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File name:	f_Watershed_Characteristics_in_Bali_Province_for_Sustainabl...
File size:	1.3M
Page count:	18
Word count:	6,235
Character count:	32,074
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Submission ID:	1746202310


Comparative Analysis of River Basin Watershed in Bali Province for Sustainable Water Resources Management
Eryani, Manan, Jayantari
p-ISSN 2579-9150; e-ISSN 2579-9207, Volume 4, Number 2, page 210-227, April 2021
Accredited SINTA 2 by Ministry of Research, Technology, and Higher Education of The Republic of Indonesia No. 23/E/KPT/2019 on August 8th, 2019 from October 1st, 2018 to September 30th, 2023

Indonesian Journal of Urban and Environmental Technology
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COMPARATIVE ANALYSIS OF WATERSHED CHARACTERISTICS IN BALI PROVINCE FOR SUSTAINABLE WATER RESOURCES MANAGEMENT

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ABSTRACT

Aims: This research will provide an overview of the comparative analysis of watershed characteristics in Bali which are differentiated from watersheds flowing to the north, and watersheds flowing to the south of Bali Province. The aim is to determine the characteristics of each, and proper sustainable management for each watershed. **Methodology and Results:** This is a descriptive, quantitative research that analyzes and compares the characteristics of the Saba watershed and Unda watershed, where the characteristics analyzed are morphometric and hydrological. From the analysis, it was observed that the Unda watershed, which has a flow direction to the south of the island of Bali, and the Saba watershed, flowing to the north of the island of Bali, possess several differences and similarities. The similarities include rainfall patterns, high temperatures, and the comparison values between Qmax and Qmin is significant. Meanwhile, the differences include the Saba watershed slope being steeper than the Unda watershed, and the Saba has young geomorphic features, while the Unda watershed possesses advanced geomorphic features. **Conclusion, significance, and impact of study:** Differences in watershed characteristics lead to differences in the management carried out. Furthermore, in terms of hydrology, where there are lesser differences, the sustainable management of the Saba and Unda Watershed also require conservation in form of a reservoir (weir or dam). This is to enable the storage of water in the rainy period for the dry season.

MANUSCRIPT HISTORY

- Received November 2020
- Revised Februari 2020
- Accepted March 2021
- Available online April 2021

KEYWORDS

- Geomorphic features
- Hydrology
- Morphometric
- Sustainable
- Watershed

DOI : 10.25105/urbanenvirotech.v4i2.8862

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1. INTRODUCTION

Solid waste refers to material residues from the extraction of the juice or during processing. These composites are of no significant socio-economic or environmental value, and therefore, are known causes of pollution. In addition, common sources include sugar, pulp, paper, rayon, plywood, nuclear waste, fruit, fish or meat preservation.

Watershed (DAS) is a land area which is an integral part of rivers and their tributaries, which functions to accommodate, store, and flow water from rainfall to lakes or the sea naturally, the boundaries on land are a topographical separator and boundary in the sea to water areas that are still affected by land activities (Bali Provincial Government, 2009). Nowadays, several watersheds in Indonesia have been degraded. Watershed degradation is marked by the expansion of critical land, erosion on steep slopes both used for agriculture and other purposes such as settlements and so on has had a wide impact on the environment, including floods that are getting bigger and their frequency increases (Ambar and Asdak, 2001).

The rivers that flow in Bali Province are the Bali Penida River Basin Unit which consists of 391 Watersheds (BWS Bali-Penida, 2012). The rivers in Bali flow to the North and South due to the division of Bali Island by mountains that stretch from west to east on this island (Eryani, 2015)

Degradation of watersheds in Bali Province today is increasingly concerning, resulting in natural disasters, floods, landslides, water crises, and/or drought which have had an impact on the economy and community life order (Bali Provincial Government, 2009).

Conservation, efficient use, and sustainable management of watershed resources are efforts to address watershed degradation. Improper watershed management can cause problems related to water sustainability (Koan *et al.,* 2020). To provide input for the preparation of a natural resource management plan in a watershed, each watershed/sub-watershed area needs to know the characteristics of the watershed, both morphometric and hydrological characteristics. This research will provide an overview of the comparative analysis of watershed characteristics in Bali which are differentiated between watersheds that flow to the northern and watersheds that to the south of Bali Province. The aim is to determine the characteristics of each watershed and determined the proper sustainable management for each watershed.

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2. RESEARCH METHODOLOGY

2.1 Research Location

This research was conducted in two potential watersheds in Bali Province, Indonesia. The location selection was based on the direction of the river estuary, because the purpose of this study was to determine the differences in the characteristics of the watersheds in Bali, which start to the north and the south, so two potential watersheds were selected, namely Saba Watershed and Unda Watershed (Figure 1). Saba watershed that flows to the north of Bali, and Unda watershed that flows to the south of Bali. The Saba Watershed and Unda Watershed are two potential watersheds in Bali Province, with a perennial river type.

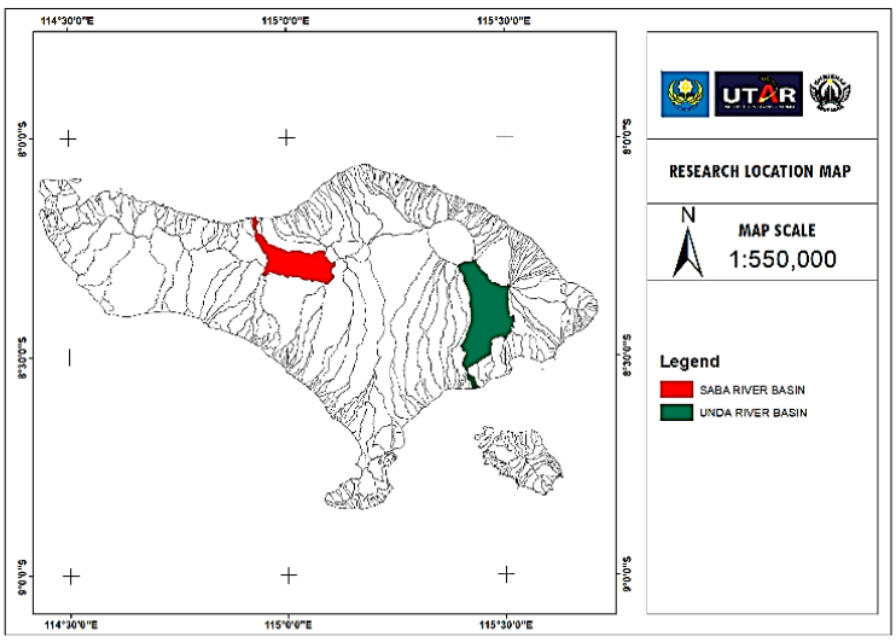

Figure 1 Research location

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2.2 Research Tools and Materials

2.2.1 Research Tools

The tool used in processing data in this research is a laptop with software: HEC-HMS 4.6.1, QGIS 3.1, Microsoft Office (Excel and Word).

2.2.2 Research Material

The data used in this research are primary data and secondary data. Primary data obtained from direct observations in the field to see the existing conditions of the watershed directly to match the results of the analysis. Secondary data required is the Bali Province Digital Elevation Model (DEM) that obtained from DEMNAS data, watershed boundary data obtained from BWS-Bali Penida, hydrological data in the form of 2003-2016 rainfall, temperature, and humidity in 2016, and discharge from years. 2013-2016 which was also obtained from BWS Bali Penida.

2.3 Data Analysis Technique

This research is a descriptive quantitative research that analyzes and compares the characteristics of the Saba Watershed and Unda Watershed, where the characteristics analyzed are morphometric i.e. river order, number of rivers, river length, average length of river, length ratio of rivers, bifurcation ratio, average bifurcation ratio, drainage density, slope, form factor, elongation ratio, and circularity ratio and hydrological characteristics i.e. rainfall, meteorology, and discharge. From the characteristics of the watershed, the appropriate management of water resources is formulated by the characteristics so that the potential of the watershed can be sustainable. To facilitate morphometric analysis, spatial data of the river were made from automatic delineation with the help of HEC-HMS 4.6.1 with preprocessing sink, preprocess drainage, identification River (in this study the minimum area value identified as a river was 2 km^2 after that, an outlet point is made according to the location of the discharge measurement, then the delineation results are automatically obtained for the sub-basic and river spatial data. The river spatial data already contains the river length, slope, and river order values.

2.3.1 Average River Length (Lsm)

Average river length (Lsm) is a dimension related to the drainage network component and the

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watershed surface (Vittala *et al.,* 2004).

$$Lsm = Lu / Nu \quad (1)$$

Lsm = average length of river,

Lu = the total length of the river of the order "u",

Nu = number of river segments of the order "u"

2.3.2 River Length Ratio (RL)

The river lengths ratio is obtained by dividing the total length of the river in a certain order by the total length of the river in the lower order.

$$RL = Lu / L_{u-1} \quad (2)$$

RL = river length ratio,

Lu = the total length of the river of the order "u",

Lu-1 = total length of the river in the previous order (lower order)

2.3.3 Bifurcation Ratio (Br)

The bifurcation ratio is calculated by dividing the number of river segments in a certain order by the number of river segments in a higher order.

$$Br = Nu / N_{u+1} \quad (3)$$

Br = bifurcation ratio,

Nu = number of river segments of the order "u",

Nu + 1 = number of orders of higher order rivers

2.3.4 Drainage Density (Dd)

Drainage density is an index number that shows the number of tributaries in a watershed. The flow density level can be used as an indication of the resistance level of the geological formation of the relevant watershed. The river flow density value is the result of a comparison between the length of the river and the area of the watershed.

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$$Dd = L / A \quad (4)$$

Dd = drainage density (km/km^2),

L = total length of the river of all orders in a watershed (km),

A = area of the watershed (km^2)

3. RESULTS AND DISCUSSION

The Saba River Basin (DAS Saba) is located in the northern part of Bali Province. The Saba watershed is a potential river with an area of 141.701 km^2 of the watershed that crosses 2 Tabanan and Buleleng Regencies. Along the Saba watershed and its tributaries, there are 11 irrigation weirs with an irrigated area of 3.768 ha. While the Unda River Basin covers 3 districts, are Karangasem Regency, Klungkung Regency, and Bangli Regency with a total watershed area of 230.91 km^2 with the length of the main river. The flow of water from the Unda River is widely used, especially for raw water and to meet the needs of irrigation water, with an area of 4542.3 hectares of agricultural land, mostly in the Karangasem Regency area.

3.1 Morphometric Characteristics

Morphometric is a form of quantification of morphology. The value of each morphometric parameter in a watershed determines the watershed characteristics (Rai *et al.,* 2017). Watershed morphometric analysis is considered an appropriate method in understanding the relationship between various aspects of a watershed such as river order, number of rivers, river length, average length of river, length ratio of rivers, bifurcation ratio, average bifurcation ratio, drainage density, slope, form factor, elongation ratio, and circularity ratio

Watershed analysis based on morphometric parameters is very important for watershed planning because it provides information on slope characteristics, topography, soil conditions, runoff water characteristics, surface water potential, and others (Chandrashekar *et al.,* 2015).

In addition to watershed planning, watershed morphometric analysis is also often used for disaster studies (Kar *et al.,* 2009). Some of the morphometric parameters calculated in this study include river order, number of rivers, length of rivers, average length of rivers, length ratio of rivers, bifurcation ratio, average bifurcation ratio, drainage density, slope, form factor, elongation ratio, and circularity ratio.

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3.1.1 River Order

The river order is the position of the river flow branching in its sequence to the main river in a watershed. To know the morphometric characteristic river order analysis is the first step that must be done. In this analysis, the determination of the river order is assisted by the HEC-HMS application in the GIS menu, where the tools are available in HEC-HMS to handle models that have spatial information. It includes spatial references to hydrological elements and tools for describing watersheds from digital elevation models. From the results of DEM data processing at HEC-HMS, spatial data are obtained in the form of catchment and river. The river spatial data resulting from HEC-HMS already contains River order information and River length for each order River.

Figure 2 shows that the Saba watershed has 3 river orders; $1^{st,}$ 2^{nd}, and 3^{rd} orders, 1^{st} order has 15 river segments with total length of 45.61 km; 2^{nd} order has 9 river segments with a total length of 45.54 km, and the 3^{rd} order has 4 river segments with a total length of 10.26 km. Meanwhile, Unda Watershed has 4 river orders; namely 1^{st}, 2^{nd}, 3^{rd}, and 4^{th} orders. 1^{st} order has 29 river segments with a total length of 103.89 km; 2^{nd} order has 16 river segments with a total length of 23.99 km; the 3^{rd} order has 10 river segments with a total length of 33.12 km, and the 4th order has 10 river segments with a total length of 4.35 km.

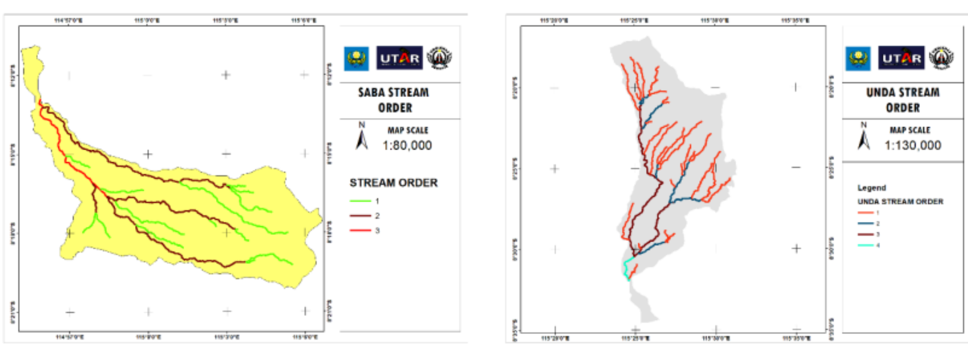

Figure 2 Saba and Unda River order

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3.1.2 Average River Length (Lsm)

In general, the average length of the river will increase as the order of the river increases, the fewer the number of river segments. Meanwhile, regarding the total length of rivers per order, the higher the order of the river, the smaller the total length of the river (Vittala *et al.,* 2004).

Table 1 Average river length (Lsm)

River Order	Saba Watershed			Unda Watershed		
	Nu	Lu (km)	Lsm = Lu/Nu	Nu	Lu (km)	Lsm = Lu/Nu
1	15.00	45.61	3.04	29.00	103.89	3.58
2	9.00	45.54	5.06	16.00	23.99	1.50
3	4.00	10.26	2.56	10.00	33.12	3.31

Based on the results of the calculation of Lsm values for the Saba watershed and Unda watershed (Table 1), it does not show a linear relationship with increasing orders, the largest Lsm in the Saba watershed is 5.06 km obtained in order 2 while in the Unda watershed 3.58 km is obtained in order 1. This may be due to the accuracy in delineation, very high elevation variations, lithological variations, and steep slopes in the watershed.

3.1.3 River Length Ratio (RL)

The trend (tendency) to increase the RL value from a lower order to a higher order indicates an advanced geomorphic stage in the watershed (Vinutha and Janardhana, 2014). The RL value of the Unda watershed tends to the RL value to increase from a lower order to a higher order, while the Saba watershed. This indicates that the Unda watershed has an advanced geomorphic stage while the Saba watershed has a young geomorphic stage (Table 2).

Young geomorphic are characterized by the ability to erode their channel, which can occur if the river gradient is steep. Young rivers are usually narrow, with steep cliffs consisting of bedrock. The irregular (uniform) river gradient is caused by variations in the rock structure (hard-soft). Whereas in rivers with advanced geomorphic, there are floodplains formed from the deposition of clastic material deposited in the area near the river forming a point bar.

On either side of the river, thick sediment accumulates along the river and forms a natural embankment. If the flow of the river becomes weaker, the clastic material carried by the river

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flow will be deposited on the bending of the slope, the inner side of the meanders, the confluence of two river flows, and changes in gradient. If the alluvial sediment of the river that has been formed is then eroded again by the river flow, river steps will be formed, and it is a river rejuvenation in adulthood or old age.

Table 2 River Lengths Ratio (RL)

Watershed	River Lengths Ratio (RL)		Classification
	II/I	III/II	
Saba	0.998	0.225	Young Geomorphic
Unda	0.231	1.380	Advanced Geomorphic

3.1.4 Bifurcation Ratio (Br)

Based on Table 3, the Saba watershed and Unda watershed have Br value <3, which indicates that both watersheds have river channels that have a rapid rise in flood water level, while the decline is slow. Sriyana (2011) states that the bifurcation ratio is classified as follows:

- Br <3: river channel has a rapid rise in flood water level, while its decline is slow
- Br 3-5: then the river channel has an increase and decreases in the flood water level, neither too fast nor too slow
- Br> 5: river channel has a rapid rise in flood water level, likewise its decline is rapid (Sriyana, 2011).

Table 3 Bifurcation Ratio (Br)

Watershed	Bifurcation Ratio (Br)		Average
	I/II	II/III	
Saba	1.67	2.25	1.96
Unda	1.81	1.60	1.71

3.1.5 River Slope

River slope is the slope value of the river. Based on the results of the analysis using QGIS, it was found that the slope of the Saba Watershed was 0.0512, while the Unda Watershed was 0.0248, the greater the slope value shows the steeper of the area. Based on the calculation

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results in Table 4, it can be seen that the Saba Watershed is steeper than the Unda Watershed, the steeper the topography, the higher the erosive power of the runoff.

Table 4 River Slope

Watershed	River Slope	Percentage (%)
Saba	0.0512	5.12%
Unda	0.0248	2.48%

3.1.6 Drainage Density (Dd)

A low drainage density is characterized by a flow area with minimal branching, an elongated watershed shape, and a sloping topography and there are basins. This causes the response to the entry of rainfall is very slow and the concentration time is long.

The drainage density also affects the concentration time. In watersheds that have a high drainage density, the concentration time is short and the runoff rate is large. The time required for water from the farthest point to arrive at the control point is relatively short in watersheds with high drainage density compared to watersheds with low density.

Table 5 Drainage density (Dd)

Watershed	Area (A)	Total Length (L)	Drainage density (Dd)
Saba	129.26	101.41	0.78
Unda	223.06	165.35	0.74

Sriyana (2011) states that the river flow density index can be classified into:

- Dd : <0.25 km/km^2 : low
- Dd : 0.25 - 10 km/km^2 : moderate
- Dd : 10 - 25 km/km^2 : height
- Dd : > 25 km/km^2 : very high

Based on the results of the calculation of the Dd value for the Saba watershed, it is 0.78 km/km^2 and for Unda watershed, it is 0.74 km/km^2 (Table 5). The two watersheds have moderate Dd values because they have moderate drainage density, the Saba watershed, and

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Unda watershed has a moderate concentration time with a moderate surface flow rate so that the response to the influx of rainfall is also moderate.

3.1.7 Shape of the Watershed

The shape of the watershed can be determined based on the ratio of the circularity ratio (Rc) to the elongation ratio (Re). The circularity ratio is one of the morphometric parameters to determine the shape of the watershed. As well as the circularity ratio and form factor, the elongation ratio is also used to assess the shape of the watershed (Table 6).

Table 6 Shape of the watershed

No	Index	Classification	Characteristics
1	Re<Rc	Rounded	The surface flow rate is faster so that the water concentration is faster
2	Re>Rc	Lengthwise	The runoff rate is slower so the water concentration is slower

Source: Kahirun et al., (2017)

Table 7 Shape of the Unda and Saba watershed

Watershed	Area (A)	Perimeter (P)	Length (Lb)	Rc	Re	Shape
Saba	129.26	73.66	25.54	0.299	0.284	Rounded
Unda	223.06	95.48	24.85	0.307	0.383	Lengthwise

Based on the results of the calculation, the classification of watershed forms was obtained (Table 7). The Saba watershed has a Re value of 0.284 and an Rc of 0.299, the Saba watershed has a rounded shape where the value of Re<Rc. Meanwhile, the Unda watershed has a Re value of 0.383 and an Rc of 0.307, the Saba watershed has an elongated shape where the value of Re>Rc. The elongated shape of the drainage area indicates that the flood discharge will be relatively small because the flood travels from the tributaries are different in time. The radial shape (resembling the shape of a fan or circle) has the nature of a rapid increase in flood discharge because the flow comes almost simultaneously, and can cause major flooding (Supangat, 2012).

DOI : 10.25105/urbanenvirotech.v4i2.8862

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3.2 Hydrological Characteristics

3.2.1 Rainfall Data

Rainfall is intermittent, and the character of precipitation when it occurs is highly dependent on temperature and weather conditions (Mawonike and Mandonga, 2017). Rainfall in a watershed is also a parameter of the water potential availability.

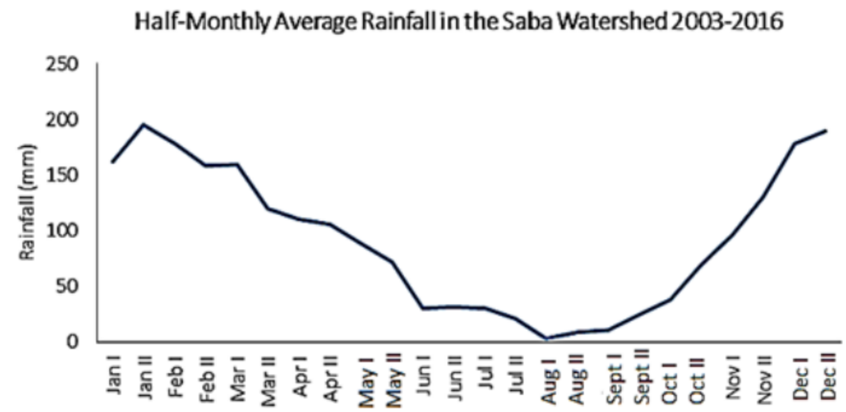

Figure 3 Half-monthly average rainfall in the Saba watershed 2003-2016

Based on the calculation of the area average rainfall, it can be seen in Figure 3 that the maximum semi-monthly average rainfall in the Saba watershed is in January II (the second half of the month in January) with an average rainfall of 195.15 mm, and a minimum of 3.34 mm in August I (first half of August).

As for the Unda watershed (Figure 4), it is known that the maximum semi-monthly average rainfall occurs in January I (first half-month in January) with an average rainfall of 159.57 mm, and a minimum of 8.59 mm in August I (first half month in August).

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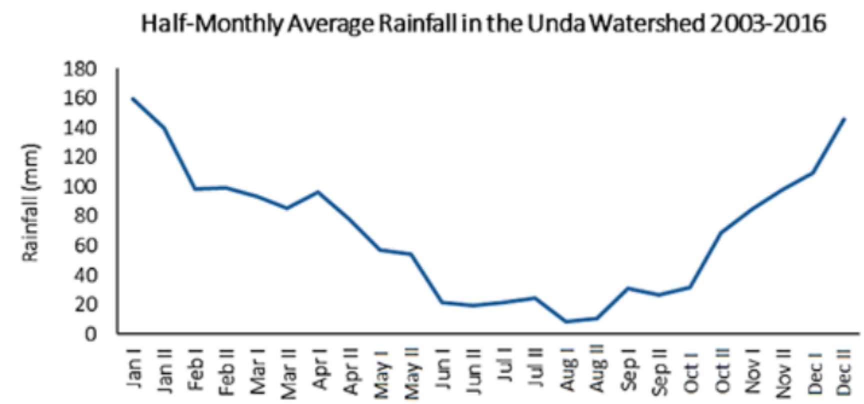

Figure 4 Half-monthly average rainfall in the Unda watershed 2003-2016

3.2.2 Meteorological Data

Temperature is a measure of the warmth or coldness of an object or substance concerning standard values. Temperature affects rainfall in many ways; high temperatures can lead to very high potential levels of evaporation and low rainfall. This results in areas dominated by arid or semi-arid landscapes. In other cases, high temperatures cause more evaporation and consequently increase condensation leading to heavy rainfall (Mawonike and Mandonga, 2017).

Table 8 Meteorological data

Parameter	Unda			Saba		
	Temperature (t) (C)	Relative Humidity (Rh) (%)	Wind Speed (u) (km/jam)	Temperature (t) (C)	Relative Humidity (Rh) (%)	Wind Speed (u) (km/jam)
Average	31.00	94.85	1.57	32.13	87.69	1.25

Source: BWS Bali-Penida, (2016)

From the data in Table 8, it can be seen that the Saba watershed has an average temperature of 32.13 °C, higher than the Unda watershed which averages 31 °C, this can indicate that the Saba watershed will have a greater potential for evaporation compared to the Unda watershed. The wind speed of the Unda watershed has an average value of 1.57 km/hour which is greater than the Saba watershed which is only 1.25 km/hour. For relative humidity,

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Unda watershed has a relative humidity value of 94.85% which is greater than Saba watershed which is 87.69%.

3.2.3 Discharge

Based on the data on the discharge records for the year 2012-2015 (Figure 5 and 6), the average discharge of the Saba watershed was 4.76 m^3/s, with a maximum discharge of 11.10 m^3/s that occurred in September 2015, and a minimum discharge of 0.26 m^3/s. Meanwhile, the Unda watershed was 2.69 m^3/s, with a maximum discharge of 7.29 m^3/s which occurred in July 2013, and a minimum discharge of 0.00 m^3/s. In general, it can be seen that the average discharge of the Saba watershed is greater than that of the Unda watershed.

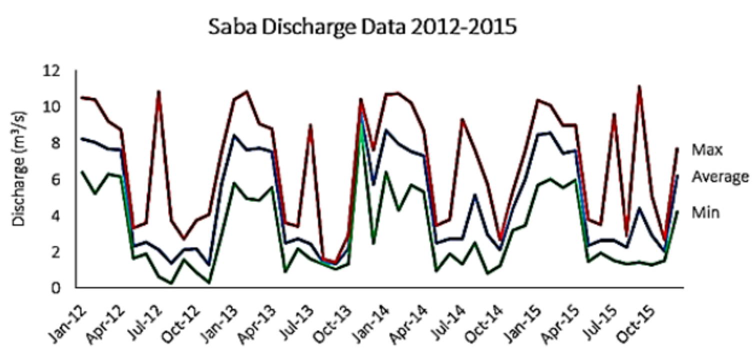

Figure 5 Saba watershed discharge 2012-2015

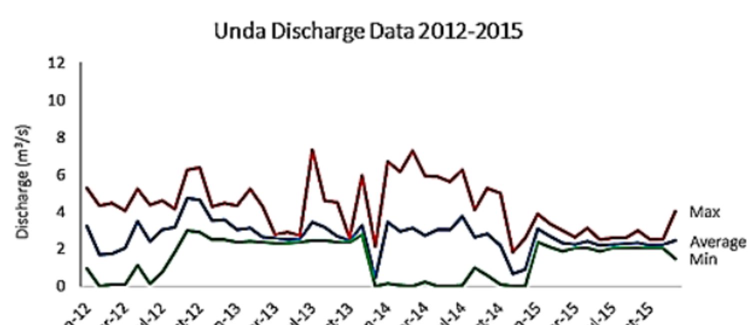

Figure 6 Unda watershed discharge 2012-2015

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Table 8 River regime coefficient

DAS	Saba Maximum Discharge (m^3/s)	Saba Minimum Discharge (m^3/s)	KRS	Unda Maximum Discharge (m^3/s)	Unda Minimum Discharge (m^3/s)	KRS
2012	10.84	0.26	41.69	6.39	0.02	412.36
2013	10.85	0.92	11.74	7.29	0.00	-
2014	10.74	0.81	13.25	7.27	0.00	-
2015	11.10	1.31	8.45	4.03	1.49	2.70

The River Regime Coefficient value is the comparison value of Qmax and Qmin. A high river regime coefficient indicates a large difference in the range of Qmax and Qmin values, or it is said that the range of runoff values in the rainy season that occurs is large, while in the dry season the water flow that occurs is very small or indicates drought. This condition indirectly shows that the land absorption capacity is less able to hold and store falling rainwater and much of the runoff continues to enter the river and is wasted into the sea so that the availability of water in the watershed during the dry season is low (Sunardi, 2016).

3.3 Sustainable Water Resources Management

In the effort to utilize, manage and walk water sources, a coordination forum that is capable of managing water resources holistically and comprehensively is needed because since the development of the population and the struggle for control of water, it has been realized that scarcity, conflict, and pollution of water sources and the environment has begun to be felt. Management of water resources in a watershed must be adjusted to the characteristics of the watershed to obtain optimal results. Sustainable water resources management focuses on the efficient use and conservation of water resources. Efforts to conserve water resources are carried out by controlling surface flow to minimize the destructive power of water, accommodating and holding rain runoff to be used optimally and water has a longer opportunity to enter the ground.

For the Saba watershed, which has a young geomorphic type and a steeper slope than the Unda watershed, the degradation of the watershed that can occur is erosion in the area around the river. So it is necessary to arrange the river area by making river embankment and

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conservation such as planting vegetation so that the potential for erosion that can cause flooding and landslides can be prevented. With this management method, it is hoped that the water potential of the Saba watershed can be sustainable. High temperature conditions and a significant ratio between Qmax and Qmin require conservation in the form of a reservoir (weir or dam) so that the potential for water in the rainy period can be stored for the dry season. Whereas in the Unda watershed, based on its geomorphic characteristics, which causes high deposition, and coupled with the type of longitudinal watershed and the discharge is not large enough, the degradation that may occur in the Unda watershed is sedimentation which is not impossible to cause silting, silting will reduce the holding capacity of the river so that when a large discharge occurs the river cannot accommodate the discharge and there is a flood. So that to manage the existing potential, it is necessary to analyze the deposition that occurs and carry out routine maintenance for dredging the river channel. Then in terms of hydrology, which is not much different from the Saba Watershed, sustainable management of the Unda Watershed also requires conservation in the form of a reservoir (weir, or dam) so that the potential for water in the rainy period can be stored for the dry season.

4. CONCLUSION

Based on the results of the analysis, it is known that the Unda watershed, which has a flow direction to the south of the island of Bali, and the Saba watershed, which flows to the north of the island of Bali, has several differences and similarities where the similarities include rainfall patterns, high temperatures, and comparison values between Qmax and a significant Qmin. Whereas the differences owned, such as the Saba watershed slope is steeper than the Unda watershed, then the Saba watershed has young geomorphic features, while the Unda watershed has advanced geomorphic features. The different characteristics make a difference from the management carried out, where for the Saba watershed to maintain the sustainability of the potential of water resources it can be managed by arranging the river basin and making river embankment to reduce the potential for erosion that occurs, while in the Unda Watershed it can be managed by carrying out routine maintenance for dredging. River channels to reduce the potential for flooding due to silting. Then in terms of hydrology, which is not much different, sustainable management of the Saba Watershed and Unda Watershed also requires conservation in the form of reservoirs (weirs, or dams) so that the potential for water in the

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rainy period can be stored for the dry season.

5. ACKNOWLEDGEMENT

The authors express gratitude to the Acknowledgments submitted to Warmadewa University who have supported the completion of this paper

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