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Runoff Coefficient Analysis After Regional Development in Tambakbayan Watershed, Yogyakarta, Indonesia

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ABSTRACT
The Tambakbayan Watershed has experienced changes in its land utilization. Based on land-use data from 2006 and 2017, built-up land was found to have encroached on vegetated areas and showed a substantial increase in area. Such conversion can alter and modify runoff coefficients, as a measure of watershed response. This research aimed to evaluate land-use change in the watershed from 2006 through 2017 and its effects on runoff coefficients. It used descriptive quantitative methods combining literature study and data calculation. The secondary data were obtained from digital land-use maps (RBI) in 2006 and 2017, SRTM images, soil types, and the drainage network of the watershed. Runoff coefficient analysis confirmed that the land-use change between 2006 and 2017 caused by regional development increased the runoff coefficients of the watershed observed.

Kata kunci: Watershed, land-use change, runoff coefficient, regional development

ABSTRAK
Daerah Aliran Sungai Tambakbayan telah terjadi perubahan, berdasarkan data penggunaan lahan tahun 2006 dan tahun 2017. Perubahan yang terjadi berupa meningkatnya lahan terbangun dan berkurangnya lahan bervegetasi. Perubahan penggunaan lahan yang terjadi dapat mengakibatkan perubahan respon DAS yang dikuantifikasikan dalam bentuk koefisien aliran. Tujuan penelitian adalah mengevaluasi perubahan penggunaan lahan daerah penelitian dari tahun 2006 dan 2017, kaitannya dengan koefisien aliran. Metode yang digunakan adalah deskriptif kuantitatif berdasarkan studi pustaka dan perhitungan. Data sekunder yang digunakan adalah Peta Rupa Bumi Digital Indonesia Tahun 2006 dan 2017, Citra SRTM DAS Tambakbayan, Jenis Tanah DAS Tambakbayan, dan Jaringan Drainase DAS Tambakbayan. Perubahan penggunaan lahan akibat perkembangan wilayah, mengakibatkan peningkatan koefisien aliran pada tahun 2017 apabila dibandingkan dengan koefisien aliran pada tahun 2006.

Kata kunci: Daerah Aliran Sungai, perubahan penggunaan lahan, koefisien aliran, perkembangan wilayah

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1. Introduction

Land use continues to change over time as population size multiplies. Population growth will lead to an upturn in the economy and demands on basic necessities (Suprayogi et al., 2019). More and more people will need food, shelter, and occupations; consequently, land functions will need to be modified to fit their activities and needs. In the context of a watershed as an integrated ecosystem, such modification should be managed because land and soil play a significant part in watershed responses (Birkinshaw et al., 2021).

Built-up land represents a conversion of the physical appearance and function of a land surface for various purposes. Vast agricultural areas have been converted into residential buildings, creating extensive areas of impermeable land and increasing the amount of rainfall that ends up as runoff (Sriwongsitanon and Taesombat, 2011). Runoff coefficient is ratio of certain amount of water drained during rainfall and the volume of precipiration during certain perion in the certain area or watershed (Machado, et al., 2021). The wider the built-up area, the greater the proportion of rain that becomes surface runoff. Floods will occur if the river system cannot accommodate the constantly increasing flows. This research use hidrological model for runoff coefficient to represent the land use change effects toward runoff in the watershed (Beck et al., 2017).

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Tambakbayan is a sub-watershed of the Opak River that traverses the Special Region of Yogyakarta (SRY), Indonesia. Over the last few years, the amount of agricultural land has been shrinking as it has been transformed into non-agricultural areas at an annual rate of 1.3% (Ministry of Public Works, 2010). Given that this process significantly alters the watershed's response to rain, integrated and sustainable resource development planning and management that regulate land use, along with a spatial plan, become necessary.

Land use or space management is regulated in the Regional Spatial Plan (RTRW) documents. The spatial plan of the Tambakbayan Watershed is mostly included in the Spatial Plan of the Sleman Regency, whose government has provisions on built-up land function, maximum height, number of floors, setbacks or buffers, floor area ratio (FAR), basement floor area ratio, a city's utility network, building coverage ratio (BCR), and green area ratio (GAR). BCR and GAR are closely related to land-use change, and they indirectly affect surface runoff. The Regional Spatial Plan can be used to control a city's development and land utilization in an attempt to minimize environmental damage in the Tambakbayan Watershed. This impact to runoff coeffiecient is complex (Lallam et al, 2018)

It is against this background that the research report was designed to evaluate surface runoff within the context of land-use change from 2006 to 2017. This research aims to evaluate land-use change in the watershed from 2006 through 2017 and its effects on runoff coefficients.

2. Methods

2.1. Study Area

Tambakbayan is a watershed in the SRY and is undergoing rapid economic growth following the expansion of the built-up land area. The area's growing population needs land for various purposes and interests, including to satisfy the demand for housing. This leads to an increase in the size of the impermeable surface area, which in turn affects the watershed's ability to store water and, ultimately, transforms a large proportion of the rain that falls in the area into runoff.

2.2. Data Analysis

2.2.1. Drainage Density Calculation

The drainage density was calculated using the equation below:

$$Dd = L/A \quad (1)$$

where:

Dd = Drainage Density (Km/Km2)
L = Stream Length (Km)
A = Sub-watershed Area (Km2)

In this calculation, the Tambakbayan Watershed was divided into several sub-watersheds.

2.2.2. Slope Gradient Calculation

Slope gradients were converted automatically from the elevation data presented in the SRTM image data using the Slope tool. As such, the slope variations in the Tambakbayan Watershed were categorized into four classes: 0–5%, 5–10%, 10–30%, and >30%. Each class wasassigned a score based on the criteria in the Cook method. The slope map was created using ArcMap 10.4.1 software.

2.2.3. Runoff Coefficient Mapping

The Cook method was used to generate runoff coefficient maps comprising layers of physical parameters: slope maps, infiltration maps (derived from soil maps), land-use maps, and drainage density maps. These four maps were scored according to the requirements presented in Table 1 and then overlaid to produce runoff coefficients (C) in the watershed observed. There were two sets of land-use maps, for the two years of 2006 and 2017; hence, there were two runoff coefficients, one for each of 2006 and 2017.

2.2.4. Calculation Result Analysis

The calculation result of runoff was estimated using runoff coefficient based on cook's method by examining the watershed infiltration, vegetation cover, slope, and drainage density (Miardini and Susanti, 2016). The results were presented in tables, graphs, and maps and analyzed using the descriptive qualitative method. The land-use types and distributions in 2006 and 2017 were evaluated for any differences and effects on runoff coefficients. Changes in the runoff coefficients weredepicted in the runoff coefficient maps, while changes in the area of each runoff coefficient were presented in graphs

3. Results and discussion

3.1. Slope Gradients

After converting the elevation data derived from SRTM imagery, the slope gradients of the watershed observed were divided into four classes: undulating (0–5%), rolling (5–10%), steep (10–30%), and very steep (>30%). The data processing produced the slope map shown in Figure1, with the area of each slope class presented in Table 2.

The Tambakbayan Watershed had mainly steep slopes (10–30%) covering an area of 31.38 km^2. This slope class was given a score of 30, meaning that it contributes to fairly high streamflow and surface runoff. The steeper the slope, the higher the score and the greater the amount of surface runoff it produces. Steeper slopes have a larger gravity force than flat to gentle slopes. As a result, soil on the former retains and stores less water because it has fewer fine pores that can be filled with water, therefore creating more surface runoff compared to soil on the latter (Suryanto and Wawan, 2017)

3.2. Infiltration

The infiltration capacity was computed from the most widely distributed soil texture in the watershed. Based on the field survey data provided by the Yogyakarta Environmental Agency, the Tambakbayan Watershed contains several different soil textures, namely loam, sandy loam, silty loam, and loamy sand. These four soil textures were classified as having good to very good infiltration, as seen in Table 3. Loamy sand has very good infiltration because it can transmit water very well, and this texture was given a score of 5. Meanwhile, sandy loam, silt loam, and loam were all categorized as having good infiltration, with a score of 10. The infiltration classification of the Tambakbayan Watershed can be seen in Figure 2.

3.3. Drainage Density

The drainage density is the ratio of river length to the sub-watershed area and can be differentiated into four classes: high (Dd <1.6 km/km^2), moderate (1.6≤Dd<3.2 km/km^2), low (3.2≤Dd<8.0 km/km^2), and very low (≥8.0 km/km^2) (Linsley, 1979 in Indriatmoko and Wibowo, 2007). As seen in Figure 3, the Tambakbayan Watershed has three classes ofdrainage density: low, moderate, and high. Lowdrainage density is characterized by a small and easily recognized drainage system (Indriatmoko and Wibowo, 1984). Table 4 shows each drainage density area. Of the three classes of drainage identified, high drainage density covered the largest part of the watershed.

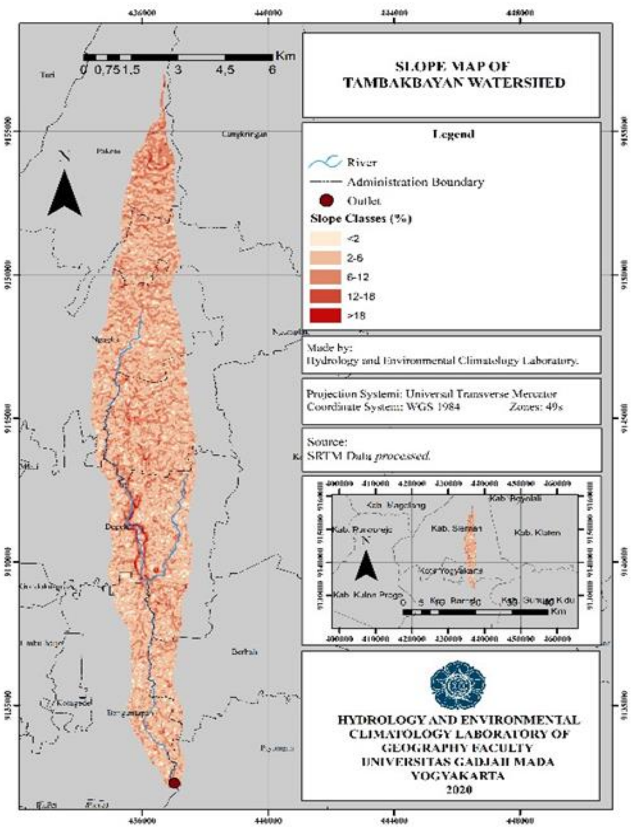

Figure 1. Slope Map of the Tambakbayan Watershed

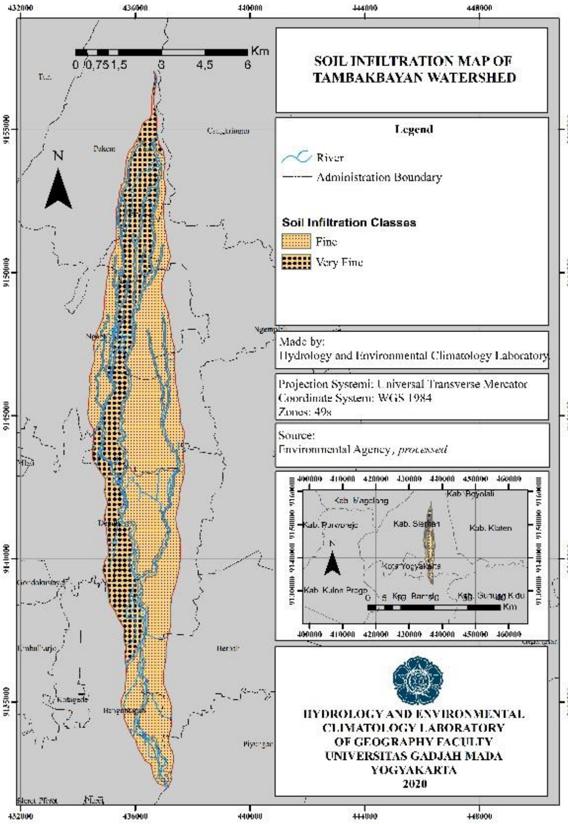

Figure 2. Soil Infiltration Map of theTambakbayan Watershed

Table 1. Watershed Characteristics According to the Cook Method

Considered watershed characteristics	**Runoff coefficients (C)**			
	100 (Extreme)	**75 (High)**	**50 (Normal)**	**25 (Low)**
Slope/Relief (R)	Very Steep (>40%)	Steep (10–30%)	Moderate (5–10%)	Flat to gentle (0–5%)
Weight values	40	30	20	10
Soil Infiltration (I)	Rock covered by thin soil	Clay	Sandy loam, silty loam, loam, clay loam	Sand, loamy sand
Weight values	20	15	10	5
Vegetation Cover(L)	Settlement, open land	Irrigated paddies, rainfed paddies, and dry agricultural fields	Multi-species plantations, less dense forest	Dense forest
Weight values	20	15	10	5
Drainage Density (Dd, km/km^2)	Neglected: some shallow surface depression, steep and small drainage channels (≥ 8)	Low: small drainage channels and easily recognized drainage system (3.2–8)	Normal: depression storage in lakes, swamps, and ponds is no more than 2% (1.6–3.2)	High: high surface depression storage, difficult-to-recognize drainage system, there are many lakes, swamps, and ponds (<1.6)
Weight values	20	15	10	5

Source: Data Analysis, 2020

Table 2. Slope Classification of the Tambakbayan Watershed

Slope (%)	Class	Score	Area (km^2)	Percentage (%)
0–5	Flat to gentle	10	27.61	58.23
5–10	Moderate	20	16.85	35.54
10–30	Steep	30	2.95	6.22

Source: Data Analysis, 2020

Table 3. Soil Infiltration Classification ofTambakbayan Watershed

Soil textures	Area (km^2)	Score	Infiltration Class
Sandy loam, silt loam, loam	33.58	10	Good
Loamy sand	13.85	5	Very good

Source: Data Analysis, 2020

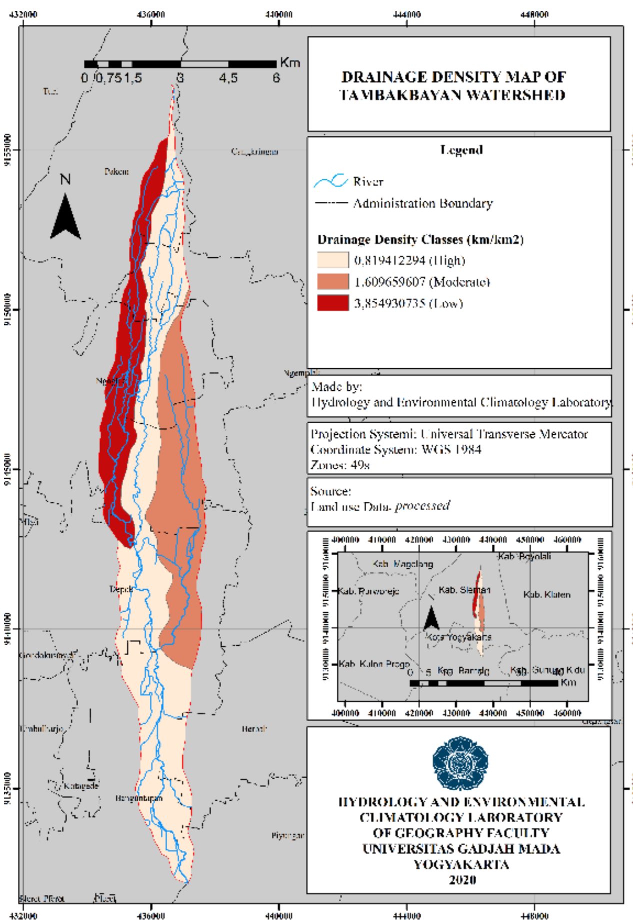

Figure 3. Drainage Density Map of theTambakbayan Watershed

Table 4. Drainage Density Classification of the Tambakbayan Watershed

Drainage Density	Area (km^2)	Score
High	25.71	5
Moderate	12.52	10
Low	9.18	15

Source: Data Analysis, 2020.

3.4. Land Use

According to the Cook method, land use is a parameter of runoff coefficients. Unlike the first three parameters that have relatively stable conditions, land use is more dynamic and is the one most likely to change in line with population growth. Rapid development and concomitant land-use conversion can change the runoff coefficient of a watershed. This research compared the two parameters in different years: 2006 and 2017. The land-use types and distributions are presented in **Tables 5 and 6.**

Based on the land-use area calculation, in 2006, the Tambakbayan Watershed was mainly used for paddies and dry agricultural fields. In 2017, some changes were apparent in that most of the agricultural areas were smaller in size following the conversion of such areas into residential buildings. This land use was given ascore of 20, indicating that a greater proportion of rainfall was transformed into surface runoff. The land-useconversion was determined by comparing the land-use conditions in 2006 with those in 2017, as presented in **Figures 4.a. and 4.b.**

3.5. Runoff Coefficient (C)

The runoff coefficient (C) of the Tambakbayan Watershed was calculated based on the land-use types and distributions in 2006 and 2017. It was also influenced by slope, soil texture, and drainage density. In the calculation, these parameters were combined using predetermined weight values to produce the runoff coefficients. The distribution of the runoff coefficients in 2006 and 2017 isshown in **Figure 5.a. and 5.b.**

According to Permatasari et al. (2017), land use is a determinant of a watershed's hydrological functions, which are represented by runoff and baseflow. In 2011, the majority of the watershed area had a high runoff coefficient, meaning that almost the entire watershed contributed to the formation of its large runoff. The score of 60 (high runoff coefficient) had the widest distribution (11.73 km^2), followed by the score of 65, which covered the second-largest area (10.25 km^2). Both scores were evenly distributed throughout the Tambakbayan Watershed, notably because of the extensive residential land, paddies, and plantations.

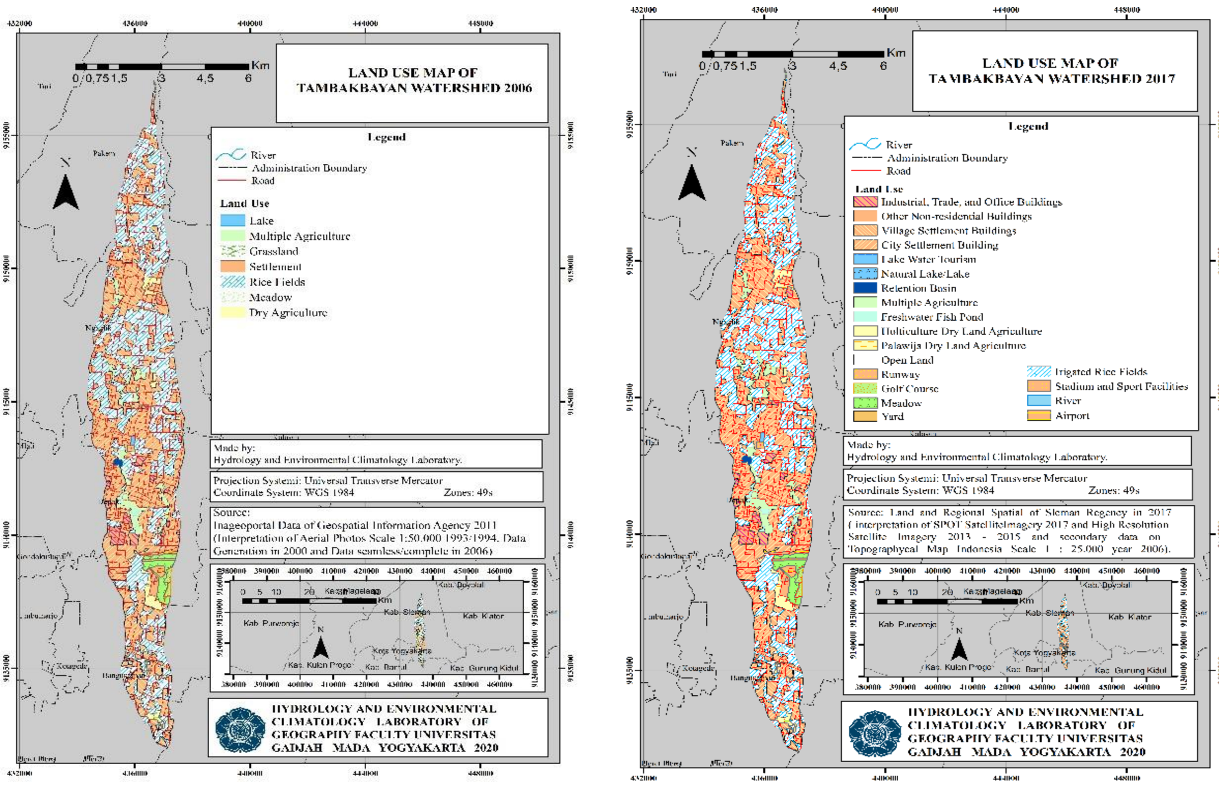

Figure 4.a. Land-use Map of the Tambakbayan Watershed in 2006 and Land-use Map of the Tambakbayan Watershed in 2017

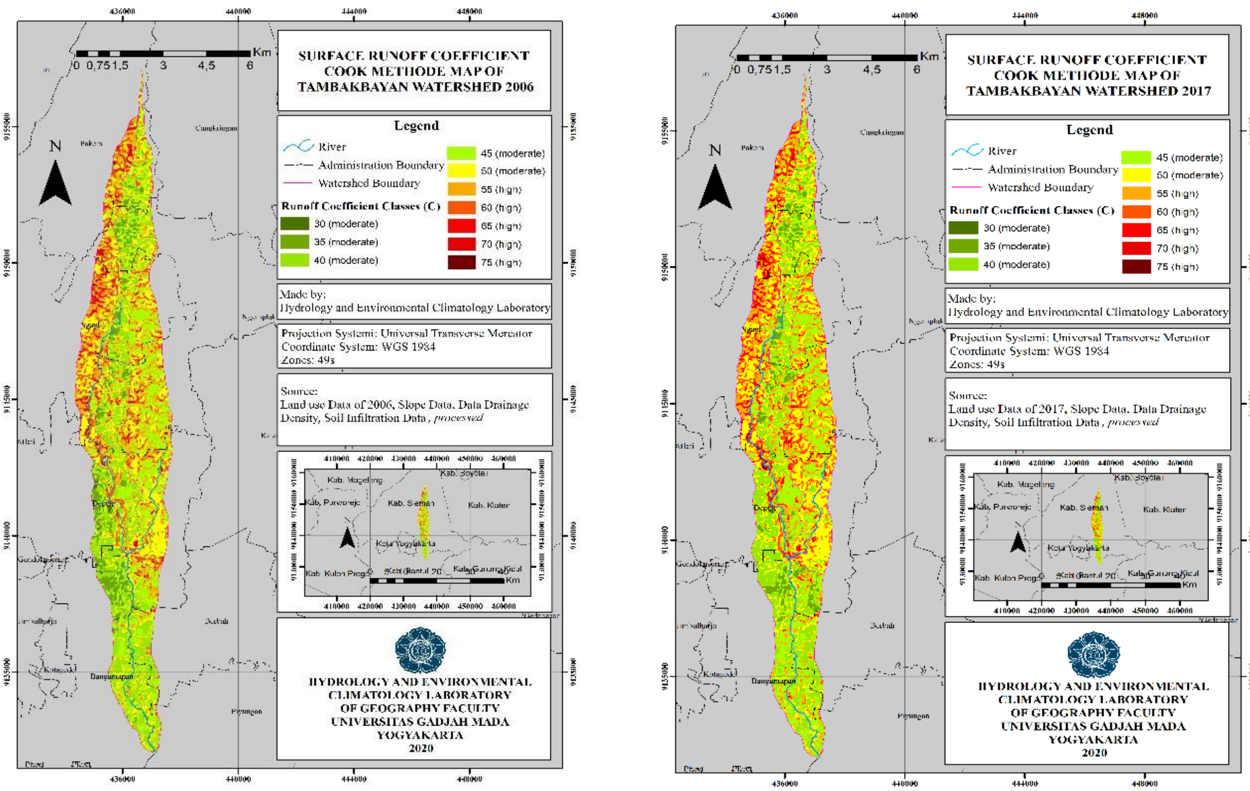

Figure 5.(a). Runoff Coefficient Map of the Tambakbayan Watershed in 2006 based on the Cook Method (b). Runoff Coefficient Map of the Tambakbayan Watershed in 2017 based on the Cook Method

Table 5. Land-Use Type and Distribution in the Tambakbayan Watershed in 2011

Land Use*	Area (km^2)	Area by score (km^2)	Score
Grassland	0.03		10
Meadow	0.71	2.70	10
Multi-species Plantation	1.94		10
Paddy	22.87	27.39	15
Dry Agricultural Land	4.52		15
Settlement	17.37	17.38	20
Lake	**0.01**		20

Note: * Classification used in RBI 2006

A score of 60 (high) was the most extensive, with 65 the second-most prevalent and thus covering the second-largest area. In 2017, the main determinants of these figures were the settlements, paddies, and plantations that were evenly distributed in the watershed. Scores of 65–75 (high) and 80–85 (extreme) dominated the western and eastern parts of the watershed (i.e., the Pakem, Ngaglik, Depok, and Ngemplak Districts). The high and extreme runoff coefficients in the upper reach indicate the significant role played by land use in the formation of runoff. These hydrological states are attributable to the steep slopes (mostly >30%), which immediately transform rainfall into surface runoff that flows to the lower areas (Dipayana et al., 2012) and significantly influences the hydrological conditions downstream.

However, the land-use maps for 2006 and 2017 did not show any significant changes, except for an increase in the extent of the built-up areas and a narrowing of the paddy areas. Based on **Figure 6**, scores of 65–75 were more widespread, while there was a decline in the incidence of scores of 50–60 in the area. The former is mostly associated with settlements/built-up areas, and the result reflects the greater number of residential buildings in 2017 compared to 2006. Meanwhile, the latter scores represent paddies; thus a decline in the prevalence of these scores indicates fewer paddies in 2017 than in 2006. Such changes intensify the watershed response to rainfall and increase surface runoff. Buildings cover the ground surface with impermeable layers that prevent water from infiltrating into the soil; instead, water flows fast across these layers (Febryanto and Farda, 2016).

Table 6. Land-Use Type and Distribution in the Tambakbayan Watershed in 2017

Land Use*	Areas (km²)	Areas by score (km²)	Scores
Multi-species plantation	1.63	2.43	10
Meadow	0.79		10
Yard	0.0039		10
Dry horticulture cultivation area	0.36	19.59	15
CGPRT** cultivation area	0.72		15
Irrigated paddies	18.50		15
Industrial, trade, and office building	1.10	25.39	20
Other non-residential building	0.39		20
Rural settlement	10.33		20
Urban settlement	12.52		20
Lake (tourist attractions)	0.046		20
Natural lake/lake	0.002		20
Retention basin	0.07		20
Freshwater fish pond	0.22		20
Open land	0.01		20
Runway	0.08		20
Golf course	0.16		20
Stadium and sport facilities	0.10		20
River	0.0007		20
Airport	0.32		20

Notes: * Classification used in RBI 2017; ** CGPRT = coarse grains, pulses, roots, and tubers

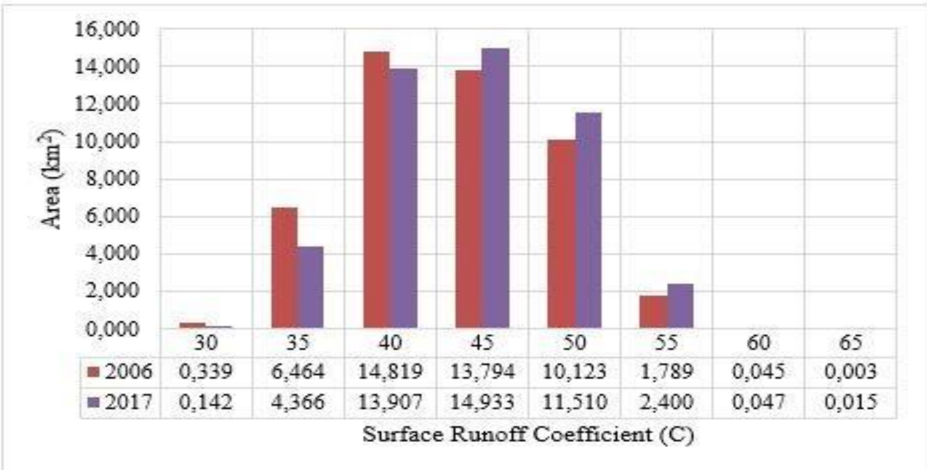

Figure 6. Graph of Runoff Coefficients and Areasper Coefficient in the Tambakbayan Watershed in 2006 and 2017.

There has been an increase in land use over the last five years, with a switch from agricultural to non-agricultural land. This has altered the surface of the watershed area and, correspondingly, the runoff coefficients. A runoff coefficient approaching 100 indicates land characteristics that support the formation of large amounts of surface runoff. The land-use change from 2006 through 2017 showed an increase in surface runoff despite the same rainfall amounts for both years. Changes in runoff coefficients are most likely to be followed by a change in the maximum flood discharge (Nurdiyanto et al., 2016). If unmanaged, such changes can lead to various types of degradation and disasters in the future.

The elongated shape of the Tambakbayan Watershed does not produce a high peak discharge because the water in the tributaries reaches the main river channel at different times (Sutapa, 2006). However, in flood events, water tends to remain in the watershed for a long time as only a small volume will flow out to the main river channel and outlet over an extended period. Thus, despite the low peak discharge, the change in land use to built-up areas is most likely to increase the peak discharge and lead to greater incidence of floods.

Land management can solve various kinds of hydrological problems that potentially arise due to land-use change. Spatial planning is an alternative to land management as it regulates land utilization to meet the provisions in the Regional Spatial Plan (RTRW) documents. In Sleman Regency, many buildings are located outside the designated or predetermined area. The Tambakbayan Watershed, which consists administratively of seven sub-districts, has varying regional characteristics. Pakem, Ngaglik, and Ngemplak Sub-districts are intended to serve as a recharge zone, the surface of which is not covered by many buildings, while Depok, Berbah, Banguntapan, and Piyungan Sub-districts are located outside the recharge zone (Widowati, 2013). Land management can also regulate buildingconstruction outside the zone so as not to affect water infiltration as well as increase the percentage of green open space in every residential building and the installation of infiltration wells.

An artificial lake or reservoir offers an alternative for tackling runoff problems at the same time as collecting and storing runoff to meet local people's water needs. Tambakbayan Watershed contains one artificial lake, Embung Tambakboyo, in Ngemplak District. It can accommodate more than 82,000 m^3 of water and is primarily used to conserve water, raise the water level, provide raw water, and serve/increase the economy (Alexander and Harahab, 2009). This type of utilization can substantially reduce the volume of surface runoff, prevent it from flowing directly downstream, and avoid overflowing or flooding in the lower reaches.

4. Conclusion

From 2006 to 2017, runoff coefficients of 70–75 became more widespread, meaning more land in Tambakbayan Watershed was used for settlements or residential buildings. Meanwhile, there was a decline in the spread ofrunoff coefficients of 50–60, indicating a decline in the amount of vegetated and agricultural land. This type of land-use conversion increases the volume of surface runoff as it covers the watershed area with impermeable layers. Thus, as a result of continuously multiplying the number of settlements every year, water is prevented from infiltrating into the soil and the peak discharge increases.

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