

Investigation on Impact of Changes in Land Cover Patterns on Surface Runoff in Ayung Watershed, Bali, Indonesia Using Geographic Information System

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ABSTRACT

Population growth, urbanization, and infrastructure development activities have resulted in the land conversion of forests and farmlands to residential and commercial zones. Such land conversion causes changes in the land cover, as experienced in the Ayung Watershed, in the island of Bali, Indonesia. Here, the land cover undergoes rapid changes due to the growing tourism sector, affecting the runoff coefficient. This study evaluated the changing land cover patterns and surface runoff in the Ayung Watershed between 2012 and 2019. An increase in the surface runoff during the high rainfall events may lead to flooding in the area. The identification of land change patterns in the Ayung Watershed was carried out by a manual digitizing process on Google Earth maps. The runoff coefficient was calculated by Cook's method using the four physical characteristics of the watershed: land cover, infiltration rate, land slope and drainage density; showing significant changes in the land cover in the study area. Farmlands and forests were reduced by 647.8 ha and 553.1 ha respectively, converted into fast growing grasslands or unproductive land. Such land cover changes have a negative impact by increasing the runoff coefficient in the area. During the study period, the runoff coefficient was consistently found to be more than 0.6 (high-risk category). Several sections in the city of Denpasar experienced an increase in the runoff coefficient by more than 5%. Consequently, there was a high-risk of flooding in the area because of the increasing surface runoff.

1. INTRODUCTION

Bali is an international tourist destination that had been growing gradually until the COVID-19 pandemic hit at the beginning of 2020. The number of international tourists visiting Bali increased from 3.3 million in 2013 to 5.7 million in 2017 and 6.3 million in 2019 (Directory, 2020; Woods, 2020) with an average of 4.62 million people/year from 2012-2019 (BPS, 2021a). This number exceeded the total population in Bali, which was 4.34 million in 2019 (BPS, 2021b). Large land areas have been converted into settlements to accommodate the growing population and tourism sector in Bali (Sutawa, 2012; Hua, 2017; Ayele et al., 2018; Nuarsa et al., 2018).

Surface runoff is the rainwater that is not absorbed into the soil before it reaches the waterbodies

(Bellamy and Cho, 2019). The runoff coefficient (C) indicates the quantity of surface runoff and is used to determine the peak discharge during flood (Dickinson, 2017; Sudaryatno et al., 2020). Floods that occur because of high rainfall, result in an increase in the surface runoff coefficient which increases the potential for runoff; thus, the runoff coefficient is important for predicting the occurrence of surface runoff, and subsequently, flooding (Aponte, 2007; Mahmoud et al., 2014; Miardini and Susanti, 2016; Suprayogi et al., 2020).

Four factors affect the runoff coefficient: changes in the land cover, infiltration rate, slope of land and drainage density (Mahmoud et al., 2014; Lemma et al., 2018). Land cover significantly affects the infiltration ability of the soil, subsequently

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increasing the surface runoff (Tali and Kanth, 2011; Bellamy and Cho, 2019; Weber and Sciubba, 2019; Suprayogi et al., 2020).

The Ayung Watershed is one of the largest watersheds on the island of Bali and plays an important role in maintaining the hydrological balance on the island. It provides irrigation water for farmlands and clean water for the people inhabiting it, as well as serving as a popular tourist destination (Sumarniasih, 2015). However, the Ayung Watershed is currently experiencing problems owing to the increased surface runoff as a result of the changes in the land cover patterns. This has led to flooding in several parts of the watershed with flash floods occurring in 2016, 2017, and 2020, resulting in the loss of property and threatening human life (Sumarniasih, 2015; Berkarya, 2016; Widyaswara, 2017; Darna, 2020). A study of the runoff coefficient in some areas of the Ayung Watershed was conducted for the period ranging from 1992-2000 (Dharma et al., 2007). However, studies on the runoff coefficient and its impacts on the surface runoff of the entire Ayung Watershed have not been carried out.

The geographic information system (GIS) is a tool for analyzing the changes in the land cover and runoff coefficient, using the QGIS 3.20 software with a manual digitization method. The runoff coefficient can be calculated by Cook's method using the physical characteristics of the watershed: land cover,

infiltration rate, slope of land, and drainage density (Auliyani and Nugrahanto, 2020). Obtaining the runoff coefficient by combining the physical characteristics of the watershed is a very effective method that uses limited data for mapping flood risk areas, and has yielded satisfactory results in several studies (Mahmoud et al., 2014; Asare-Kyei et al., 2015; Mousavi et al., 2019).

This study aimed to determine the patterns of land cover changes and surface runoff coefficients in the Ayung Watershed between 2012 and 2019 to evaluate the potential risk of flooding. The study was carried out for a period of only eight years owing to the limited data available and low quality of the related images available on Google Earth. Similar studies for such time durations have been conducted and reported on the significant land cover changes during the study period (Abdelaty, 2016; Dadson, 2016).

2. METHODOLOGY

2.1 Study area

The study area for this research is the Ayung Watershed on the island of Bali, Indonesia as shown in Figure 1. The watershed with an area of 271.5 km², is located at 8°12'26.08"S-8°39'47.38"S latitude, and 115°11'1.68"E-115°16'12.9"E longitude. The Ayung River is the main river in this watershed with a length of 68.5 km.

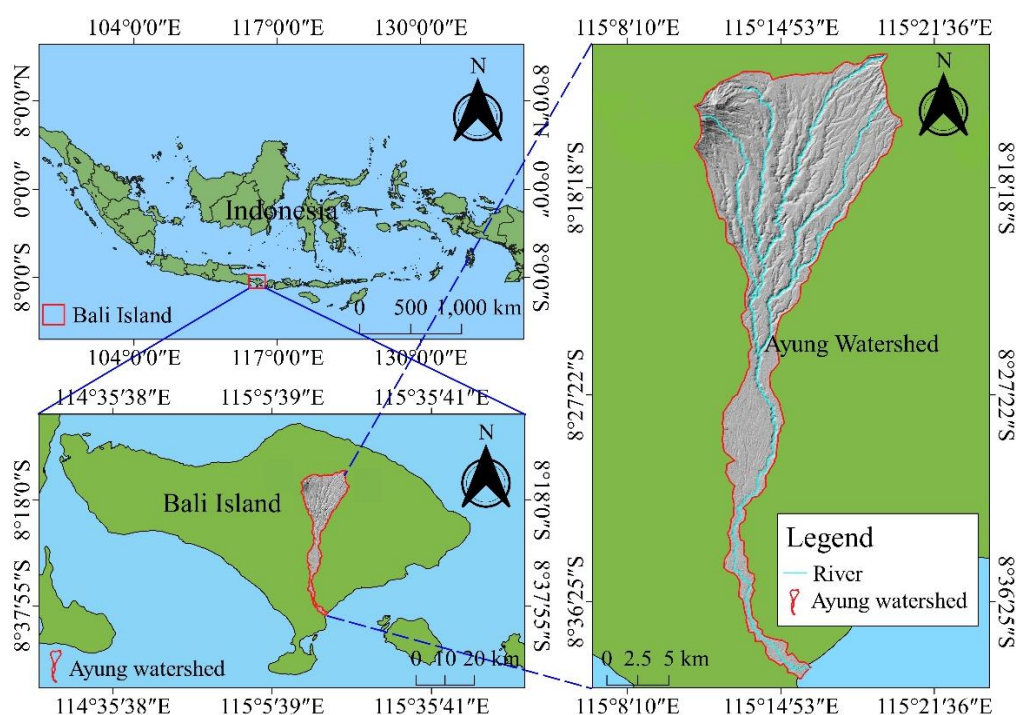


Figure 1. Maps of Indonesia, Bali Island and Ayung Watershed

2.2 Data collection

The data required to evaluate the land cover changes and runoff coefficient in the Ayung Watershed, include: the digital elevation model (DEM), land cover map, drainage density map, infiltration map, and watershed map.

The DEM for the study area had a resolution of 30 m, and was extracted from Google Earth (Rusli et al., 2013; El-Ashmawy, 2016) and interpolated using the filtering method to improve the quality and accuracy with the aim of getting it as close as possible to the actual surface pattern (Nikolakopoulos et al., 2005; Ma et al., 2020). The DEM was obtained under a resolution of 8 m through the filtering process, and was sufficient for use in hydrological modeling (Blackwell and Wells, 1999). The DEM was then used to obtain maps of the land slope and drainage density.

Google Earth provides maps with a resolution of 30 cm (Maxar Technologies, 2021) thus, the details of the objects on the Earth's surface can be seen more accurately (Cunningham, 2006; Ragheb and Ragab, 2015). Land cover maps were obtained from Google Earth maps by manual digitization at a scale of 1:20,000 for the 2012-2019 period. The land cover was divided into four categories: forest, farmland, grassland and settlement.

Soil texture maps and watershed maps were obtained from the Regional Development Planning Agency for Bali Province and the Directorate of Forest Resources Inventory and Monitoring, Republic of Indonesia, respectively.

2.3 Data analysis

The runoff coefficient was calculated by overlaying maps of the four parameters following the methods proposed by Risky et al. (2017), Auliyani and Nugrahanto (2020), and Sudaryatno et al. (2020). The data were analyzed using a quantitative descriptive research method. Each parameter, namely land cover, infiltration, slope, and drainage density, was divided into four categories and assigned with scores (Sv, Ss, St, and Sd, respectively) as shown in Table 1 and Table 2.

The scores for each category for four parameters were assigned based on the Cook's scoring system that has been widely applied to calculate the runoff coefficient (C) (Indriatmoko and Wibowo, 2007; Auliyani and Nugrahanto, 2020; Sudaryatno et al., 2020).

The drainage density was calculated using the following equation.

$$D_d = L/A_d \quad (1)$$

Where; Dd=drainage density (km/km²), L=the total length of all channels (km); and Ad=the area of the drainage basin (km²).

The overall runoff coefficient for each parameter was calculated using the following equation.

$$C = \frac{[\sum_{n=1}^4 (Sv_n \times Av_n) + \sum_{n=1}^4 (Ss_n \times As_n) + \sum_{n=1}^4 (St_n \times At_n) + \sum_{n=1}^4 (Sd_n \times Ad_n)]}{100} \quad (2)$$

Table 1. Scores for land cover and infiltration rate

No	Land cover	Score (Sv) (%)	Infiltration rate	Score (Ss) (%)
1	Good to excellent (approximately 50%-90% covered by trees)	5	Fast, infiltration rate is more than 2 cm/h (sandy soil)	5
2	Fair (approximately 10% to <50% covered by trees)	10	Normal, infiltration rate varies from 0.75-2.00 cm/h (sandy clay)	10
3	Poor (1% to <10% covered by trees)	15	Slow, infiltration range from 0.25-0.75 cm/h (clay loam)	15
4	No effective plant cover or only ground layer (<1%)	20	Soil with negligible infiltration (rock layers)	20

Table 2. Scores for slope and drainage density

No	Slope (%)	Score (St) (%)	Drainage density (km/km ²)	Score (Sa) (%)
1	Flat (<5%)	10	High (>8)	20
2	Rolling (5%-10%)	20	Normal (3.2-8.0)	15
3	Hilly (10%-30%)	30	Low (1.6 to <3.2)	10
4	Steep (>30%)	40	Very low (<1.6)	5

Where; C =overall runoff coefficient (C) for the watershed and n =order of category (1 to 4). A_v =ratio of each land cover area to the total area of watershed; A_s =ratio of infiltration rate area to the total area of watershed; A_t =ratio of slope area to the total area of watershed; A_d =ratio of drainage density area to the total area of watershed. A factor of 100 is required to convert the overall runoff coefficient value from percentage to decimal (Indriatmoko and Wibowo, 2007; Sudaryatno et al., 2020).

The runoff coefficient typically has values between 0 and 1, and is used to indicate the flood vulnerability of the area being analyzed (Dickinson, 2017; Mohamed and El-Raey, 2020).

The flood risk classification is determined using the following equation (Iswandi et al., 2016; Suhana et al., 2020).

$$I = (c-b)/k \quad (3)$$

Where; I =the class interval; c =the highest score; b =the lowest score; and k =number of the classes.

Based on the value of the runoff coefficient, the flood risk of any area is divided into five categories as shown in Table 3 (Mousavi et al., 2019).

Table 3. Runoff coefficient and flood risk category

No	Runoff coefficient (C)	Risk category
1	<0.2	Very low
2	0.2-0.4	Low
3	0.4-0.6	Moderate
4	0.6-0.8	High
5	>0.8	Very high

3. RESULTS AND DISCUSSION

3.1 Changes in the land cover

Land cover maps for the Ayung Watershed in the years 2012, 2015, and 2019, were used to represent the land cover changes during the 8-year period (Figure 2). A summary of the changes in land cover areas from 2012 to 2019 is presented in Table 4.

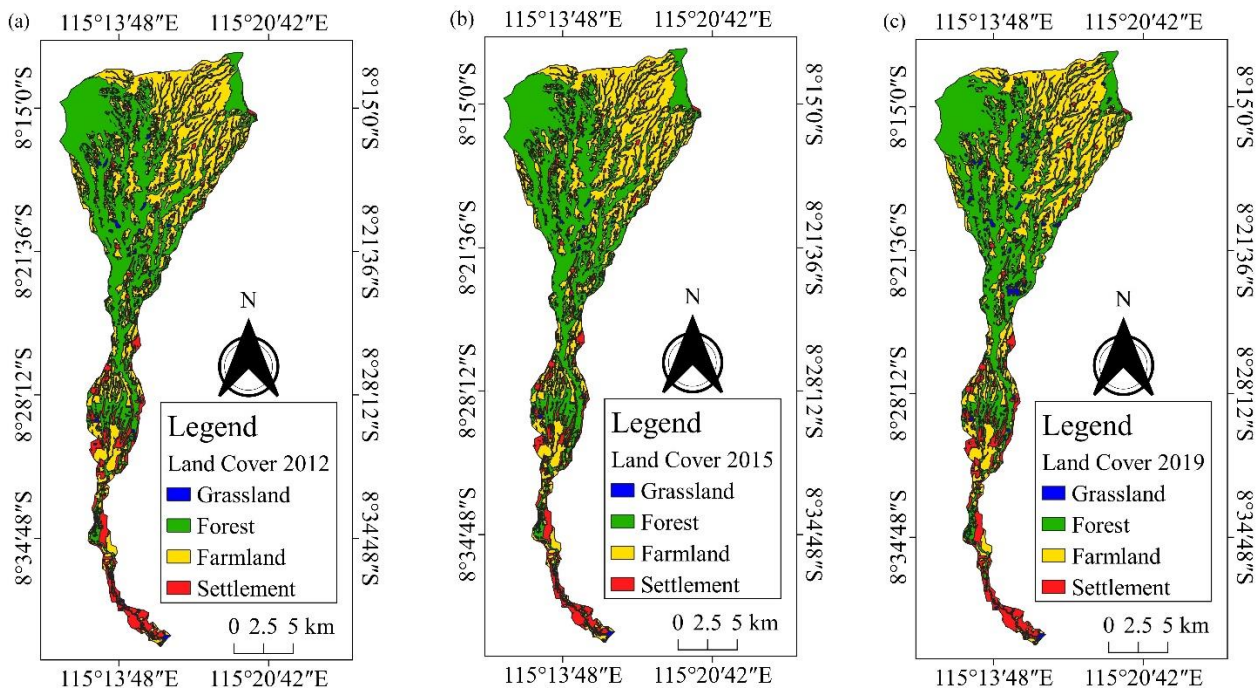


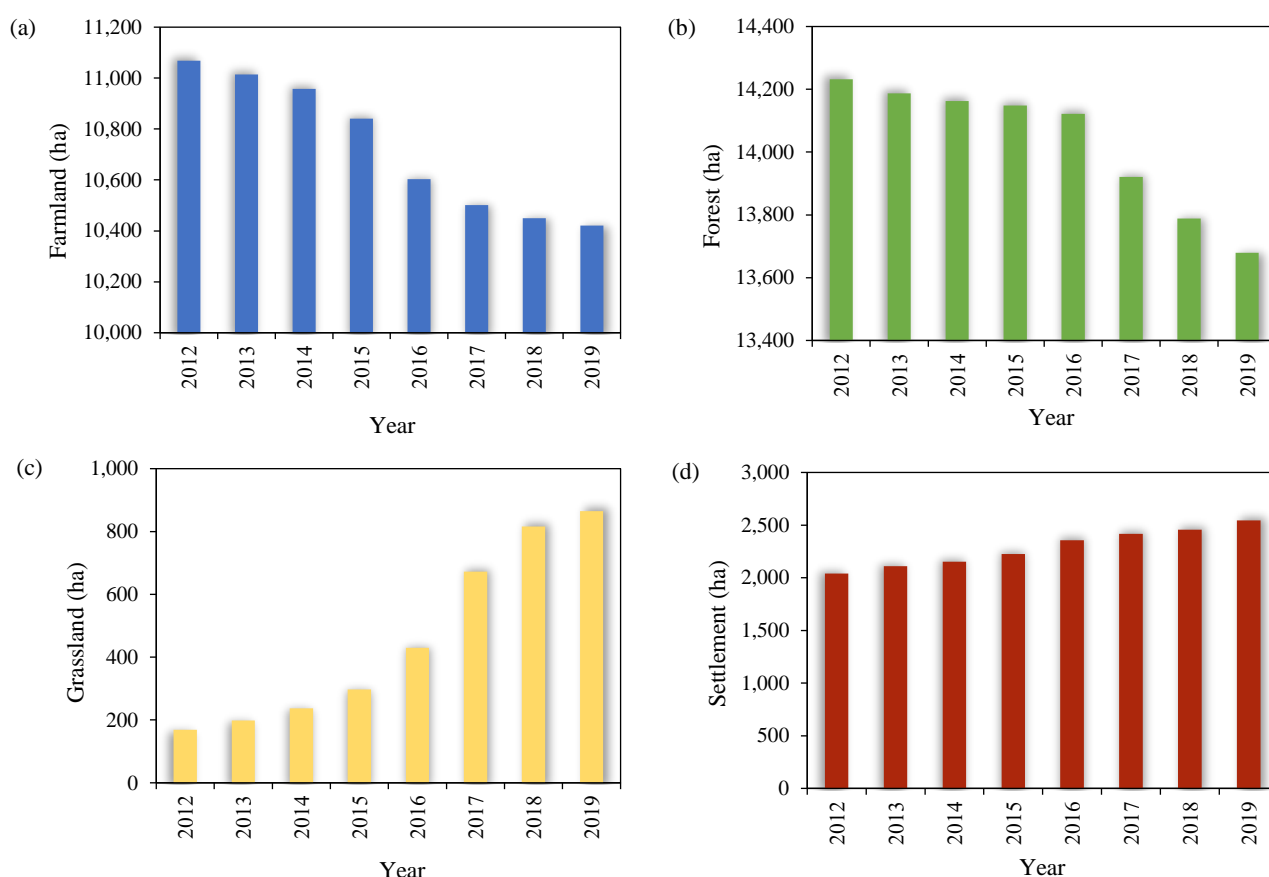
Figure 2. Land cover maps for the Ayung Watershed for years 2012, 2015, and 2019

Based on Figure 2 and Table 4, it can be seen that the highest land cover change occurred in the farmlands with a reduction in area of 647.8 ha (2.35%). Conversion of farmland to settlement also occurred in other areas of the Bali between 2012 and 2017 (Lanya et al., 2017; Rimba et al., 2019). This was

also reflected by the decrease in the number of people in Bali, who were originally farmers, but opted to change their profession to work in the tourism sector (Suartika, 2005). A summary of the changes occurring in each land cover category in Ayung Watershed during 2012-2019 is shown in Figure 3 and Table 5.

Table 4. Changes in the land cover in the Ayung Watershed from 2012-2019

Year	Land cover area (ha)							
	Farmland		Forest		Grassland		Settlement	
2012	11,068.8	(40.23%)	14,232.3	(51.73%)	168.7	(0.61%)	2,040.9	(7.42%)
2013	11,013.9	(40.03%)	14,187.5	(51.57%)	198.2	(0.72 %)	2,111.1	(7.67%)
2014	10,958.0	(39.83%)	14,162.1	(51.49%)	236.8	(0.86%)	2,153.8	(7.8 %)
2015	10,841.0	(39.41%)	14,148.2	(51.43%)	297.2	(1.08%)	2,224.3	(8.09 %)
2016	10,602.8	(38.54%)	14,122.3	(51.33%)	429.5	(1.56%)	2,356.1	(8.56%)
2017	10,501.0	(38.17%)	13,921.3	(50.60%)	672.1	(2.44%)	2,417.1	(8.79%)
2018	10,449.6	(37.98%)	13,788.5	(50.12%)	815.5	(2.96%)	2,457.1	(8.93%)
2019	10,421.0	(37.88%)	13,679.2	(49.72%)	865.1	(3.14%)	2,545.3	(9.25%)
Total changes	-647.8		-553.1		696.5		504.4	

**Figure 3.** Summary of the changes in the land cover between 2012 and 2019 (a) Farmland, (b) Forest, (c) Grassland, and (d) Settlement**Table 5.** Changes in the land cover in the Ayung Watershed between 2012 and 2019

Year	Land cover change (%)			
	Farmland	Forest	Grassland	Settlement
2012-2013	-0.20%	-0.16%	0.11%	0.25%
2013-2014	-0.20%	-0.08%	0.14%	0.16%
2014-2015	-0.42%	-0.06%	0.22%	0.26%
2015-2016	-0.87 %	-0.10%	0.48%	0.47%
2016-2017	-0.37%	-0.73%	0.88%	0.23%
2017-2018	-0.19%	-0.48%	0.52%	0.14%
2018-2019	-0.10%	-0.40%	0.18%	0.32%
Average change (%)	-0.34%	-0.29%	0.36%	0.26%

The highest average decrease occurred in the farmland (-0.34%) followed by forests (-0.29%), and the highest average increase occurred in grassland (0.36%) followed by settlement (0.26%). This is in accordance with some reported trends of the land cover changes in Bali, where there was a decrease in farmlands and an increase in grasslands (As-syakur, 2011; Adnyawati, 2019).

3.2 Slope, drainage density, and infiltration rate

The maps of the slope, drainage density and infiltration rate in the Ayung Watershed are shown in Figure 4.

As shown in Figure 4(a), most of the watershed is dominated by hilly plains with an area of 11,677.8

ha. Hilly slopes accelerate the flow and reduce water absorption thereby increasing the runoff coefficient (Duhita et al., 2020). Figure 4(b) shows that the drainage density in the Ayung watershed is very high (>8 km/km²), especially in the upstream region that covers a substantial area of 25,526.2 ha (92.8%). Figure 4(c) shows that the soil texture in the Ayung Watershed is dominated by clay loam with an area of 22,880.8 ha (83.2%), while the rest is sandy clay with area of 4,629.9 ha (16.8%). Clay loam soil has low water infiltration ability (Pitt and Lantrip, 2000), causing a high runoff coefficient (Amatya et al., 2015). The area distributions under each category of infiltration rate, slope and drainage density, are listed in Table 6.

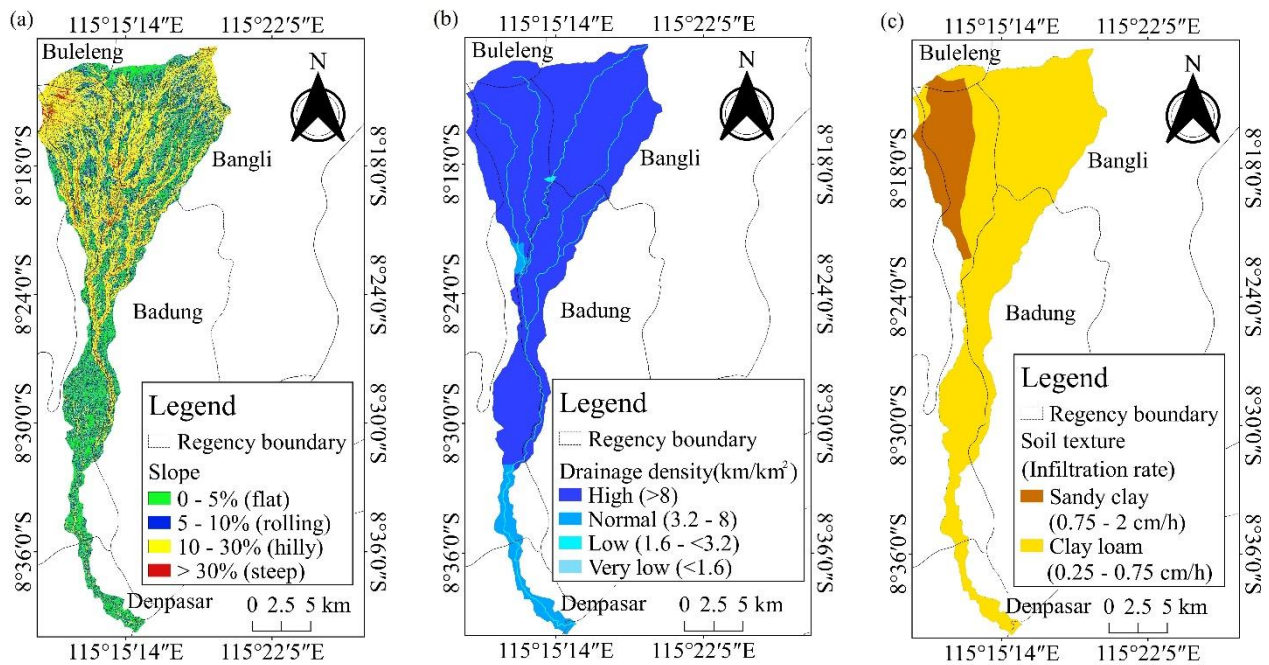


Figure 4. Ayung Watershed maps: (a) slope, (b) drainage density, and (c) infiltration rate

Table 6. Area distributions in the Ayung Watershed under each category of infiltration rate, slope and drainage density

Infiltration rate	Area (ha)		Slope (%)	Area (ha)		Drainage density (km/km ²)	Area (ha)	
Fast, infiltration rate is more than 2 cm/h (sandy soil)	-	(0.0%)	Flat (<5%)	7,256.5	(26.4%)	High (>8)	25,526.2	(92.8%)
Normal, infiltration rate varies from 0.75-2.00 cm/h (sandy clay)	4,629.9	(16.8%)	Rolling (5%-10%)	7,549.9	(27.4%)	Normal (3.2-8.0)	1,952.4	(7.1%)
Slow, infiltration range from 0.25-0.75 cm/h (clay loam)	22,880.8	(83.2%)	Hilly (10%-30%)	11,677.8	(42.5%)	Low (1.6 to <3.2)	33.0	(0.1%)
Soil with negligible infiltration (rock layers)	-	(0.0%)	Steep (>30%)	1,025.9	(3.7%)	Very low (<1.6)	-	(0.0%)

3.3 Runoff coefficient

The maps of the changes in the runoff coefficient in the Ayung watershed in 2012, 2015, and 2019 are shown in Figure 5. The areas in the Ayung watershed for different runoff coefficient (C) under

the different risk of flood categories between 2012 and 2019 are shown in Table 7. Based on the runoff coefficient values, a flood risk map of the area can be created (Aponte, 2007).

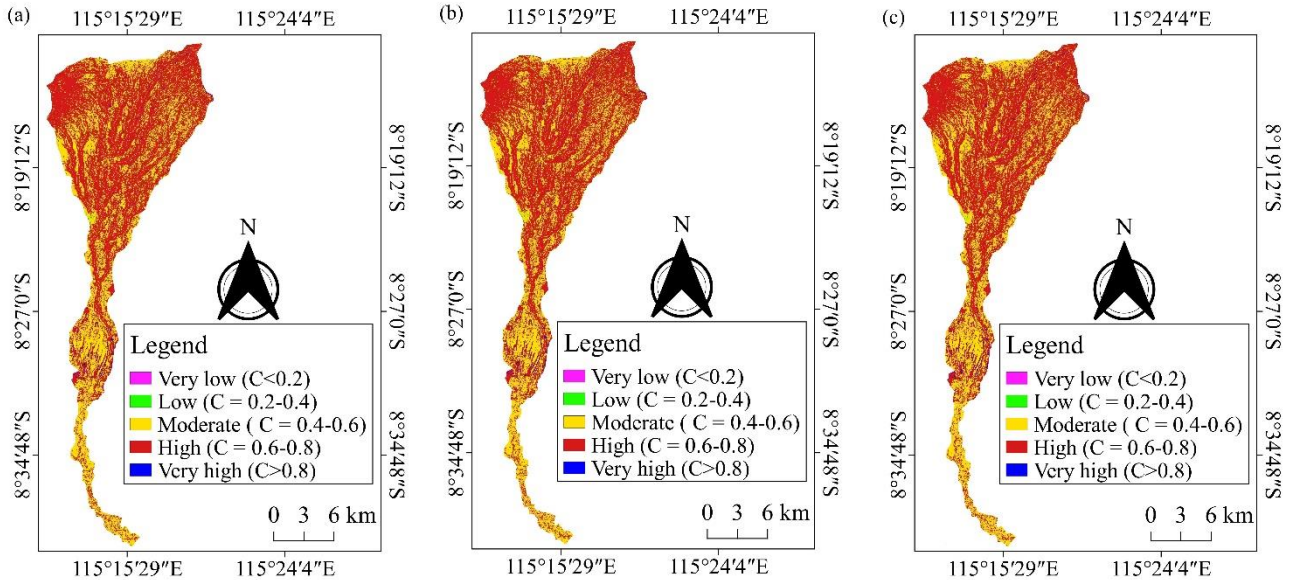


Figure 5. Runoff coefficient maps for the Ayung Watershed in (a) 2012, (b) 2015, and (c) 2019

Table 7. The areas in the Ayung Watershed with the run off coefficient (C) under the risk of different flood categories during 2012-2019.

Year	Risk category area (ha)				
	Very low (C<0.2)	Low (C=0.2-0.4)	Moderate (C=0.4-0.6)	High (C=0.6-0.8)	Very high (C>0.8)
2012	0 (0.00%)	45.1 (0.16%)	10,176.3 (36.99%)	17,029.8 (61.90%)	259.5 (0.94%)
2013	0 (0.00%)	37.1 (0.13%)	10,139.8 (36.86%)	17,068.4 (62.04%)	265.5 (0.96%)
2014	0 (0.00%)	32.8 (0.12%)	10,129.8 (36.82%)	17,083.1 (62.10%)	265.0 (0.96%)
2015	0 (0.00%)	32.8 (0.12%)	10,079.0 (36.64%)	17,126.9 (62.26%)	272.0 (0.99%)
2016	0 (0.00%)	38.1 (0.14%)	9,996.6 (36.34%)	17,171.2 (62.42%)	304.8 (1.11%)
2017	0 (0.00%)	37.9 (0.14%)	9,919.0 (36.05%)	17,237.2 (62.66%)	316.6 (1.15%)
2018	0 (0.00%)	37.8 (0.14%)	9,786.5 (35.57%)	17,359.6 (63.10%)	326.8 (1.19%)
2019	0 (0.00%)	36.8 (0.13%)	9,704.3 (35.27%)	17,440.3 (63.39%)	329.2 (1.20%)
Total changes	0	-8.3	-472.0	410.5	69.8

From Table 7, it can be seen that there was an increase in the high-risk category from 17,029.8 ha (61.90%) in 2012 to 17,440.3 ha (63.39%) in 2019. The total increase in the area under the high-risk category between 2012 and 2019 was 410.5 ha (1.5%). Meanwhile, the areas under the moderate risk category for flooding decreased from 10,176.3 ha (36.99%) in 2012 to 9,704.3 ha (35.27%) in 2019. Thus, the total decrease in the moderate flood risk category area between 2012 and 2019 was 472 ha (1.7%).

The overall runoff coefficient in the Ayung Watershed between 2012 and 2019 was obtained using Equation (2) and presented in Table 8.

Based on these results, the impact of changes in each type of land cover can be determined based on the runoff coefficient in the Ayung Watershed. It is clear that the decreasing farmland and forest areas, resulted in an increase in the areas of grassland and settlement, which increased the runoff coefficient.

As shown in Table 8, the overall runoff coefficient between 2012 and 2019, did not change significantly (from 0.644 in 2012 to 0.646 in 2019). However, there were several sections of Denpasar City that had a fairly high increase in the runoff coefficient, as shown in Table 9 and Figure 6. The increase in the runoff coefficient has a large impact because Denpasar is the capital city of the province of Bali with a high population density of 7,022 persons/km² (PU-net, 2017) leading to an increased risk of the loss of life during flooding.

Table 8. The overall runoff coefficient in the Ayung Watershed between 2012 and 2019.

Year	Runoff coefficient (C)
2012	0.644
2013	0.644
2014	0.644
2015	0.645
2016	0.645
2017	0.646
2018	0.646
2019	0.646

Table 9. Sections of Denpasar City with a fairly high increase in the runoff coefficient between 2012 and 2019

Sections	Runoff coefficient (C)								Total change (%)
	2012	2013	2014	2015	2016	2017	2018	2019	
Kesiman	0.592	0.607	0.610	0.613	0.615	0.618	0.622	0.631	6.59%
Kesiman Kertalangu	0.607	0.611	0.623	0.629	0.633	0.639	0.640	0.642	5.77%
Kesiman Petilan	0.601	0.606	0.615	0.622	0.626	0.630	0.633	0.635	5.66%
Penatih	0.605	0.611	0.620	0.633	0.634	0.638	0.640	0.646	6.78%

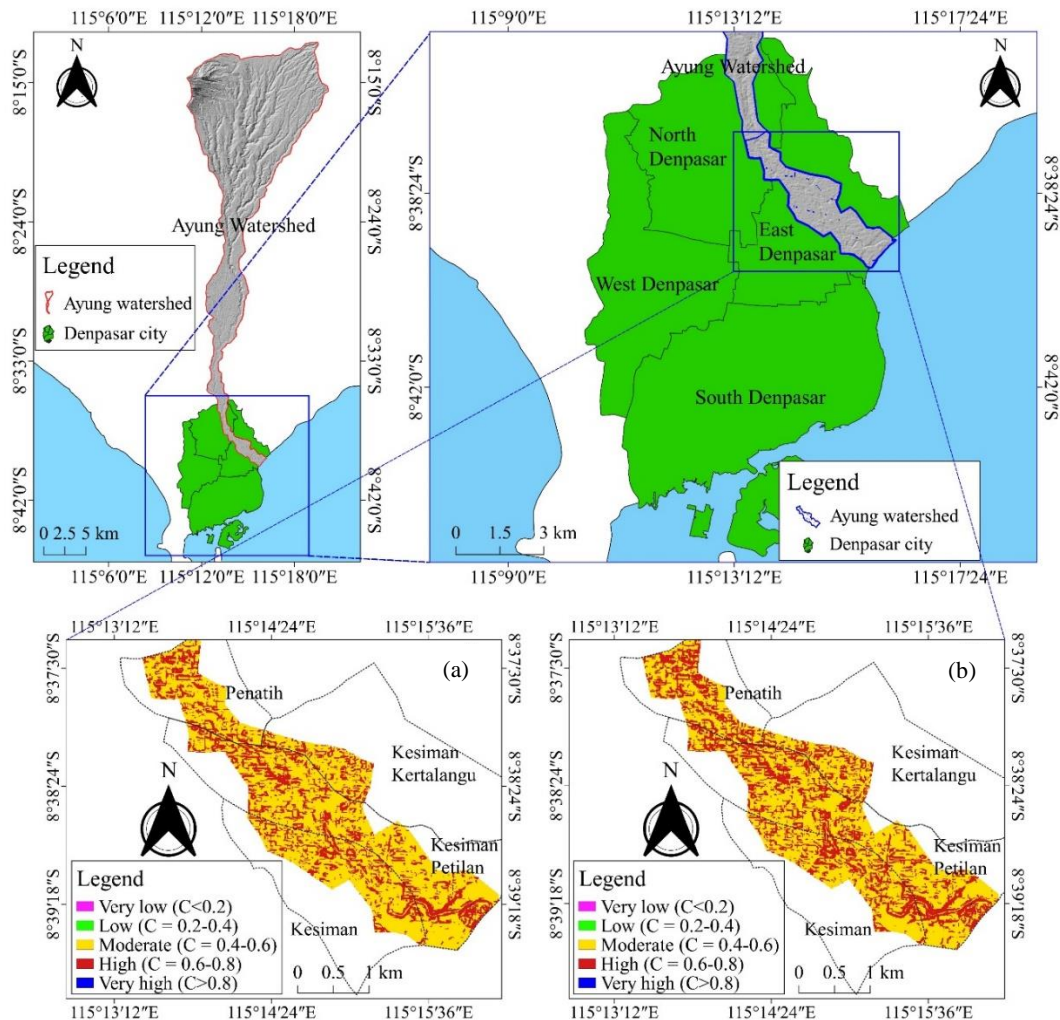


Figure 6. Maps of the flood risk areas in Denpasar City in the Ayung Watershed: (a) 2012 and (b) 2019

As shown in Table 9, several sections in the city of Denpasar experienced an increase in the runoff coefficient by more than 5% between 2012 and 2019. This is relatively high compared with that reported in several previous studies (Shi et al., 2007; Atharinafi and Wijaya, 2021). This can also be seen in Figure 6, which shows the maps of the changes in the areas under flood risk between 2012 and 2019. The higher runoff coefficient values were because of changes in the land cover, which increase the maximum flood peak discharge and thus increasing the risk of flooding (Shi et al., 2007; Suprayogi et al., 2020).

The results of this study conducted on the increased flood risk areas in the four sections of Denpasar City, are similar to a previous study that reported moderate to high flood risk in the same areas due to the increased runoff coefficient (Kusmiyarti et al., 2017). In general, the overall runoff coefficient in the Ayung Watershed between 2012 and 2019 was more than 0.6 (high flood risk category), leading to a high surface runoff that certainly increases the risk of flooding (Suprayogi et al., 2020). The results for the Ayung Watershed are similar to those in some previous studies conducted in other locations in Indonesia (Indriatmoko and Wibowo, 2007; Miardini and Susanti, 2016; Risky et al., 2017; Suprayogi et al., 2020).

4. CONCLUSION

Based on the runoff coefficient mapping of the Ayung Watershed between 2012 and 2019, it is clear that several areas are under high flood risk categories (runoff coefficient >0.6). The situation worsens with the conversion of forests and farmlands into grasslands and settlements leading to an increased runoff coefficient. Specifically, several sections in Denpasar, have experienced a significant increase in the runoff coefficient over the period 2012-2019 ($>5\%$). The increased risk of flooding in the densely populated city of Denpasar may have a negative impact on its population.

This study provides evidence that changes in the land cover patterns have increased the potential for flooding in the Ayung Watershed. Such information could be useful for the governments of Denpasar City and Bali Province in anticipating floods to avoid losses in the future.

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