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Mitigation Strategy for the Impact of Changes in Land Use in the Badung Watershed Based on GIS

[1,]I Gusti Agung Putu Eryani, [2,]Made Widya Jayantari
[1,]Department of Civil Engineering, Warmadewa University, Denpasar, Bali 80239, Indonesia
[2,]Department of Civil Engineering, Udayana University, Badung, Bali 80361, Indonesia

ABSTRACT : Changes in land use can affect the hydrological cycle in several ways. Changes in vegetation and land cover can affect the extent of rainfall that falls in an area and the evaporation rate. The Badung River flows through Denpasar City and experiences significant changes in land use. This study aims to determine the land changes that have occurred by utilizing the GIS approach, their impact on the Badung Watershed, and the appropriate mitigation strategies to be implemented. Analysis of land use classification with Maximum Likelihood is a method commonly used in image processing to classify and map land use based on the pattern of pixels in the image. After analyzing changes in land use and their impact on the Badung Watershed, an appropriate mitigation strategy is developed. Land changes occurred in the Badung Watershed from 2013 to 2019, where the types of land use, vegetation, and irrigation areas tended to decrease. However, the situation differed for water bodies and built areas as they increased. The trend of maximum rainfall from 2013 to 2019 increased yearly, with an average annual increase of 1.30 mm. The average maximum rainfall in the Badung Watershed was 87.72 mm per day. Due to changes in land use, the curve number increased. From the calculation of the return period discharge, there was an increase, and in 2019, a significant change was observed in the return period discharge. The impacts of land use changes can mitigate with several strategies that need to be implemented. These include improving floodplain management, enhancing infrastructure, promoting natural water retention measures, land use planning, early flood warning systems, and developing settlement waste management systems.

KEYWORDS: Land Use, Rainfall, GIS, Mitigation, Watershed.

I. INTRODUCTION

Land use change is a common phenomenon that occurs in various regions around the world [1]–[4]. This process involves the conversion of natural land to agriculture, urban expansion, deforestation, and other land-use changes. These changes in land use can have a significant impact on the hydrological characteristics of an area, especially in the context of watersheds. The impact of land use/land cover change on hydrological processes within watersheds has been the subject of many studies worldwide in recent decades[5]–[8].Changes in land use can affect the hydrological cycle in several ways. Changes in vegetation and land cover can affect the extent of rainfall that falls in an area and the evaporation rate [9]–[11]. For example, land cover with forest can reduce surface runoff and increase water infiltration into the soil [12]–[14], while urban land dominated by non-draining surfaces can increase surface runoff. Changes in land use can also affect river flow. Forest conversion to agricultural or urban land can change river flow patterns and increase flow velocity [15]. This condition increases the risk of flooding and soil erosion along the watershed.

The Badung River, which flows through Denpasar City, with a watershed area of ± 37.7 km^2 and a channel length of ± 25.17 km with its headwaters located 12 km north of Denpasar City and empties into Benoa Bay, is an essential source of water for Denpasar City and Southern part of Badung Regency. This river has a dual function: as a source of irrigation water and drainage for Denpasar City and parts of Badung Regency. During high rain intensity, the Badung River often overflows [16]–[18]. Watersheds in urban areas experience significant changes in land use. Population growth and the need for land for settlements, industry, and urban infrastructure have led to converting natural land into urban land. In changing land use in urban areas, the vegetation and green land cover that originally existed around watersheds can decrease. The land covered with non-permeable surfaces such as concrete and asphalt displaces natural vegetation, which can change water flow patterns and increase surface runoff. Decreased green cover and increased surface runoff can lead to a faster river flow, exacerbating the potential for flooding during heavy rains.A Geographic Information System (GIS) is a valuable tool for understanding and analyzing land-use change's effect on watersheds' hydrological characteristics [19], [20]. In one integrated system, GIS enables integrating of spatial data such as satellite imagery, land use maps, and hydrological data.

GIS allows users to visualize and analyze land data in a spatial context by looking at land data in the form of maps or satellite imagery, an understanding of the pattern and distribution of land change. GIS also allows the comparison of land changes over different periods. By comparing spatial data over time, we can see changes, such as urban expansion, deforestation, changes in land use, or other impacts. Mitigation strategies for land use change impacts are critical to reducing watershed hazards. A watershed is a geographic area where all the water within its boundaries flows into a single point, such as a river or lake. Land-use changes, such as urbanization, deforestation, agricultural expansion, or industrial development, can significantly and often negatively impact watersheds. Currently, no research examines Mitigation Strategy for the Impact of Changes in Land Use in the Badung Watershed using GIS. This study aims to determine the land changes that have occurred by utilizing the GIS approach, their impact on the Badung Watershed and the appropriate mitigation strategies to be implemented. With this mitigation effort it is hoped that it can reduce the impact of land change in the Badung watershed.

II. RESEARCH AREA

The Badung River watershed has an area of 52,497 km^2 with a river length of 19,601 km (Figure 1). This river flows through two districts/cities, namely Denpasar City 37,120 km^2 and Badung Regency 15,377 km^2 [21]. Its strategic position, which passes through Denpasar City, makes Badung River important, especially for Denpasar City itself as the capital of the Province of Bali. For this reason, several supporting facilities/infrastructures have been built in Badung River, especially in water resources.

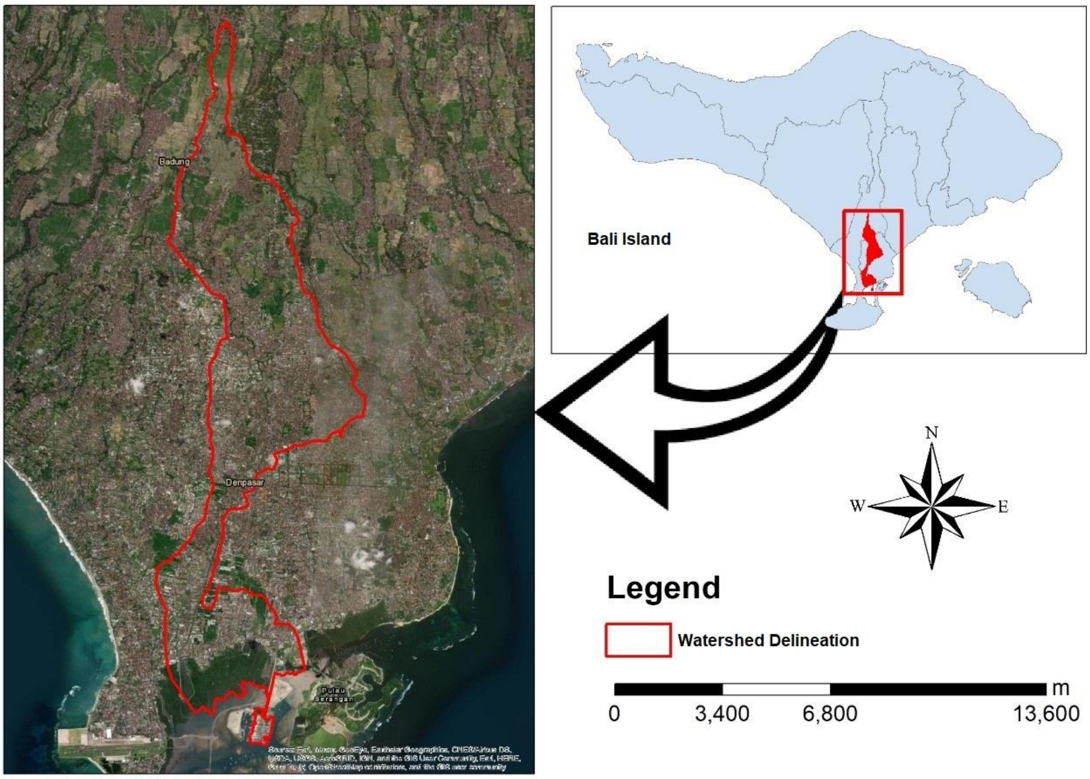

Figure 1. Badung Watershed

III. RESEARCH METHODS

In this research, the data used were Badung watershed satellite images in 2013, 2016, and 2019. These satellite images were obtained from Google Earth satellite data which were then georeferenced using GIS. In addition to satellite imagery data, this research also used characteristic hydrological data in the form of annual rainfall data and annual average discharge data in 2013, 2016, and 2019 which were obtained from the Bali Penida River Basin Office. Analysis of land use classification with Maximum Likelihood is a method commonly used in image processing to classify and map land use based on the pattern of pixels in the image. This method is based on a statistical approach that uses the probability density function and the principle of likelihood to classify each pixel into different land use categories. In conducting the analysis of land use classification with Maximum Likelihood, the steps taken are image selection. Satellite imagery or aerial imagery with a resolution suitable for analytical purposes. This image must cover the area to be analyzed. Then the selection of training samples is carried out. Pixel samples representing each land use category in the image. This sample should be taken at random and adequately represent the variation within each category. Each pixel sample must be identified with the appropriate land use category. Then perform feature extraction. Feature extraction involves measuring or extracting the characteristics of each pixel sample that will be used to differentiate land use categories. These features can include spectral (e.g., intensity values across various bands), textures, shapes, or other relevant features. Then do class probability estimation. In this step, class probabilities (land use categories) are estimated based on the training sample. This is done by calculating the probability density function for each class using the existing training samples. And finally the classification is done. After class probabilities are estimated, the Maximum Likelihood method calculates the likelihood for each pixel in the image based on the extracted features. Pixels are classified into the land use category that has the highest likelihood. After analyzing changes in land use and their impact on the Badung Watershed, an appropriate mitigation strategy is then developed.

IV. RESULT AND DISCUSSION

Land Use Change : Based on Table 1 and Figure 2, it can be observed that there were land use changes in the Badung Watershed from 2013 to 2016. The land use type "vegetation" decreased from 8.11 km^2 in 2013 to 7.88 km^2 in 2016, representing a decrease of 2.9% from the initial area. From 2016 to 2019, it further decreased from 7.88 km^2 to 7.46 km^2, which is a reduction of 5.5%. A similar trend is noticed for the "irrigation area." From 2013 to 2016, the irrigation area decreased from 19.76 km^2 to 17.01 km^2, a decline of 16.2%, and from 2016 to 2018, it decreased further to 12.47 km^2, representing a 36.4% decrease. However, unlike vegetation and irrigation areas, the "water body" and "built area" land use types increased from 2013 to 2019. The water body area increased from 2.03 km^2 in 2013 to 2.50 km^2 in 2016 and reached 2.63 km^2 in 2019. The built area also showed an increasing trend, expanding from 25.05 km^2 in 2013 to 27.05 km^2 in 2016, and further growing to 32.38 km^2 in 2019. In the Badung Watershed, the dominant land use type is built area.

Table 1. Land Use Area

Year	Vegetation (km^2)	Water Body (km^2)	Irrigation Area (km^2)	Built Area (km^2)	Total Area (km^2)
2013	8.11	2.03	19.76	25.05	54.95
2016	7.88	2.56	17.01	27.50	54.95
2019	7.46	2.63	12.47	32.38	54.95

Source: Result Analysis (2023)

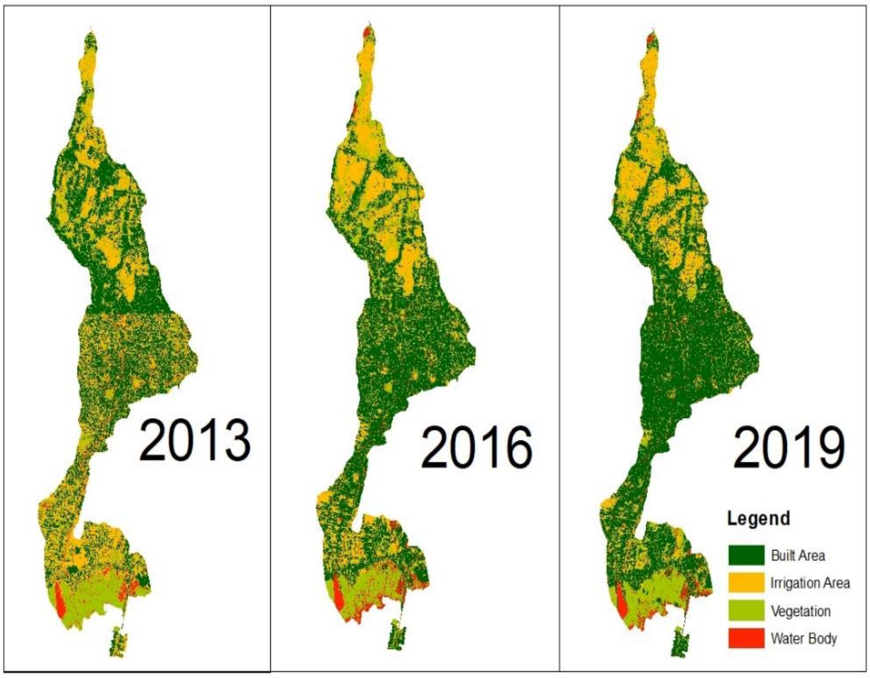

Figure 2. Land Use Change From 2013-2019

Changes in Maximum Rainfall : Based on Figure 3, it can be observed that the trend of maximum rainfall from 2013 to 2019 shows a tendency of annual increase with an average rise of approximately 1.30 mm per year. The average maximum daily rainfall in the Badung Watershed is 87.72 mm. A significant increase occurred in 2017, where the maximum rainfall reached 162.47 mm per day. This increase in maximum rainfall will have an impact on flood discharge occurrences.

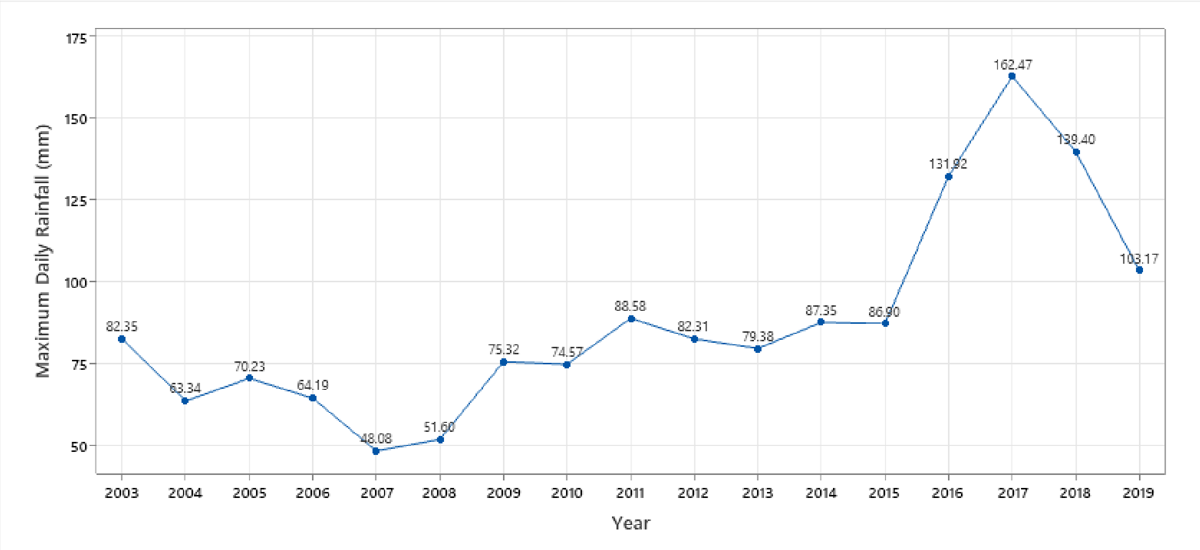

Figure 3. Changes in Maximum Rainfall from 2003 to 2019

Changes in Curve Number Values : In hydrology and engineering, the curve number is defined as a parameter used to estimate direct runoff from rainfall in a specific area. It is a critical factor in various hydrological models, such as the Soil Conservation Service (SCS) curve number method, which is commonly employed for hydrological modeling and design. The curve number is a dimensionless value typically ranging from 30 to 100, representing the combined effects of land use, soil type, and antecedent soil moisture conditions on the watershed's response to a particular rainfall event. Lower curve numbers indicate lower runoff potential (more infiltration), while higher curve numbers indicate higher runoff potential (less infiltration). The Badung River Watershed consists of regosol and andosol soil types, classified as Type A soils. As shown in Table 2, the curve number calculations for different land use types from 2013 to 2019 indicate an increasing trend, with the curve number rising from 71.40 in 2016 to 72.94 and further to 75.29 in 2019. A higher curve number implies an increase in runoff and a decrease in infiltration. This can result in more frequent flooding during the rainy season and reduced water availability during dry seasons.

Table 2. Curve Number

CN 2013	CN 2016	CN 2019
71.40	72.94	75.29

Source: Analysis Result (2023)

Changes in Return Period Discharge : Based on the maximum rainfall and resulting curve number values, calculations for the return period discharge were performed for the years 2013, 2016, and 2019, considering the return periods of 2, 5, 10, 25, 50, 100, and 1000 years for each land use type. In hydrology, the return period refers to the average time between occurrences of a specific discharge or flow rate of a river or stream. For example, a 100-year return period discharge means that a particular flow rate is expected to be equaled or exceeded approximately once every 100 years. However, it is not certain that such an event will occur precisely every 100 years. Using the Nakayasu unit hydrograph method, the flood hydrographs for the specified return periods in 2013, 2016, and 2019 were obtained. As shown in Figure 4, the peak discharges for the 2-year return period amounted to 7230.941 m^3/second. For the 5-year return period, it was 8307.602 m^3/second, for the 10-year return period, it was 8800.225 m^3/second, for the 25-year return period, it was 9261.781 m^3/second, for the 50-year return period, it was 9524.005 m^3/second, for the 100-year return period, it was 9734.144 m^3/second, and for the 1000-year return period, it reached 10224.572 m^3/second.

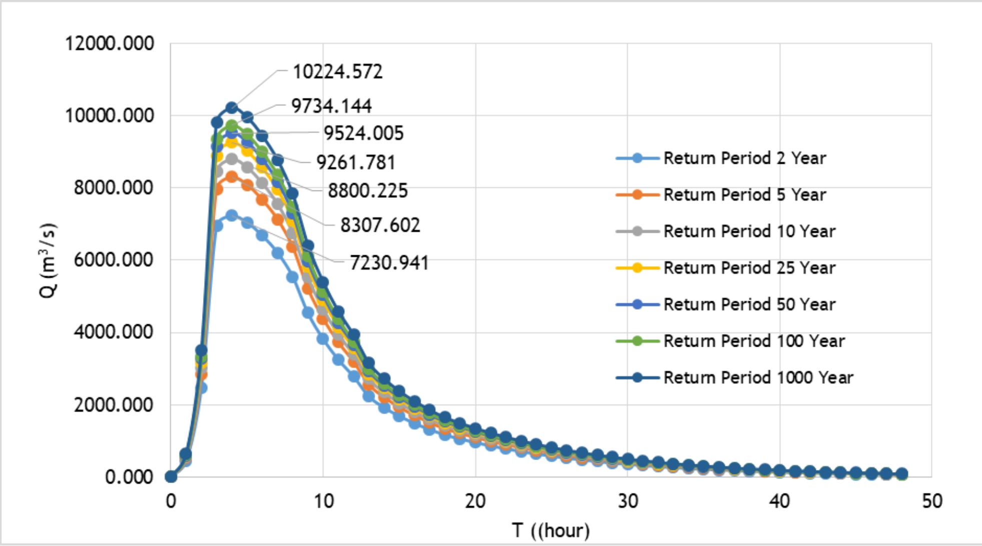

Figure 4. Return Period Discharge Data for the Year 2013

Subsequently, an analysis was conducted for the return period discharge using data from the year 2016. The results of the calculations for the return period discharge show an increase corresponding to the rise in maximum rainfall and the runoff coefficient or curve number. The findings, as presented in Figure 5, indicate that for the 2-year return period, the peak discharge increased to 7682.629 m^3/second. For the 5-year return period, it increased to 9524.163 m^3/second, for the 10-year return period, it increased to 10709.240 m^3/second, for the 25-year return period, it increased to 12180.531 m^3/second, for the 50-year return period, it increased to 13259.961 m^3/second, for the 100-year return period, it reached 14334.772 m^3/second, and for the 1000-year return period, it escalated to 17971.584 m^3/second.

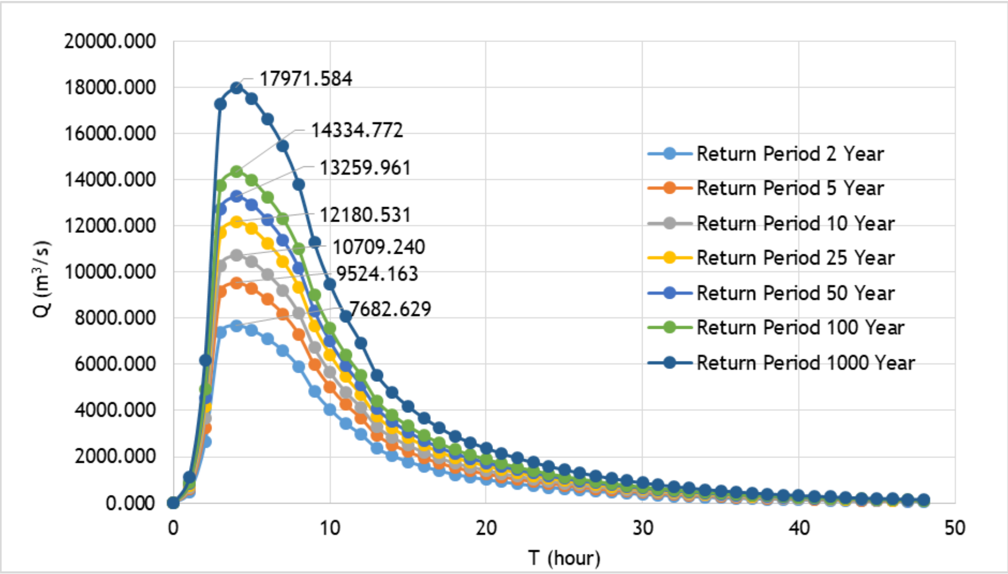

Figure 5. Return Period Discharge Data for the Year 2016

For the year 2019, the calculation of the return period discharge indicates a significant increase. The results, as shown in Figure 6, demonstrate that for the 2-year return period, the peak discharge increased to 8599.151 m^3/second. For the 5-year return period, it increased to 11500.847 m^3/second, for the 10-year return period, it increased to 13605.679 m^3/second, for the 25-year return period, it increased to 16478.502 m^3/second, for the 50-year return period, it increased to 18782.533 m^3/second, for the 100-year return period, it reached 21227.863 m^3/second, and for the 1000-year return period, it escalated to 30685.532 m^3/second. This increase is due to not only an elevation in maximum rainfall but also an increase in built-up land areas in the Badung Watershed, which has raised the runoff coefficient

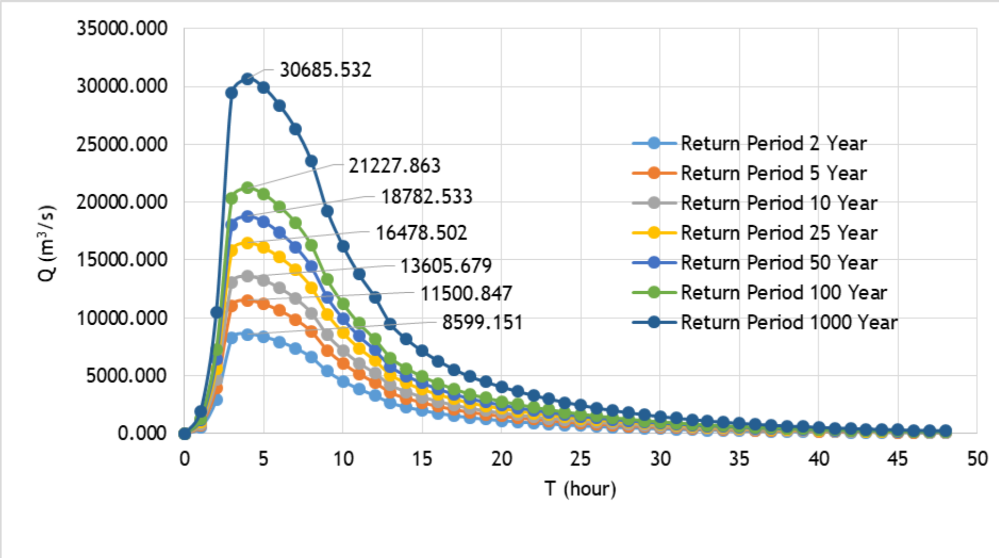

Figure 6. Return Period Discharge Data for the Year 2019

Increasing the return period discharge signifies larger and more intense flood events. This can lead to higher flood risks in low-lying areas and result in extensive damages to properties, crops, and infrastructure, such as roads, bridges, and buildings. The rise in return period discharge indicates a decrease in the frequency of extreme events or high flows. In other words, historically rare occurrences (e.g., 100-year floods) are happening more frequently. Higher return period discharges indicate higher flood risks. As these extreme events occur more often, there is a possibility of increased damage to infrastructure, property, and even loss of life in flood-prone regions. Infrastructure constructions like bridges and culverts are often designed based on historical hydrological data, including return period discharges. An increase in extreme events can render some of these structures inadequate, leading to higher maintenance and reconstruction costs. The impacts of increasing return period discharges can be significant and can affect both the natural environment and human activities. As shown in Figure 7, during the rainy season, the Badung River experiences an increase in river discharge, leading to an elevated occurrence of flooding.

Figure 7. Increase in Badung River Discharge during the Rainy Season

Impact Land Use Change on Water Quality of Badung Watershed : The increase in built-up land, primarily residential areas, in the Badung Watershed can heighten the risk of water pollution due to intensified human activities in the region. Disposal of domestic waste, use of fertilizers, and pesticides can contaminate water sources and degrade their quality. In Figure 8 (a), the water in the Badung River appears red, caused by poorly managed industrial screen printing waste. Figure 8 (b) shows soap suds flowing in the Badung River as a result of household waste. Additionally, Figure 8 (c) exhibits sedimentation in the Badung Watershed due to household waste, which can further increase during periods of high rainfall.

(a)

(b)

(c)

Figure 8. Pollution in the Badung Watershed due to Built-Up Areas Nearby

Mitigation Strategy for the Impact of Changes in Land Use in the Badung Watershed

To mitigate the impact of land use changes, several engineering strategies need to be implemented in the Badung Watershed. The following are some of the key strategies:

1. Enhanced Floodplain Management
   Implementing floodplain zoning regulations and restrictions on construction in flood-prone areas can help minimize flood risks. Preserving natural floodplains and avoiding developments in these regions can also reduce potential flood damages.
2. Improved Infrastructure
   Designing and constructing resilient infrastructure, such as bridges, culverts, and drainage systems, capable of handling higher flood discharges can mitigate flood impacts and enhance public safety.
3. Natural Water Retention Measures
   Implementing nature-based solutions, such as constructing retention ponds, restoring wetlands, and creating green spaces, can help attenuate floodwaters and reduce peak flows downstream.
4. Land Use Planning
   Applying intelligent land use planning techniques, incorporating hydrological considerations, can direct development away from high-risk areas, protecting critical zones from flood hazards.
5. Early Flood Warning Systems
   Installing and maintaining early flood warning systems with real-time monitoring can provide timely alerts to communities and authorities, enabling effective emergency response and evacuation measures.
6. Implementing Waste Management Systems for Settlements
   Establishing effective waste management systems for residential areas near river basins can prevent pollution and mitigate the negative impacts of urban runoff on water quality.

V. CONCLUSION

Changes in land use occurred in the Badung Watershed from 2013 to 2016, where the land use type vegetation experienced a decline from 2013 to 2019. The same trend was observed for the irrigation area land use type. However, in contrast to vegetation and irrigation areas, the water body and built area land use types increased from 2013 to 2019. The trend in maximum rainfall from 2013 to 2019 showed a consistent increase each year, with an average annual increase of approximately 1.30 mm. The average maximum daily rainfall in the Badung Watershed was 87.72 mm. Due to changes in land use from 2013 to 2019, there was an increase in the curve number from 71.40 in 2016 to 72.94 and further to 75.29 in 2019. A higher curve number implies increased runoff and reduced infiltration. The calculations of the return period discharge indicated an increasing trend from 2013 to 2019, with a significant change in the return period discharge observed in the year 2019.

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