

Impacts of Land-Use Change on Runoff Oyo Downstream Sub-Watershed, Bantul Regency, Special Region of Yogyakarta

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Article Information	ABSTRACT
Article History Received : March 13, 2025 Revised : March 20, 2025 Published : April 10, 2025	Land use changes from year to year have a significant impact on several flood disasters in the Oyo Downstream River. The purpose of this study was to calculate the amount of surface runoff in the Oyo Downstream Sub-watershed. Runoff discharge can be approximated using an empirical equation, namely by using the rational method. The amount of Runoff in the Oyo Downstream Sub-watershed is determined based on rainfall data for the last 10 years, topographic conditions and land cover conditions in the Sub-watershed area. Based on Google satellite aerial photo images in 2007, 2010, and 2022, changes in land use in the Oyo Downstream Sub-watershed can be seen. The land cover type classification process uses the supervised periodic satellite imagery method, where the results of the classification of each type of land use can be seen in the percentage of land use changes. Based on the results of satellite image analysis, there has been a significant reduction in the area of land cover in forests and trees, namely 28.4% from 2007 to 2023. In contrast to settlements and open land which experienced an increase of 40% and 60% respectively. The results of the calculation of direct runoff discharge in each land cover condition show that there was an increase of 11% from 2007 to 2010, and an increase of 15% from 2010 to 2022. This condition causes flooding in several locations in the Oyo Downstream Sub-Watershed area due to overflowing rivers during the rainy season. In addition, several locations also experience inundation due to poor drainage systems causing rainwater runoff to not be able to flow into the water body/river area.
Keywords: <i>Land-use changes; Runoff; Flood.</i>	

INTRODUCTION

The development of infrastructure in a region, which affects land use changes, can lead to several issues in a watershed. Problems arising in a watershed due to uncontrolled land use changes include a decline in clean water quality, soil erosion, river sedimentation, an increase in river discharge, and even flooding. This is caused by the reduction of infiltration areas within the watershed and the expansion of residential and building areas, leading to an increase in runoff discharge.

Precipitation serves as the primary source of water on Earth. However, its distribution is inconsistent across different regions and periods, significantly influenced by climate and land utilization (Malikarjuna et al, 2012). In water resource evaluations, precipitation and runoff are the key hydrological elements (Ibrahim et al, 2020). Runoff results from the interplay between climate, topography, and land use within a drainage basin. Climate change has the potential to

modify the spatial and temporal patterns of precipitation, impacting both the volume and distribution of runoff. Alterations in land use can also affect water flow dynamics, further influencing runoff. While climate change is a major factor in runoff variations, human activities also play a crucial role (Shang et al, 2019). Changes in land cover and climate have global implications, significantly affecting hydrological processes in river basins (Desta et al, 2019).

Changes in land use can have a direct impact on the hydrological characteristics of a watershed, such as increased peak discharge, changes in river flow patterns, and decreased soil infiltration capacity (Ahmadi-sani et al, 2022). Previous studies have shown that uncontrolled land conversion can exacerbate the risk of flooding by increasing the volume of rainwater runoff into rivers. This is exacerbated by the reduction in vegetation that functions as a water absorber and increased sedimentation due to uncontrolled soil erosion. Generally, a higher vegetation cover reduces surface runoff and erosion. However, these relationships are not always straightforward, as the impact of tree cover depends on species type and canopy structure (Selkimaki et al, 2019). Even dense forests have a limited ability to retain precipitation, especially during extreme rainfall events (De Jong, 2016). Research has suggested that rainfall intensity is a key determinant of runoff, with forests and other vegetation not always being able to absorb significant amounts of rainwater (Zhao et al, 2019)

The flooding problem in the downstream Oyo Sub-Watershed is closely related to land use changes. The construction of several public facilities, university buildings, and residential areas has reduced infiltration areas within the watershed, leading to an increase in surface runoff. The rise in surface runoff discharge within the watershed significantly impacts the increase in river discharge. The sedimentation of the Oyo downstream river has reduced its water storage capacity, so when there is an increase in discharge due to rainfall, flooding occurs.

Studies on the relationship between changes in vegetation cover and water runoff dynamics provide information for the regulation of water resources and effective mitigation of the damage caused by land-use changes (He et al, 2013). Watershed management is based on controlling the hydrological processes, mainly runoff (Kumar et al, 2021). Analyzing the long-term dynamics of runoff has practical significance since the new knowledge enhances the management and sustainable use of water resources (Yin et al, 2017).

The problems that occurred in the Oyo downstream Sub-Watershed in the last 5 years are the occurrence of flooding in the Imogiri District area which submerged residential areas and highways. In addition, several drainage channels and rivers experienced sedimentation which resulted in reduced river cross-section capacity. The Oyo Downstream Sub-Watershed has an important role in the hydrological and ecological systems in the Bantul area, so a comprehensive study is needed regarding the effect of land use changes on the potential for increased runoff. This study aims to analyze the pattern of land use changes in the Oyo Downstream Sub-watershed and its impact on increasing runoff flow. Thus, the results of this study are expected to be the basis for planning more sustainable watershed management and as a consideration in flood disaster mitigation efforts in the area.

Through a spatial data-based approach and hydrological analysis, this study will identify the main factors that contribute to increased runoff flow in the Oyo Downstream Sub-watershed. The results of this study are expected to provide appropriate policy recommendations in land use management and flood disaster mitigation to support sustainable development in Bantul Regency, Special Region of Yogyakarta.

RESEARCH METHODS

Study Area

This research was conducted in the Oyo Downstream Sub-watershed located in Imogiri District, Bantul Regency, Special Region of Yogyakarta. The Oyo Downstream Sub-watershed is one of the sub-watershed that is part of the Opak Watershed.

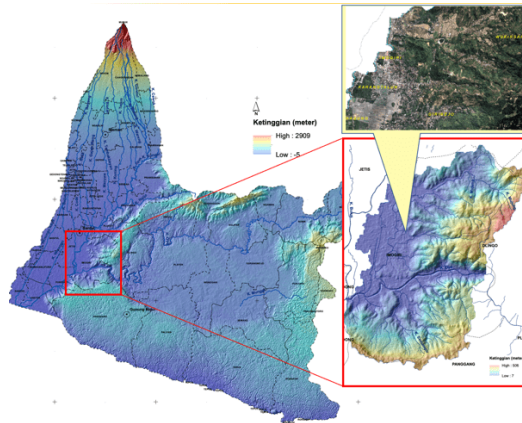


Figure 1. Oyo Downstream Sub-Watershed

Data Requirements and Steps of Analysis

The data used in this study are secondary data obtained from various institutions and open-source websites. The following is a detailed list of the data used in this study :

Tabel 1. Data Requirements

No	Data Requirement	Data Source
1	10-year rain data series	BBWS SO Ministry of Public Works
2	Land-use 2007, 2010, and 2022	Satellite Imagery
3	Digital Elevation Models (DEM)	Satellite Imagery https://tanahair.indonesia.go.id/portal-web/

Daily precipitation was collected from 3 rainfall stations (Fig. 2). Land-Use 2007, 2010 and 2022 was generated from google satellite imagery. The analysis steps carried out in this study are as follows:

1. Literature Study

Literature study is needed to obtain a theoretical basis and various literatures to support research activities on the rate of surface run off in the Oyo downstream Sub-watershed.

2. Data Collection

The data used in this study are secondary data obtained from various agencies and websites. The data requirements in this study have been described in Table 1.

3. Rainfall Analyze

The rainfall stations used to determine regional rainfall in this study are the Sta. Bedugan, Sta. Terong and Sta. Barongan rainfall stations. The first stage in determining regional rainfall in the Oyo downstream Sub-watershed tershed . The distribution of regional rainfall of the entire Oyo downstream Sub-watershed using the Thiessen polygon method. The next process is to conduct a frequency analysis of the 10-year rainfall series data. The frequency of rainfall is the probability of a certain amount of rainfall being equaled or exceeded, while the return period is the

hypothetical time at which rainfall with a certain amount will be equaled or exceeded (Suripin, 2004). In statistics, there are several types of frequency distributions. Some distributions that are often used in hydrology are (Suripin, 2004):

- ### 1) Normal Distribution

$$X_T = \bar{X} + K_T S_d \quad (1)$$

- ## 2) Log Normal Distribution

$$\text{Log } X_T = \text{Log } \bar{X} + K_T S_{d_{\log X}} \quad (2)$$

- ### 3) Log-Person Type III Distribution

$$\text{Log } X_T = \text{Log } \bar{X} + K_T S_{d_{\log X}} \quad (3)$$

- #### 4) Gumbel Distribution

$$X_T = \bar{X} + K_T S_d \quad (4)$$

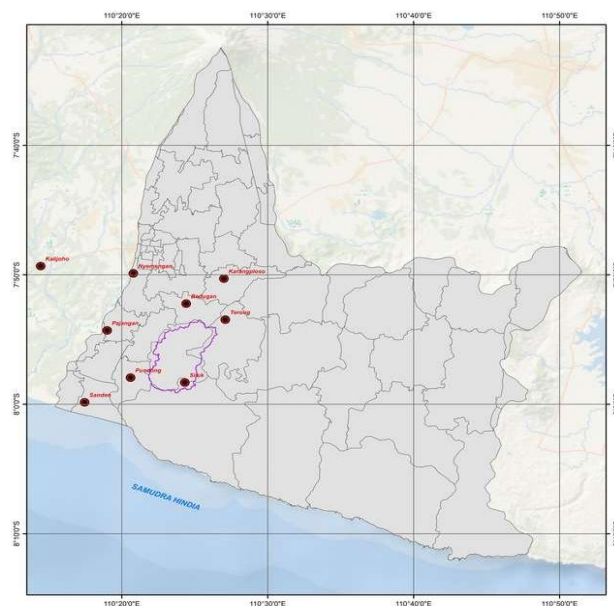


Figure 2. Rainfall Stations

4. Calculation Intensity, Duration and Frequency (IDF)

Rain intensity is the amount of rainfall in a unit of time, expressed in mm/hour, mm/day or even mm/year (Triatmodjo, 2008). The calculation of rainfall intensity in this study uses the Mononobe equation (Triatmodjo, 2008) :

$$I_t = \frac{R_{24}}{24} \left[\frac{24}{t} \right]^{\frac{2}{3}} \quad (5)$$

With :

 I_t : Rainfall intensity (mm/hour)

t : Duration of rainfall (hour)

R_{24} : Maximum rainfall depth over 24 hours (mm)

The concentration time t_c is the time required by water particles to flow from the furthest point in the catchment area to the point being reviewed (Triatmodjo, 2008). The concentration time is greatly influenced by the characteristics of the catchment area, land use, and the distance

of the water path from the furthest point to the station being reviewed. Concentration time (t_c) of flow is determined using the Australian Rainfall Runoff equation in equation 2. . Furthermore, create an IDF curve based on the calculation of rainfall intensity at each time.

$$t_c = 0,76A^{0,38} \quad (6)$$

Where A is the area of the Watershed.

5. Determination of Catchment Area Boundaries

Determination of DTA boundaries is used to determine the boundaries of rainwater catchment areas that have the potential to become runoff flows and will flow into water body areas or rivers. Determination of DTA boundaries based on topographic data in the form of DEM (Digital Elevation Models) data downloaded via <http://tanahair.indonesia.go.id/> with a density of 8m x 8m in 1 pixel. With DEM data, the topographic conditions and slope of the land at the location can be determined. With Arc GIS 10.3 software, the Catchment boundaries in the Oyo downstream Sub-watershed can be determined.

6. Land Cover Analysis

Land cover analysis aims to determine the type of land cover in the Watershed area. The type of land cover greatly influences the amount of surface runoff. The type of land cover is based on satellite imagery data downloaded via Google satellite imagery in 2007, 2010, and 2022. Then it is processed into a land cover map using Arc GIS 10.3 software. Land cover classification process uses the Supervised Periodic Satellite Imagery method.

7. Runoff Coefficient Analysis

Runoff coefficient analysis is based on the land cover map. Each type of land cover can determine the runoff coefficient value. The runoff coefficient value (C) is entered into the land cover map attribute to then be used as a runoff coefficient map with raster format with the Arc GIS 10.3 software.

8. Runoff Discharge Calculation

The amount of runoff discharge is calculated using the rational method with equation 3. This method is very simple and easy to use but is limited to small watersheds. Small watersheds are less than 300 ha (Goldman et. al., 1986 in Suripin, 2004). Meanwhile, according to Ponce (1989) in Triatmodjo (2008) explains that a watershed is called small if the distribution of rainfall can be considered uniform in space and time, and usually the duration of rainfall exceeds the concentration time. A watershed area of less than 2.5 km² can be considered a small watershed. the mathematical equation of the rational method is shown in the form:

$$Q = 0,278 CIA \quad (7)$$

With:

- Q : Discharge (m³/s)
- I : Rainfall Intensity (mm/jam)
- A : Area of Watershed (km²)
- C : Runoff Coefficient (C)

The calculation of runoff discharge is carried out by multiplying the rainfall intensity raster map, the runoff coefficient value raster map, and the DTA area boundary map. The raster map multiplication process uses Arc GIS 10.3 software

9. Generate the Map of Surface Runoff

Surface Runoff map based on the results of multiplying the rainfall intensity raster map, the runoff coefficient value map and the Catchment area map in the Oyo downstream Sub-watershed. The surface runoff shows the magnitude of the surface flow rate at each location in the Oyo downstream Sub-watershed. The process of generating a surface flow rate map uses Arc Gis 10.3 software.

RESULTS AND DISCUSSION

Rainfall Design and IDF Curve

Design rainfall is an estimate of rainfall that will occur in the future with a certain return period. The first step in calculating design rainfall is to calculate the frequency distribution with several statistical parameters. Based on the results of the rainfall distribution analysis using the Log Pearson Type III distribution, the Design Rainfall (R_t) value is shown in Table 2.

Tabel 2. Rainfall Design of Oyo Downstream Sub-Watershed

No	Return Period	X_t (mm)
1	2	80,8
2	5	126,33
3	10	163,38

The calculation of rainfall intensity in this study used the Mononobe equation (Equation 1) while the concentration time was determined using the Australian Rainfall Runoff equation (Equation 2). The calculation of concentration time (t_c) is done spatially on each type of land cover. Rain intensity (I_t) is determined. The results of the intensity duration frequency calculations are shown in Figure 3.

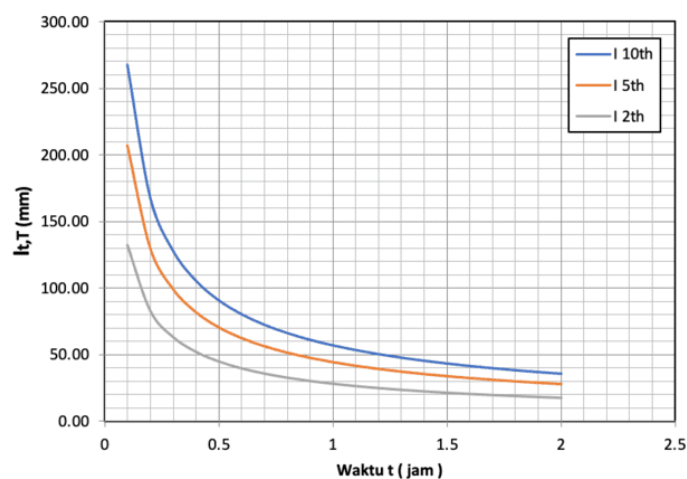


Figure 3. IDF Curve

The IDF curve is a representation of rainfall characteristics in a particular area, because it is based on historical rainfall data and local climatological factors. The IDF curve is in the form of a curved line which shows that the longer the duration of rainfall in an area, the lower the intensity. This means that rain with a short duration tends to have high intensity, while rain with a long duration has a lower intensity but a larger total volume.

Land Cover Analysis

The land cover type classification process in the Oyo Hilir Sub-DAS uses the Supervised Periodic Satellite Imagery method, where this method uses the color brightness level in aerial

photo image data to determine the land cover classification process. From the results of the land cover type classification process, a land cover type map can be obtained in the Oyo Hilir Sub-DAS in 2007, 2010, and 2022 which is shown in Figure 4. From the land cover type classification map, changes in land cover in 2007, 2010, and 2022 can be seen in Figure 4.

The process of classifying land cover types in the Oyo downstream Sub-watershed uses the Supervised Periodic Satellite Imagery method, where this method uses the level of color brightness in aerial photo image data to determine the land cover classification process. From the results of the land cover type classification process, a map of land cover types can be obtained in the Oyo Downstream Sub Watershed in 2007, 2010, and 2022 which is shown in Figure 5.

From the land cover type classification map in 2007, 2010, and 2022, changes in the area of land cover types can be seen, namely:

- Reduction in land area with Forest and Tree classification of 859.94 ha
- Increase in land area with Settlement classification of 450.79 ha
- Increase in land area with Rice Field or Field classification of 193.16 ha
- Increase in land area with Open Land classification of 159.42 ha
- Increase in land area with Water Body classification of 56.5 ha

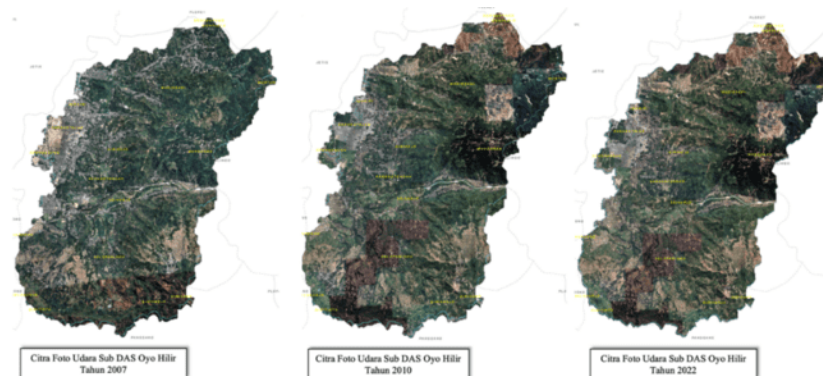


Figure 4. Downstream Oyo Sub Watershed Land Cover Based on Google Satellite Imagery in 2007, 2010, and 2022

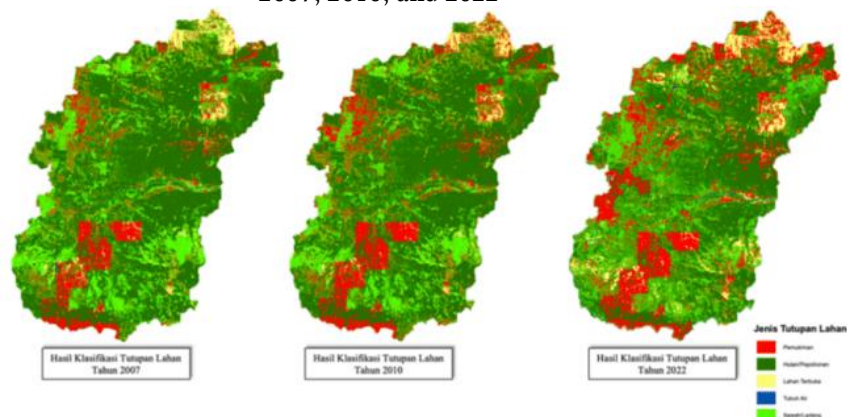


Figure 5. Oyo downstream Sub-watershed Land Cover Classification

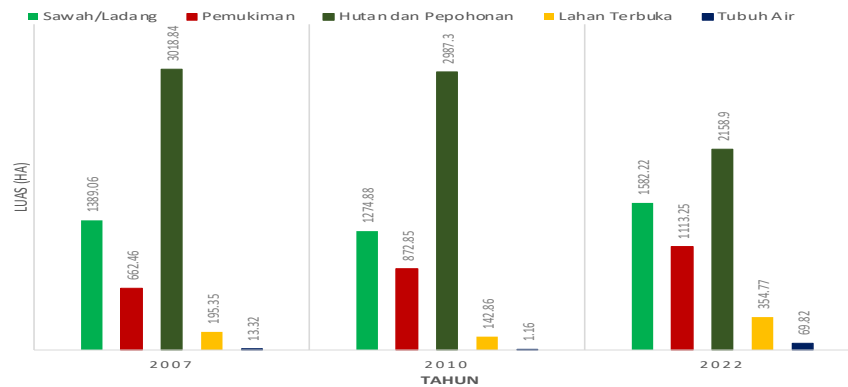


Figure 5. Land use change graph for the Downstream Oyo Sub Watershed

Runoff Discharge

The results of the calculation of runoff discharge in the Oyo downstream Sub-watershed spatially are in the form of the amount of direct runoff flow in each area in the Oyo downstream Sub-watershed area. The calculation of direct runoff discharge is carried out on each land cover condition in 2007, 2010, and 2022. The results of the calculation of direct runoff discharge are presented in a spatial map where this direct runoff discharge spatial map explains the amount of direct runoff discharge according to the color code. The spatial map of direct runoff discharge in the Oyo downstream Sub-watershed is shown in Figure 6.

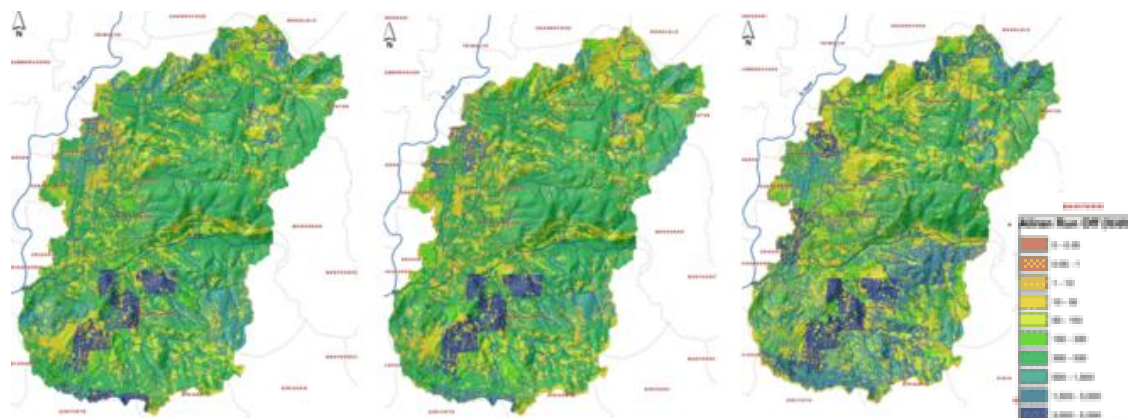


Figure 6. Spatial map of 10-year return period (Q10) direct runoff discharge in the Oyo Downstream Sub Watershed for each land cover condition in 2007, 2010, and 2022.

The calculation of direct runoff flow discharge is carried out based on the design flood discharge for 2 years return period (Q2), 5 years return period (Q5), and 10 years return period (Q10). The calculation using these 3 design flood discharges produces different direct runoff discharge amounts. The results of the calculation of the total direct runoff discharge in the Oyo downstream Sub-watershed area are shown in Table 3.

Tabel 3. The results of the calculation of direct runoff discharge in the Oyo downstream Sub-watershed with discharge design Q2, Q5, and Q10

Year	Runoff Discharge (m3s)		
	Q2	Q5	Q10
2007	197.30	308.40	399.00
2010	222.71	348.13	450.39
2022	260.99	407.95	527.79

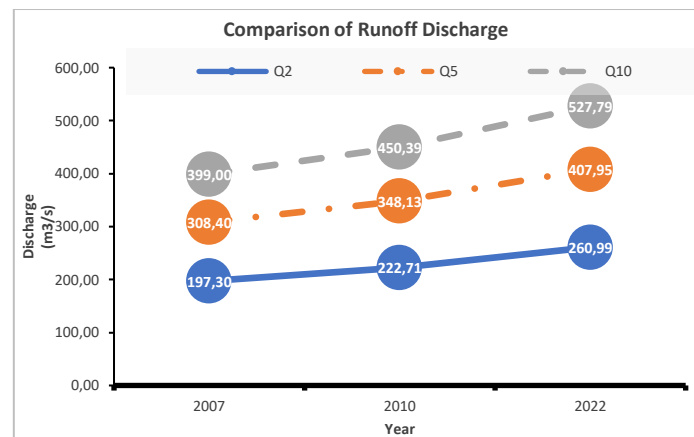


Figure 7. Comparison of direct runoff discharge in the Oyo downstream Sub-watershed with the design flood discharge Q2, Q5, and Q10

From the results of the calculation of the direct runoff discharge shown in Table 4.3, it can be seen that there has been an increase in the direct runoff discharge from 2007 to 2022. This is greatly influenced by changes in land cover that occurred in 2007, 2010, and 2022. The increase in direct runoff discharge that occurred in the Oyo downstream Sub-watershed was 11% in 2007 to 2010, and 15% in 2010 to 2022.

Discussion

This study utilizes remote sensing to identify changes in land use and applies the Rational method to evaluate the effect of these changes on water runoff. According to Ahmad-sani et al. (2022), the runoff generation process has complex, nonlinear, and dynamic characteristics, and is influenced by various interacting physical factors. The use of remote sensing and GIS techniques integrated with hydrological models provides a more economical analysis solution than conventional methods, as proposed by Sajikumar and Reyma, Kumar et al., and Al-Ghobari et al.

Climate change can have an impact on water availability and surface runoff levels Yin et al (2012). Surface runoff intensity tends to increase when heavy rainfall occurs more frequently. However, most of these changes can be attributed to human activities that modify natural ecosystems. Il Euma et al (2016) and Yin et al (2012) also concluded that land cover changes have a more significant effect on surface runoff trends than climate change.

In our case study area, land use changes caused a 15% increase in runoff volume over a 15-year period. The majority of this increase was related to changes in forestry, farming, open land and residential areas. Based on the results of satellite imagery data processing of land use in the Oyo Hilir Sub-DAS area from 2007 to 2022, there has been a significant change in land use in the forestry area which has shrunk by 28.4%. In contrast to the residential area which increased by 40% and the open land area by 60%.

The intensity of rainfall that occurs in the Oyo Downstream Sub-Watershed area also has a very large influence on the increase in the amount of runoff flow. Changes in land cover from forestry/plantations to residential areas have implications for the infiltration capacity of the soil. The role of land cover and vegetation is very large in reducing runoff. In a watershed with good vegetation cover, some rainwater will be absorbed by plants and reduce the rate of surface flow. Conversely, in areas that have experienced deforestation or urbanization, runoff tends to increase due to reduced infiltration due to impervious surfaces such as asphalt and concrete. In addition, inadequate drainage system conditions and reduced river cross-sectional capacity due to sedimentation of watersheds with poor drainage systems or limited river capacity will be more

susceptible to flooding if there is high intensity rain. Increased runoff can cause river discharge to suddenly spike (flash flood) and have negative impacts on the environment and society. This condition can be concluded that runoff in the Oyo Downstream Sub-Watershed has increased over the past 15 years. Some evidence that can be used as reasons related to the increase in runoff in the Oyo Downstream Sub-Watershed area is the occurrence of floods in the past 5 years in several residential and urban areas adjacent to the river.

CONCLUSION

Based on the results of the research that has been done and the formulation of the problem in this study, it can be concluded that the surface flow rate (run off) in the Oyo Hilir Sub-DAS in 2007 with a 2-year design flood discharge (Q_2) of 197.3 m³/sec, with an annual Q_5 of 308.4 m³/sec, and an annual Q_{10} of 399.0 m³/sec. In 2010 there was an increase of 11% from 2007, namely where the surface flow discharge in the annual Q_2 was 222.71 m³/sec, with an annual Q_5 of 348.13 m³/sec and an annual Q_{10} of 450.39 m³/sec. In 2022, there was an increase in surface flow discharge of 15%, where the surface flow discharge in the annual Q_2 was 260.99 m³/sec, with the annual Q_5 of 407.95 m³/sec and in the annual Q_{10} of 527.79. The increase in direct runoff discharge was caused by changes in land use in 2010 and 2022 where several rainwater catchment areas such as forests were converted into open land areas and settlements/buildings. So that the increase in direct runoff discharge has a significant impact on the increase in flow discharge in the Oyo Hilir River. This condition is not balanced by efforts to conserve the watershed in reducing the runoff flow rate to mitigate flooding. In addition, drainage channel maintenance activities are still very minimal by the local government, such as efforts to excavate sediment in the drainage channels or normalize rivers that are experiencing shallowing and narrowing of the channel. Optimal watershed management plays a crucial role in reducing the risk of flooding, erosion, and other environmental degradation and the importance of cross-sectoral cooperation in the management of water resources, land, and ecosystems in order to achieve effectiveness in watershed management. In addition, integrated watershed management planning, as stipulated in the Governor's Decree on the Opak Watershed Management Plan, is also an important step in managing the watershed effectively. In general, the flood problem in the Oyo River emphasizes the importance of holistic and collaborative watershed management in Bantul Regency. The main steps to reduce the risk of flooding and preserve the environment in this area include conservation efforts, integrated planning, and inter-sectoral coordination.

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