent.

1. Introduction

Currently, Malaysia is experiencing a rapid urbanization with human population growth. Over the last decade, the urban expansion of central region of Malaysia in Kuala Lumpur has resulted its surrounding in obvious changes to the natural environment especially in hydrological cycle. This natural process has been very extensively modified in urban areas where flash flood and water crisis is at crucial issue. Surface conditions such as the amount of vegetation, land use, type of soil and condition and other factors may also affect runoff and distribution. However, the increased runoff from impervious surface is a highly major concern in urban areas [1]. Impervious surfaces are major factors in determining the impacts of urbanization. Impervious surfaces are anthropogenic features through which water cannot infiltrate into the soil such as roads, driveways, sidewalks, parking lots, rooftops and etc. The volume of runoff increases dramatically with urbanization which is directly from connected impervious area (driveways and streets) that increase the proportion to the cover of impervious surface in a watershed hence the water discharge and flood magnitudes is increased.

In addition, the expansion of urban was found to be the main factor in long-term changes in runoff [2] and [3]. Urban watershed produces greater volume peak discharge and runoff than the grassland watershed per unit area because of decrease value in infiltration of precipitation caused from impervious surface. Urban watershed also has a smaller flow travel time compared to runoff from grassland that having similar size shape, soil and slope characteristics.

Due to humid tropical condition of Malaysia, the value of rainfall is quite high therefore the

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volumes of surface runoff and the incidence of flooding and sedimentation of receiving water bodies have been greatly increased. Generally, urbanisation would increase fluctuating amount of surface runoff response to rainfall which is generated by increased of impervious surfaces. Besides, it may also influence the timing and magnitude of rainfall inputs to urban watershed. Conceptual hydrological model is driven by weather data time series such as precipitation and soil moisture. An urbanisation change is applied to study their effects on surface runoff.

In this study, remote sensing and GIS are used extensively to study the expansion of impervious surface areas to runoff volumes for year 2000, 2006 and 2010 respectively. The U.S. Department of Agriculture uses remote sensing techniques in determining watershed geometry, drainage network, soil moisture data and land use information. Besides, determination of runoff coefficient using remote sensing data has been carried out in various studies [4]; [5] and; [6].

The remote sensing satellite images that were used are multi-temporal of Landsat data whilst the runoff estimation is based on the Soil Conservation Service Curve Number (SCS CN) model developed by the USDA-Soil Conservation Service in 1972 [7]. This model includes the calculation of runoff from Curve Numbers (CN) that relates to land use, soil type, hydrological conditions and soil moisture. In determination of runoff, land use and land cover were derived from the Landsat data and land use maps. It has been widely used for water resource management and runoff estimation in urban watershed [8]; [9]; [10]; [11]; [12] and; [13].

2. Study Area

Kuala Lumpur is the federal capital city in Malaysia has been selected for the study area. It covers an area of 242.02 km^2 and has total population of 1.6 million as of 2012. The area falls within the coordinates: 3.1357°N 101.688°E (figure 1). Many locations in the area are prone to flashfloods during heavy rainfall. The Klang-Langat River basin is located in the central region of the West Coast of Peninsular Malaysia. This area is experiencing rapid urbanization that caused its surrounding an extreme runoff. The land use of the region is a forest, settlement/urban/industrial and water bodies. The high density of population caused the urban land use to increase very rapidly.

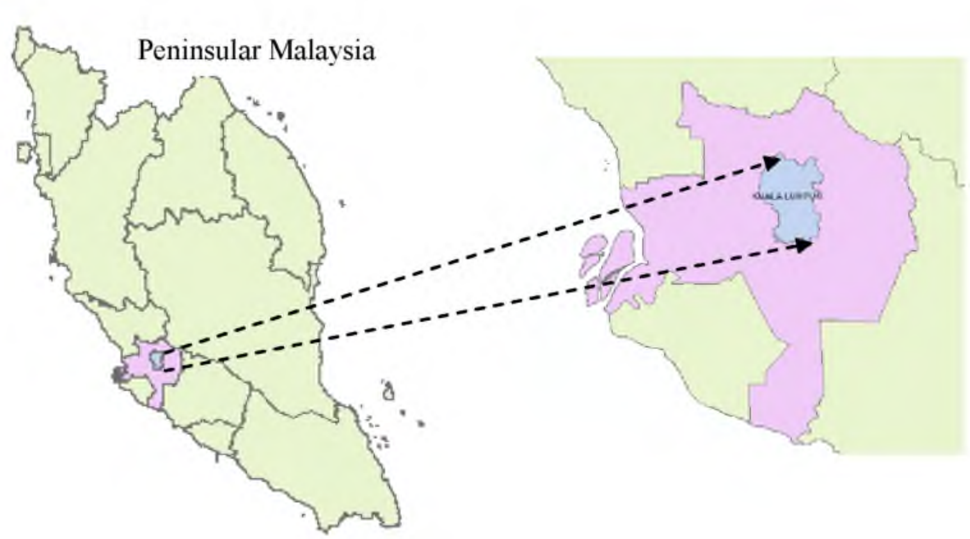


Figure 1. Study area

3. Remote sensing data and other ancillary data

This study reports on the use of the Landsat data in the detection of land use and land cover data in the central west region, Kuala Lumpur. The satellite imagery is used for deriving information that required in estimation of runoff. Other collected data are rainfall TRMM, soil type data and information on hydrological conditions.

4. Methodology

4.1. Derivation land cover data and change detection of urban areas

Land use/cover data and change detection of urban is derived by the use of Landsat Thematic Mapper data (year 2000, 2006 and 2010). The categories of land use/cover include: (1) urban or built-up area, (2) open soil, (3) forest/tree canopy, and (4) water body. Estimation of urban area is done by extracting of per-pixel based on unsupervised classification. Due to medium resolution image (30 meters), the results generated are poor. This is because of the spectral confusion between impervious surfaces and other land covers (bare soils) and the mixed pixel problems. In order to avoid spectral confusion which was richly present in the study area, a mask identifying pixels of urban areas are developed. The urban mask was applied on Landsat imageries with unsupervised classification whilst all non-urban (vegetation, water and open soil) masks were excluded from the impervious surface analysis.

Unsupervised classification method was done by manual editing of the impervious surface image to make sure that all impervious surfaces were extracted. All pixels that have probability more than 1% of being urban are classified to urban area whilst all pixels having probability more than 1% of other than urban are classified as the land-use class for which they have the highest probability. Then, supervised classification with the maximum likelihood algorithm was performed by using signature file from unsupervised classification results. The same procedure was applied to all selected Landsat images to generate multitemporal impervious surface data sets.

4.2. Hydrological modelling

In this study the hydrological models are based on the Soil Conservation Service Curve Number (SCS-CN) model is used to estimate runoff in the central region of Kuala Lumpur. Several calculations are required which are determination of runoff SCS Curve Number (CN) method.

4.2.1. Estimation of runoff To compute runoff from storm rainfall, Curve Number method is used which depends on the watershed's soil type. Determination of CN also depends on the watershed's cover conditions which the model represents as hydrologic soil type, land cover type and antecedent moisture condition (AMC). In this study, the CN value for AMC II which is moderate condition of soil (normal or average soil moisture condition) was used in estimation of runoff. The SCS equation for runoff depth is mathematically expressed as:

$$= \frac{(P-I_a)^2}{(P-I_a)+S} \quad (1)$$

Where;

Q = Actual direct runoff, mm
P = Total rainfall, mm
Ia = Initial abstraction
S = Potential maximum storage of water, mm

Ia is all the losses before runoff begins. According to studies, Ia was found to be approximately by the following empirical equation [14]:

$$I_a = 0.2\,S \quad (2)$$

To simplify the above equation, by substituting equation (2) into equation (1), gives:

$$= \frac{(P-0.2S)^2}{(P-0.8S)} \quad (3)$$

S is related to the soil and cover conditions of watershed through CN and s is related to CN by

$$S = \frac{25400}{CN} - 254 \tag{4}$$

5. Results and discussion

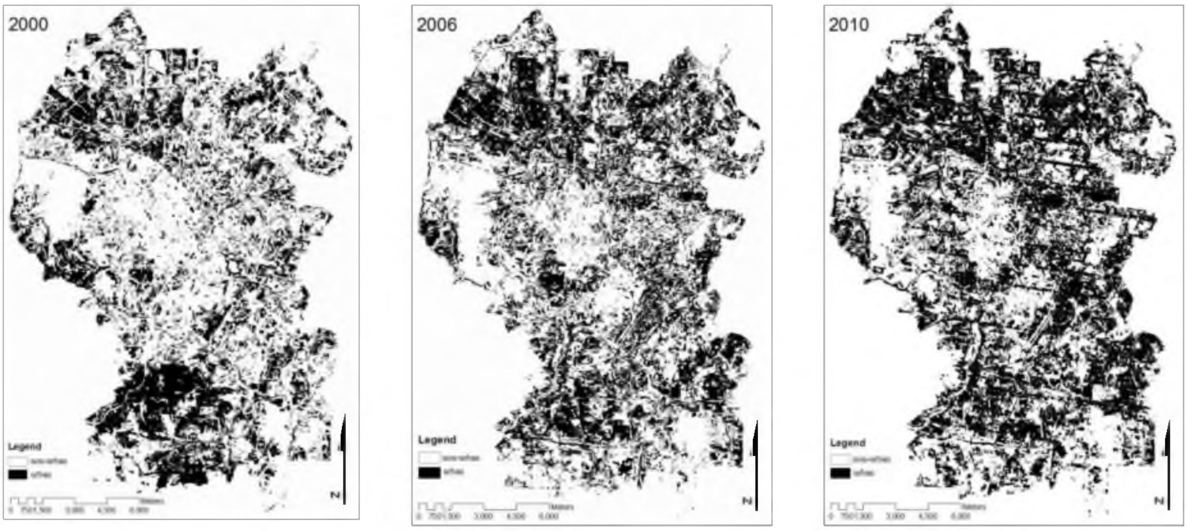
The remote sensing and GIS analysis indicates that urban or built-up area has expanded by 15 percent (35.553 km^2) during year 2000 to 2010. By overlaying the 2000, 2006 and 2010 land cover maps reveals that most urban or built-up land increases were at the expenses of forested area. Table 1 illustrate the result of this GIS overlay analysis. Figure 2 shows the binary masks of image pixels that belong to the urban area.

The impacts of urban expansion on surface runoff were examined by comparing the estimated surface runoff in year 2000 with those in 2006 and 2010. The results indicated that the annual surface runoff depth had increased by 10.227 mm during year 2000 to 2006 but had decreased -7.464 mm in year 2010 due to less amount of annual rainfall in year 2010. However, impacts of large expansion of urban areas can be examined by determining the runoff coefficient (K) as a function of rainfall in each year of 2000, 2006 and 2010 [5]. Runoff coefficient is expressed as equation (5); percentage of rainfall that appears as storm-water runoff from a surface.

$$K = \frac{Runoff\ (mm)}{Rainfall\ (mm)} \tag{5}$$

Table 1. Summary of urban expansion and its impact to runoff in Kuala Lumpur.

Year	Urban area (km^2)	Amount rainfall (mm)	Mean surface runoff (mm)	Runoff coefficient
2000	82.467	144.434	88.894	0.615
2006	98.030	157.105	99.121	0.631
2010	118.020	141.547	91.657	0.648



(a) (b) (c)

Figure 2. Expansion of urban area in year (a) 2000; (b) 2006 and; (2010)

By comparing runoff coefficients (Figure 3), the degree of urban expansion has increased from 2000 to 2010. In fact, during these periods of time, a large expansion of urban had occurred. From classified urban or built-up areas, a spread pattern can be detected. Besides, by relating urban expansion and runoff coefficient, a correlation analysis between them gives a multiple value of r is 0.9 (significant at the 0.05 level). Therefore, the effect of urban expansion to runoff can be examined significantly.

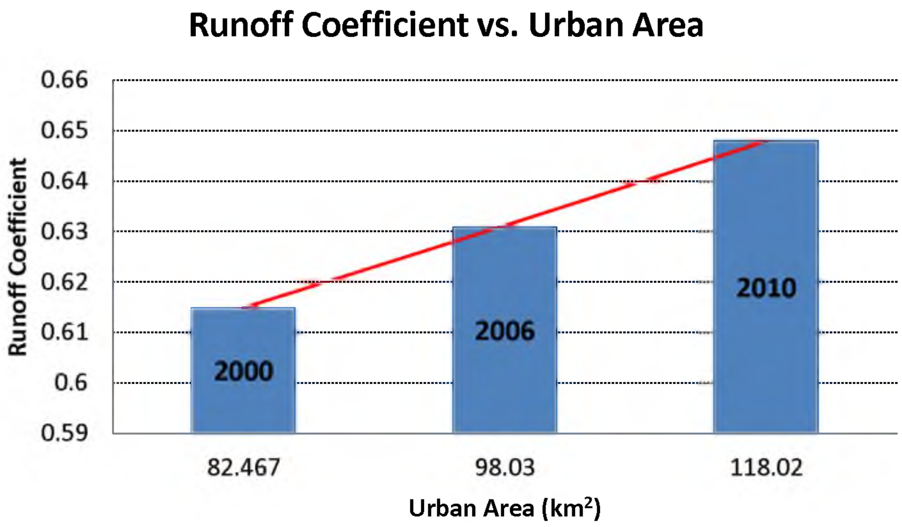


Figure 3. Relationship between expansion of urban area and surface runoff.

6. Conclusions

This paper focused on the approach of remote sensing and GIS-based hydrological models for urban growth study and its impact to water resource, i.e. runoff. The model of SCS CN is potentially compatible with remote sensing input as the major inputs are rainfall and CN. CN represents the runoff potential that are based on land use/cover from the classified images and soil groups. By integrating Remote Sensing and GIS, urban growth and it relationship can be examined through spatial analysis.

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