ANALYSIS OF LAND COVER CHANGE AND ITS IMPACT TO SURFACE RUNOFF WITHIN JAKABARING SUB BASIN

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Abstract

Jakabaring is an area in the Palembang City which has been growing rapidly for over last ten years. Most of this area has been developed for sport center, government office, business and commercial district, school, and residential areas since early 2000; which was formerly large lowland. Due to the rapidly increasing development, the lowland areas decreased which might lead to an increased risk of flooding. This study aims to analyze the land cover change within Jakabaring sub basin and its impact on surface runoff. Land cover change analysis was done using Semi-Automatic Classification plug-in installed on QGIS to Landsat images for year 2002 and 2013. The rational method was used in this study to estimate the peak runoff rate. The results of this study show that the vegetated area has decreased by as much as 527.83 ha (26.37%), while the built-up area increased by as much as 540.38 ha (27.00%). The decrease of vegetated area mostly due to the area was converted into built-up area. The land cover change within Jakabaring sub basin was estimated to increase the peak runoff rate about 30.23%. Hence, this condition could make the area become more risky to flood.

Keywords: flooding, lowland, rational method, remote sensing

INTRODUCTION

General Background

The land cover is one of important factors in hydrologic analysis. It is used to calculate the magnitude of surface runoff that can cause flooding. The changing of land cover within a sub basin especially in urban area from unpaved area to paved area can trigger the increase of surface runoff volume. As an area continues to be developed, then the analysis of land cover change becomes indispensable.

Palembang City is one of flood-prone areas in Indonesia much affected by tidal flow of Musi River. Besides that, the land cover changes especially in Jakabaring area (Figure 1) which is growing to be an economic center in Palembang may lead this area to be more risky being flooded during heavy rainfall. Since Jakabaring area was developed in the beginning of year 2000, most of this area has been changed significantly from wetland to be paved areas for sport center, government office, commercial area, school, and residential area. For the future, government has planned to develop this area to be an economic center in Palembang City. In order to anticipate the increase of flood risk in Jakabaring sub basin, it is necessary to analyze the land cover change within this area.

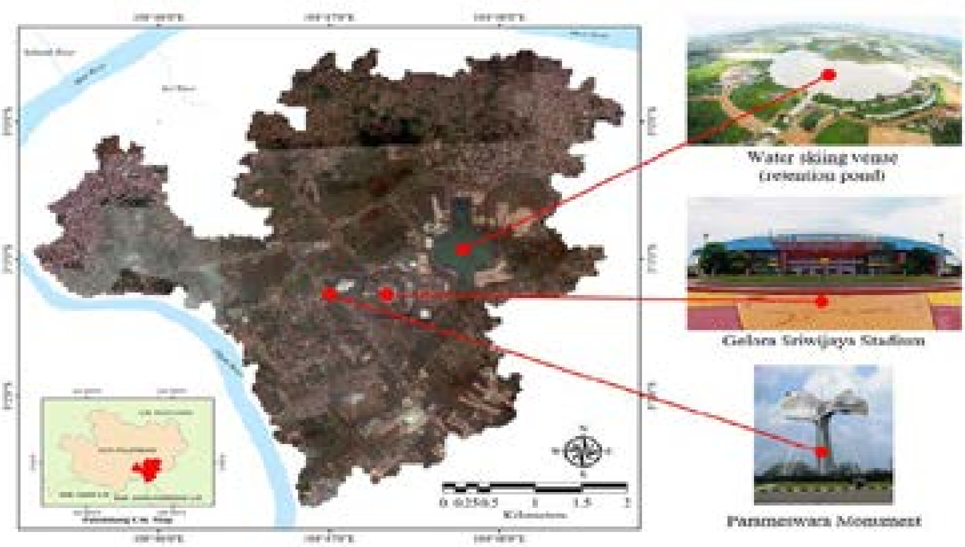

Figure 1.   Area of study

Literature Study

Many studies have been conducted to analyze the impact of land cover change on surface runoff; among them were studies carried out by Shi, et al. (2007), Wan and Yang (2007), Githui, et al. (2009), Olang, et al. (2012), Jia and Wan (2012), and also Sajikumar and Remya (2014).

The remote sensing and geographical information system (GIS) are useful for analyzing and mapping land cover change within an area in order to understand and monitor spatial changes (Africover, 2002 in Congedo and Munafo', 2012). Congedo and Munafo' (2012) developed a methodology for monitoring spatial changes through remote sensing and GIS techniques, which the processing software could be accessed from open-source software, particularly QGIS. The developed methodology used Landsat satellite images, because of their spatial and spectral resolutions, multitemporal images availability, and particularly the free cost of data; which could be retrieved from U.S. Geological Survey (USGS) online archive at http://earthexplorer.usgs.gov/.

The rational method is the most popular method used to estimate the rate of runoff for the design of storm drainage (Yen and Akan, 1999 in Mays, 2001). It is mostly used for determination of peak flow rate within urban catchments (Ghosh, 2014). The idea behind the rational method is that if a constant intensity of rainfall which is uniformly spread over an area begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration; when the entire watershed is contributing to flow at the outlet. It is thus evident that the maximum rate of runoff will occur when the rainfall duration equals the time of concentration. Using the rational method, the peak of storm runoff is estimated by the rational formula as

$$Q = 0.278\, C\, I\, A \quad (1)$$

where

Q : peak runoff rate (m^3/s)
C : runoff coefficient (-)
I : rainfall intensity (mm/hr)
A : drainage area (km^2)

The runoff coefficient C is defined as the ratio of inflow rate (the product of rainfall intensity I and watershed area A) for the system to the rate of peak discharge Q (which occurs at time of concentration). This coefficient is ranging between 0 to 1 ($0 \leq C \leq 1$) depends on the surface characteristic of area. Suggested runoff coefficients for various surface types can be seen in Chow, et al. (1988) and Ghosh (2014).

In urban areas, the drainage area usually consists of subareas of different surface coverage. As a result, an average coefficient is required to account all of surface coverage. The average runoff coefficient for use in the rational method can be calculated using the following equation:

$$\overline{C} = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i} \quad (2)$$

where

$\overline{C}$: average runoff coefficient (-)
C_i : runoff coefficient for each surface coverage (-)
A_i : area for each surface coverage (km^2)

Methodology

The analysis of land cover change in this study was done by remote sensing method using Semi-Automatic Classification plug-in installed on QGIS, which is one of the most widely used open source GIS software. The area of Jakabaring sub basin studied was approximately 2001 ha. The dataset used were Landsat 7 ETM image for year 2002, which was acquired on June 30th, 2002 and Landsat 8 OLI & TIRS for year 2013, which was acquired on June 20th, 2013. Both of images were corrected and sharpened using Dark Object Subtraction (DOS) atmospheric correction and pan-sharpening method before analyzed (Congedo, 2015). The pixel size of the images was 15 m x 15 m. The band set used for land cover classification was composed of band 2, 3, 4, 5, 6, and 7. The land cover classifications used in this study were grouped into built-up (building, parking lot, road, and etc.), water bodies (lake, retention pond, river, and etc.), vegetated areas (swamp, garden, and etc.), and bare soil. Since the supervised classification was applied in this study, the region of interest (RoI) or training area for each classification used to identify the same classes in the image and also helped by using aerial image for area of study. After completing RoI, then the land cover classifications for year 2002 and 2013 were analyzed. The changing of area on each classification between these two years is called by the land cover change. The impact of land cover change in respect to surface runoff was estimated by using rational method since no runoff data were available in the area of study.

RESULTS AND DISCUSSION

Land Cover Changes

The Landsat images for year 2002 and 2013 respectively are shown in Figure 2. The combination of band for image of 2002 is 3, 4, 7 RGB (red, green, and blue), while for image of 2013 is 4, 5, 7 RGB; which is suitable to describe vegetated area (shown as green color), built-up (shown as purple color), water body (shown as black and dark red), and bare soil (shown as light purple color). The images have corrected using DOS correction and sharpened using pan-sharpening so the image resolution or pixel size increased from 30 m x 30 m become 15 m x 15 m.

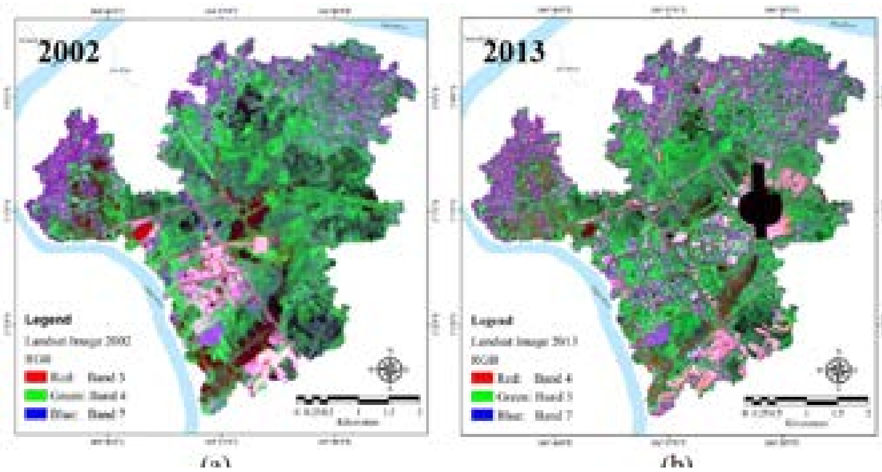

Figure 2. Landsat images for year 2002 (a), and 2013 (b)

The land cover classifications for year 2002 and year 2013 respectively are shown in Figure 3. The vegetated area is shown in green color, while the built-up, water body and bare soil are shown in red, blue, and orange respectively. From Figure 3, it is obviously can be seen that Jakabaring sub basin has changed significantly to be built-up area over last ten years. The land cover changes in Jakabaring in more detail are given in Table 1. From Table 1, the vegetated area decreased from 1133.98 ha (56.66%) in 2002 to 606.16 ha (30.29%) in 2013 or in other words decreased as much as 527.83 ha (26.37%), while the built-up area increased as much as 540.38 ha (27.00%). This condition can lead the increase of surface runoff rate in the Jakabaring sub basin. The land conversion for each classification is shown in Figure 4.

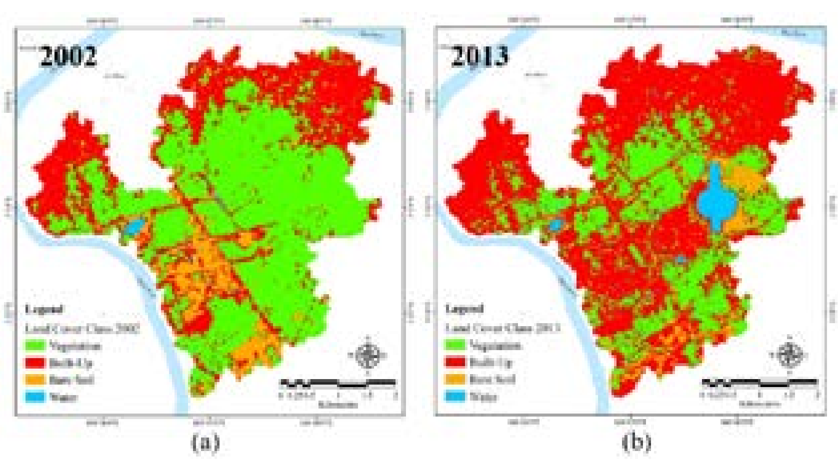

Figure 3. Land cover classifications for year 2002 (a), and 2013 (b)

Class	Land Cover Description	2002		2013		Change	
		Area, A		Area, A		Area, A	
		(%)	(ha)	(%)	(ha)	(%)	(ha)
1	Water	0.70	14.11	3.22	64.51	2.52	50.40
2	Built-Up	33.50	670.52	60.50	1210.90	27.00	540.38
3	Vegetation	56.66	1133.98	30.29	606.15	(26.37)*	(527.83)*
4	Bare Soil	9.13	182.79	5.99	119.84	(3.15)*	(62.96)*
	Total	100.00	2001.40	100.00	2001.40		

Table 1. Land cover changes within Jakabaring sub basin

*note: decreased

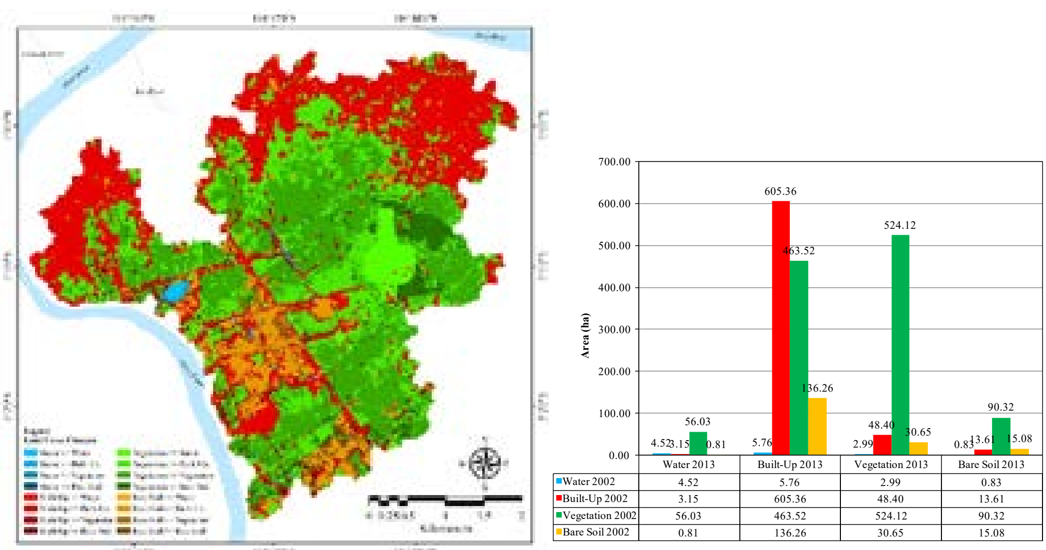

Figure 4. Land conversion for each classification

Figure 4 above shows that the largest land conversion is the conversion of vegetated area into built-up area which is covering about 463.52 ha followed by bare soil into built-up area about 136.26 ha, and vegetated area into bare soil about 90.32 ha. The land conversions could explain that the decrease of vegetated area mostly caused by the area was converted to be built-up area. Moreover, the conversion of vegetated area into bare soil and then bare soil into built-up show a strong tendency the built-up area might be more increase in the future.

Since the area consists of four different land covers, an average runoff coefficient analysis is required. The computation of runoff coefficient for each land covers using rational method given in Table 2.Based on Table 2 above, the average runoff coefficient for year 2002 can be calculated as

$\overline{C}_{2002} = 1062.84/2001.40 = 0.53$ while the average runoff coefficient for year 2013 can be also calculated as $\overline{C}_{2013} = 1384.13/2001.40 = 0.69$

Table 2. Computation of runoff coefficient using rational method

Class	Land Cover Description	2002			2013		
		A (ha)	C (-)	C . A (ha)	A (ha)	C	C . A (ha)
1	Water	14.11	1.00	14.11	64.51	1.00	64.51
2	Built-Up	670.52	0.88	590.06	1210.90	0.88	1065.60
3	Vegetation	1133.98	0.34	385.55	606.15	0.34	206.09
4	Bare Soil	182.79	0.40	73.12	119.84	0.40	47.93
	Total	2001.40		1062.84	2001.40		1384.13

Time of Concentration

The time of concentration used in the rational method is the time associated with the peak runoff from the watershed to the point of interest. Runoff from a watershed usually reaches a peak at the time when the entire watershed contributing; in this case, the time of concentration is the time for a drop of water to flow from the remotest point in the watershed to the time the entire watershed is contributing (Mays, 2001).

The time of concentration in this study was calculated using Kirpich equation (1940) as expressed in the following equation:

$$t_c = \frac{0.06628L^{0.77}}{S^{0.385}} \quad \text{..........} (3)$$

where

t_c : time of concentration (hr)

L : length of channel/ditch from headwater to outlet (km)

S : average watershed slope (km/km)

Based on GIS analysis to digital terrain model (DTM) which is also known as digital elevation model (DEM) and drainage networks as shown in Figure 5, and also land slope map (Figure 6), it was obtained the average watershed slope and length of channel repectively were 0.65 degree (1.14%) and 8.16 km. By using Equation (3), it can be calculated that time of concentration is 1.72 hour. The time of concentration is then used to calculate the intensity of design rainfall.

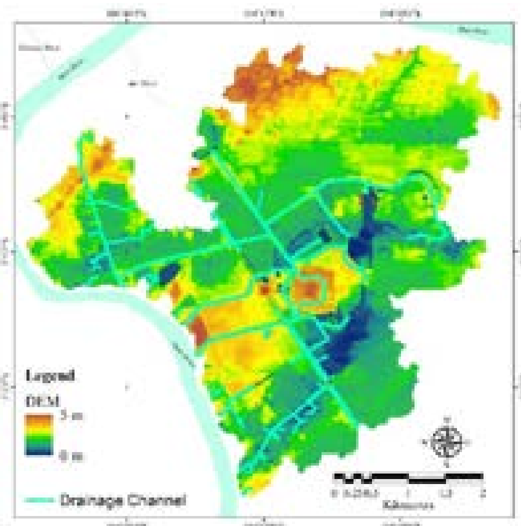

Figure 5. Digital terrain model (DTM) overlaid by drainage networks

Figure 6. Land slope map

Design Rainfall

The design rainfall for the sub basin was calculated by frequency analysis using 28 years (1988-2015) long-term observed data obtained from Plaju gage station operated by BMKG *(Badan Meteorologi, Klimatologi, dan Geofisika)* Palembang. Table 3 below shows the design rainfall according to the probabilities.

Table 3. Design rainfall according to the probabilities

$P(X \geq X_m)$	T	Design rainfall (mm/day)							
Probability	Return Period	Normal		Log-Normal		Gumbel		Log-Pearson III	
		X_T	K_T	X_T	K_T	X_T	K_T	X_T	K_T
0.9	1.1	72.936	-1.282	72.910	-1.282	78.014	-1.100	71.821	-1.334
0.5	2.	108.846	0.000	104.992	-0.138	104.243	-0.164	109.421	0.145
0.2	5.	132.429	0.842	133.402	0.876	129.006	0.719	133.782	0.852
0.1	10.	144.756	1.282	151.191	1.511	145.401	1.305	145.545	1.148
0.05	20.	154.937	1.645	167.658	2.099	161.128	1.866	154.520	1.358
0.02	50.	166.394	2.054	188.345	2.837	181.485	2.592	163.680	1.560
0.01	100.	174.033	2.326	203.536	3.379	196.739	3.137	169.181	1.677
0.001	1,000.	195.437	3.090	252.953	5.143	247.145	4.936	181.862	1.931

Based on the goodness of fit test using chi-square and Smirnov Kolmogorov method, the normal distribution was the best probability distribution for the rainfall data series. Therefore, the design rainfall was calculated using normal distribution.

The rainfall intensity during time of concentration in this study was calculated using Mononobe method which is expressed in the following equation:

$$I = \frac{R_{24}}{24}\left(\frac{24}{t_c}\right)^{2/3} \qquad (4)$$

where

I : rainfall intensity (mm/hr)

R_{24} : maximum daily rainfall (mm/day)

By using design rainfall from Table 3 and time of concentration previously obtained, the rainfall intensity for each return period can be calculated using Equation (4) where the result is given in following Table 4.

Table 4. Design rainfall intensity

T (year)	R_{24} (mm/day)	I (mm/hr)
2	108.85	26.29
5	132.43	31.98
10	144.76	34.96
20	154.94	37.42
50	166.39	40.18
100	174.03	42.03

Surface Runoff

Using rational method from Equation (1), the peak runoff rate for year 2002 and 2013 can be calculated which the result as shown in Table 5.

Table 5. Peak runoff rate for every return period

Year	Peak runoff rate, Q (m^3/s)					
	2-year	5-year	10-year	20-year	50-year	100-year
2002	77.67	94.49	103.29	110.55	118.73	124.18
2013	101.15	123.06	134.51	143.97	154.62	161.72

From Table 5 above, the magnitude of peak runoff for each return period increased on average 30.23% from year 2002 to 2013. This can be understood as the result of the increase of built-up area as much as 27%, while the vegetated area decreased as much as 26.37%. Since Jakabaring area is going to be more developed in the future, the increase of runoff can be higher than that magnitude. Furthermore, this condition can make Jakabaring sub basin becomes more risky affected by flooding.

CONCLUSION

From the analysis and previously discussion, it can be concluded as followings:

1. The Jakabaring sub basin has changed significantly for over last ten years due to lowland reclamation generally by the development of sport center, government office, commercial and residential areas.
2. The vegetated area has decreased as much as 527.83 ha (26.37%), while the built-up area has increased as much as 540.38 ha (27.00%) from year 2002 to 2013.
3. The largest land conversion is the conversion of vegetated area into built-up area which is covering about 463.52 ha followed by bare soil into built-up area about 136.26 ha and vegetated area into bare soil about 90.32 ha.
4. The land cover changes within Jakabaring sub basin estimated to increase the peak runoff as much as 30.23%, so this condition can make the area become more risky to flooding.

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