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Biophysical characteristics of Wosi Watershed area in Manokwari Regency, Indonesia

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Abstract. *Flood is number one Indonesian natural disaster in the last 10 years and its occurrence at Manokwari is frequently reported. Biophysical condition is playing a key role in carrying capacity of this catchment area. This study is to determine biophysical characteristics of Wosi Watershed to manage and mitigate flooding in Manokwari. Spatial analysis and field observation methods were used to collect the data. Biophysical variables are rainfall, watershed morphometric, slope, and land used. Carrying capacity is measured using flow regime coefficient and annual flow coefficient. The results showed that the heavy rainfall (> 100 mm) throughout the ten years with 10.5 wet months at average resulting very wet tropical climate*. *This watershed has an area of 2,346.32 ha, its circumference of 29.95 km^2 with river length of 8.38 km resulting 0.33 (triangle) and 1.027 (triangle) for Rc and Re, respectively. This morphometry is rectangular and slightly oval (triangular) formed of four rivers with drainage pattern of dendritic, which resembles the shape of a tree branch/twig. Steep slopes are dominant (58.5%), with non-forest area (62%) of the flat and steep slope for settlement (698 ha), and flat slope for mixed dry farming (707 ha). From 2016-2020, river water flow changes rapidly from low to very high to generate flooding, but the carrying capacity is sometime changeable from good to bad. Water drainage, retaining walls, replantation, early warning system, and flooding leaflets mitigation campaign, are structural and non-structural mitigation could be parallelly conducted to manage and mitigate the flooding risks in future.*

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INTRODUCTION

Throughout 2020, there were 2,952 natural disasters in Indonesia. Thirty six percent of these disasters are floods (CNN Indonesia 2020). The trend of flood continues to increase each year, including throughout 2021 and the first semester of 2022. Flood indicates the inability of the watershed ecosystem to provide environmental services as a result of the degradation and deforestation of forest and land resources (Papaioannou et al. 2015). Flood is caused by climate change, forest conversion, and land use. Thus, these factors increase surface runoff. The amount of water that directly becomes runoff increases significantly, so peak discharge becomes larger (Yan et al. 2013; Nasir et al. 2017). The conversion of forests into plantations, settlements area, and other built-up areas is sometimes not realized. Whereas in general, the rain that occurs in an area does not experience changes that have an impact on stagnant water.

The watershed is part of a complex ecosystem because it involves various bio-geophysical, social, economic, cultural, and institutional components that interact with each other. Interactions between biotic and abiotic components in watershed ecosystems have direct or indirect impacts and large or small effects. According to Junaidi and Tarigan (2011), land use influences the function of a watershed ecosystem. In addition, Supangat (2012) stated that watershed characteristics and land use are two important factors that affect the hydrological characteristics of the watershed. A comprehensive understanding of the hydrological characteristics of the watershed and the influencing factors is needed for sustainable watershed management, particularly with regard to the use of water resources and land use (Azizah et al. 2021).

Watershed characteristics (typology) are vital for watershed management plans based on Government Regulation Number 37, in 2012 concerning Watershed Management. The typology of the watershed can be identified through the analysis of the characteristics of the watershed. Among the characteristics of a watershed that often causes natural disasters, namely, flooding, one of the conditions of water management is resulting from the output of a watershed (Paimin et al. 2012). To determine the characteristics of the watershed is the biophysical condition of the watershed, which is characterized by parameters related to climate, morphometrics, topography, soil, geology, vegetation, land use, hydrology, and humans.

These climatic and biophysical characteristics will provide specific responses from the watershed to rainfall which will affect the character parameters and special features of water systems such as evaporation, transpiration, surface runoff, infiltration, interception, groundwater, and river discharge (Ningkeula 2016). Increased surface runoff has an impact on river discharge which, if the water cannot be accommodated, then flooding is inevitable. These parameters have been widely used in various geo-hydro-morphological studies, such as flood characteristics, sedimentation, and changes in watershed morphology. In addition, land use by human activities and the morphology of the watershed also affect the water system, including sedimentation.

Wosi watershed is part of 2,145 watersheds spread across Indonesia whose status “needs to be restored” (KLHK 2019). The Wosi watershed is also part of seven watersheds in Manokwari Regency, which are classified as “critical”. Pamuji and Hardianti (2019) argued that the Wosi River could not accommodate the peak flow during high-intensity of rainfall, thus causing flooding. The Wosi area is located in the capital city of West Papua Province, which will continue to grow and develop, but its carrying capacity is decreasing (Mahmud et al. 2021a). The Wosi watershed has become a source of catastrophic flooding for several regions in Manokwari, particularly those living downstream of the watershed, such as the area of Wosi market, the green valley, around the Rendani Airport, the Bugis Village, and the Javanese Village. This study aims to determine the biophysical condition or characteristics of the Wosi Watershed to examine the biophysical variables that contribute to the water system or hydrology. This information is expected to contribute to the management of the Wosi Watershed and flood mitigation in Manokwari.

METHODS

Research Location

This research was carried out for 4 months in the Wosi Watershed, which is geographically located at 133^0 0' 0.722" E – 134^0 3' 34.55"E and 0^0 50' 25.5" S – 0^0 54' 8.24" S with an area of 2,346.32 ha (Figure 1). Downstream of the Wosi Watershed is a built-up area and is the capital of West Papua Province. The upstream of the Wosi Watershed covers a fairly steep hill, and its estuary is in Doreri Bay.

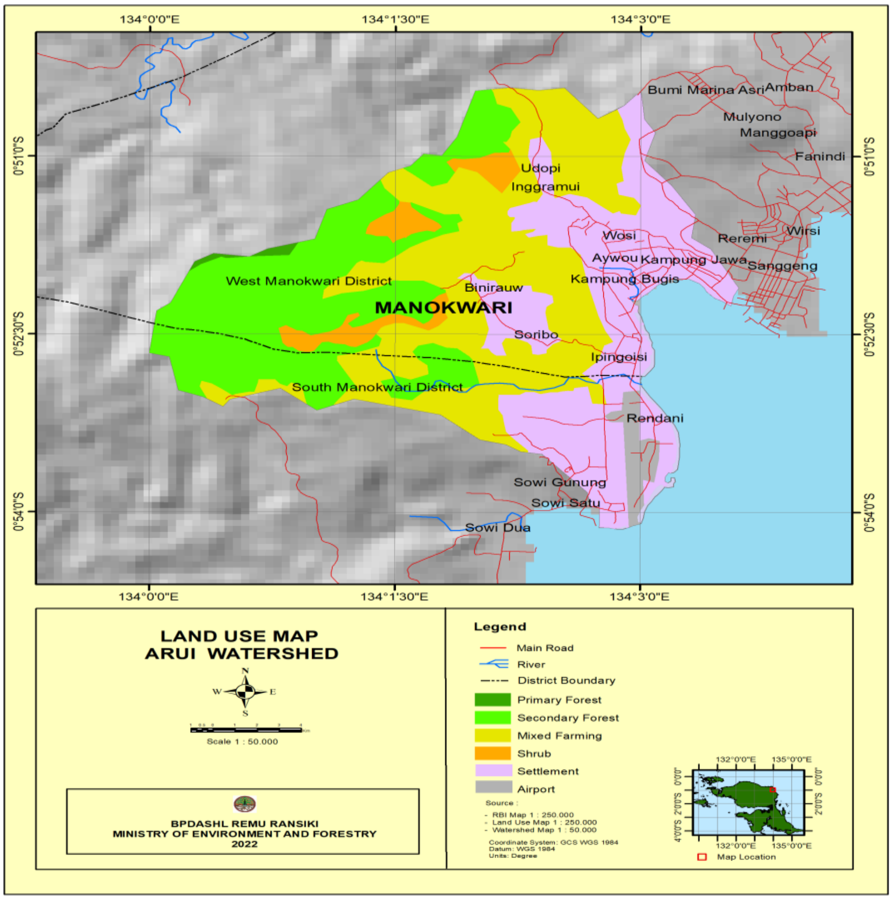

Figure 1 Study site

Data Collection

The research method used was spatial analysis and field observation. Watershed morphology includes: land use and topography observed directly and through digital elevation models. The morphometry includes: the shape of the watershed, the area of the watershed, the level of branching, the density of the flow, the flow pattern, and the length of the main river, which are measured digitally based on the guidelines for identifying characteristics of the watershed. Meanwhile, for the hydrology, the observed data installed on the *Stasiun Pengamatan Arus Sungai* (SPAS) consists of flow regime coefficients (FRC) and annual flow coefficients (AFC). Rainfall data in the last 10 years obtained from the BMKG Rendani, Manokwari Regency include: daily, monthly, and annual rainfall, wet months, dry months, and rainfall intensity. Wet month (WM): the amount of rainfall is more than 100 mm/month, humid month (HM): the amount of rainfall is between 60 - 100 mm/month, and dry month (DM): the amount of rainfall is less than 60 mm/month. The rainfall data is used to classify the climate according to Schmidt and Fergusson (1954) in (Soewarno 1991).

$$Q = \frac{DM}{WM} \text{ x } 100\%$$

Note: Q = climate; DM = number of dry months; WM = number of wet months

To determine the shape of the watershed, it is necessary to value the circulation ratio or RC (Strahler 1964) and the extension ratio or RE (Schum 1956) with the following formula:

$$RC = \frac{4\pi A}{P^2}$$

$$RE = 1{,}129 \{ \frac{A^{0.5}}{L} \}$$

Note: RC = circulation ratio; RE = elongation ratio; A = watershed area (m^2); L = length of the watershed; P = perimeter of the watershed (m); = 3.14 If RE < RC means the watershed is rounded and RE > RC means the watershed is elongated. Data on circulation ratio, extension ratio, total river length, and watershed circumference were obtained through a geographic information system (GIS). River density number of long rivers, including tributaries and wide watersheds, was obtained through GIS. River density is an index that shows the number of rivers and tributaries in a watershed. The index is obtained by the following equation (Soewarno 1991):

$$Dd = \frac{L}{A}$$

Note: Dd = river density; L = total length of the river, including its tributaries; A = watershed width. The flow regime coefficient (FRC) is obtained from the comparison between the maximum discharge (Qmax) and the minimum discharge (Qmin) in a watershed, referring to the regulation of minister Number 61/Menhut-II/2014.

$$FRC = \frac{Qmax}{Qmin}$$

FRC ≤ 20 = very low; 20 < FRC ≤ 50 = low; 50 < FRC ≤ 80 = moderate; 80 < FRC ≤ 110 = high; FRC > 110 = very high. The annual flow coefficient (AFC) is obtained from the comparison between the annual flow rate (Q) and the annual rainfall thickness (P) with the following calculation:

$$AFC = \frac{Q}{P}$$

P is obtained from the annual rainfall x the area of the Wosi watershed. AFC ≤ 0.2 = very low; 0.2 < AFC ≤ 0.3 = low; 0.3 < AFC ≤ 0.4 = moderate; 0.4 < AFC ≤ 0.5= high; AFC > 0.5 = very high (Permen N0.61/Menhut-II/2014).

Data analysis

Meteorological, morphological, and morphometric data were interpreted to obtain a descriptive qualitative description of the Wosi Watershed characteristics using the ArcGIS 10.5 application. Analysis for hydrological impacts begins with determining the value, weight, and score of the AFC and FRC indicators which refer to Regulation of Minister N0. 61/Menhut-II/2014.

RESULTS AND DISCUSSION

Watershed characteristics show specific characteristics related to water systems, such as soil type, land use, topography, slope, and slope length. Evaporation, transpiration, infiltration, surface runoff, soil water content, and water discharge are greatly dependent on the characters of the watershed in response to rainwater, which are rainfall, watershed shape, river density, watershed slope, and land use.

Rainfall

One of the sources of water on the earth's surface comes from rainfall. When it rains, before the water is absorbed by the soil in the vegetated area, the water will be temporarily held in the vegetation crown and then flow through the stem and the canopy. If a high intensity of rain occurs, then the soil cannot absorb water then the water will stagnate or flow on the ground surface. The surface runoff will go to lower areas, such as water bodies such as reservoirs, lakes, and rivers. High intensity of rainfall can threaten water quality, causing landslides, sedimentation, and even flooding (Vannier 2016). According to Biswas et al. (2017), the distribution and amount of rainfall greatly affect the occurrence of floods. Rainwater that reaches the ground can become surface runoff and infiltrates the ground (Asdak 2010; Ngongondo et al. 2011; Zhang et al. 2017). Low-absorbed rainwater will cause water to stagnate. Annual rainfall data is grouped based on the criteria of the wet month, medium month, and dry month to get the type of climate in the Wosi Watershed area (Table 1).

Based on the Schmidt and Fergusson system, the Wosi Watershed has a very wet tropical climate type/climate type A (0.028) with a value of Q = 0 Q < 0.143. As a result of the very wet tropical climate/climate type A in the Wosi Watershed and its surroundings, it receives sunlight throughout the year, and air pressure in areas with tropical climates is relatively low and changes regularly and slowly. Evaporation through the soil, vegetation, and water bodies is high. Thus, there are many clouds. The clouds gather together, and a large amount of water droplets cannot be held in the atmosphere. Moreover, soils in tropical climate areas are relatively more fertile as a result of the high intensity of rainfall. In addition, the difference in temperature is not significant between day and night.

Table 1 Wet month, medium month, and dry month

Year	**Dry month (< 60 mm)**	**Medium month (60 - 100 mm)**	**Wet month (> 100 mm)**
2012	0	0	12
2013	1	1	10
2014	0	1	11
2015	1	0	11
2016	0	0	12
2017	0	1	11
2018	0	2	10
2019	1	3	8
2020	0	3	10
2021	0	2	10
Amount	3	13	105
Average	0.3	1.3	10.5

According to Zhang et al. (2017); Worman et al. (2017); Fuchs et al. (2016), the relatively large runoff is caused by high rainfall, and the presence of vegetation is low. Table 1 shows that in the last ten years, it has been dominated by rain/wet months (>100 mm). The impact of heavy rainfall on the damaged area causes greater surface runoff. If the capacity of the river is full, the water will overflow on the ground and into settlements.

Water in the forest, litter, or soil forms clouds through the process of evapotranspiration. It is a cycle that creates a good pattern of rainfall so that long droughts and the danger of flooding will be avoided. The tree has different evapotranspiration and infiltration capabilities based on the species so that surface runoff and erosion can be reduced (Budirianto 2013). The river bank that should have been trees has turned into a plant that can't reduce runoff and sediment that enters the river. Trees with deep roots and dense crowns have turned into fibrous plants that are uprooted and washed away if there is a heavy runoff.

Vannier (2016) argued that flood often occurs if the rainfall lasts long, the distribution is uneven, and the river capacity is limited. For example, in 2017, the Cimanuk flood was caused, among others, by high rainfall (110 to 255 mm/day), land use that was not in accordance with its capabilities, and forest area, which was only 17.9% (Savitri and Pramono 2017). However, according to Mahmud et al. (2018), rainfall is not the only cause of flooding. Flood is caused by land conversion, sedimentation, river narrowing, and watershed damage. Floods will not occur if the land is able to absorb large amounts of water, the river flows smoothly, the water is accommodated in the river, and the community does not reduce the cross-sectional area of the river. On the other hand, according to Neuvel and Knaap (2010), flooding will occur if the rain is not absorbed by the soil, the water is not accommodated in water bodies, the narrowing of the river has an impact on the flow of water is not smooth, and the community reduces the size of the river bank.

Watershed Morphometric

Watershed morphometric is a term used to express the river channel, such as the area, length, width, slope, river branching level, river density, and the shape of the watershed. The shape of the watershed has an important meaning in relation to river flow/flow velocity. The shape of the watershed allegedly affects the water to reach the outlet (the endpoint of the water release). The morphometric of the Wosi Watershed is shown in Table 2.

Table 2 Morphometric conditions of the Wosi Watershed

Wosi watershed	**Watershed morphometry**	**Wosi watershed**	**Watershed morphometry**
Watershed Area (A)	23,463,200 m^2	Watershed Center Point Cg)	X = 4.5; Y = 4.08
Main River Length (Lb)	8.38 km	River Flow Mean Slope (So)	0.79%
Watershed Width (W)	3.01 km	Circulation Ratio (Rc)	0.33
Watershed Length (Ln)	5.32 km	Limniscate Constant (k)	1.01
Density River Flow (Dd)	0.35 Height	Biforcation Ratio (Rb)	Rb½ : 3; Rb 2/3 :
Flow Length (Lg)	4.63 km	Elongation ratio (Re)	2
Watershed Average	250 m asl	Watershed Average Slope (Sb)	1.027
Elevation (Ma)	29.95 km	Weighted average (Wrb)	0.126
Circumference of the	8.38 km	Factor Symmetry (SIM)	3.75
watershed (p)			1.21
Longest River (L)			
Coefficient Watershed	0.37		
Form (F)			

Source: MoLEF 2019

Table 2 shows that the Wosi watershed has an area of 2,346.32 ha, a watershed circumference of 29.95 km^2, and a river length of 8.38 km, so Rc is 0.33 (triangle) and Re is 1.027 (triangle). From these results, it can be concluded that the shape of the watershed is rectangular and slightly oval (triangular). Paimin et al. (2012) stated that the speed of water flowing to the outlet is influenced by the shape of the watershed. The shorter the time required for water to reach the outlet, the more round the shape of the watershed, so the greater the potential for flooding. On the other hand, the longer the water goes to the outlet if the shape of the watershed is more oval, the flood has low runoff. Likewise, according to Wirosoedarmo et al. (2010), the peak flood discharge value is relatively small, with a relatively long flood peak time in the form of an elongated watershed.

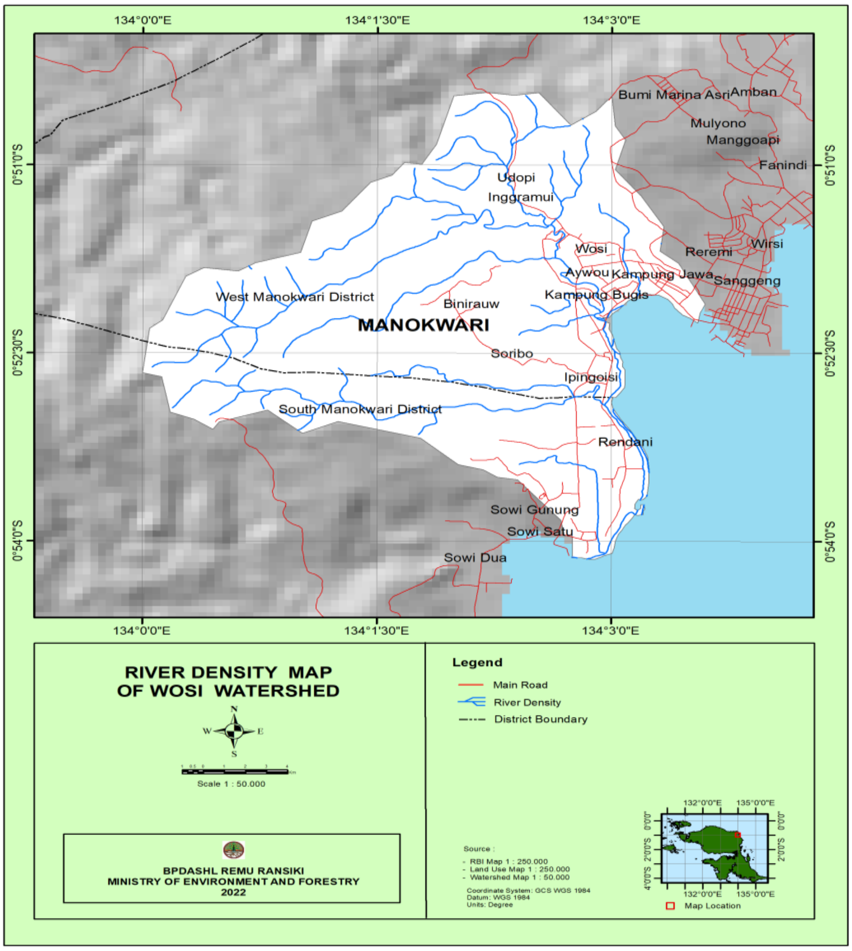

Figure 2 Watershed shape, density, and river network

There are four important rivers flowing in the Wosi Watershed, namely Rendani 1, Rendani 2, Kentek, and Dingin River (Figure 2). The drainage pattern of the Wosi Watershed in general, resembles the shape of a tree branch/twig (dendritic pattern). The river currents in the upstream and middle watersheds are relatively heavy, given the slope of the riverbed is very steep and a massive area of conversion for settlements. The upstream area where the water flows is quite heavy must be maintained as a forest because if there is a conversion to the built-up area, it will easily become a source of erosion. According to Barokah and Purwantoro (2014) upstream areas such as mountainous areas, hills, or mountain slopes are sources of erosion.

Watershed Slope

Slope/topography is the appearance of the land surface caused by the difference in height between two areas. Slope is one of the elements of the occurrence of floods, erosion, and landslides. The steeper and longer the slope, the greater the rate and amount of runoff for major erosion or landslides. On land with a large slope, the surface flow has a large velocity, so infiltration tends to decrease (Triatmodjo 2010; Helman et al. 2017). Soil slope has a very significant influence on soil degradation. An area that is flat and tends to be sunken will be prone to flooding, considering that in this area, water is easily concentrated towards lower areas. The slopes of the Wosi Watershed area are listed in Table 3.

Table 3 shows that there are only two of the slope classes in the Wosi Watershed, which is dominantly steep. The slopes have an influence on the velocity and the volume of surface runoff. Flat topography (0 - 8%) covering an area of 970.58 hectares (41.52%) has become an urban area of West Papua Province, including Wosi Village, Bugis Village, Javanese Village, Makassar Village, and Rendani. The flat topography of the lower and middle watersheds has become overcrowded into built-up areas and has begun to shift towards steeper slopes.

Table 3 Slope class in the Wosi Watershed

Slope (%)	Area (ha)	Percentage (%)
0 - 8%	970.58	41.52
25 - 40%	1,366.91	58.48
Total	2,337.49	100

According to Oktinova and Rudiarto (2019), the community began to change their behavior in land use in the suburbs from non-built land to built-up land. Furthermore, the steep slopes (25 - 40%) covering an area of 1,366.91 hectares (58.47%) of the Wosi watershed area include the villages of Udopi, Ingramui, and Soribo, with slopes ranging from flat to very steep at an altitude of 0 – 1,450 m from sea level. The steeper the slope, the greater the runoff velocity if the area is less vegetation. Mahmud et al. (2021b) argue that land use for settlements/built-up areas has higher runoff and sediment than forest areas. The results of the survey of areas located on steep slopes that were previously plantations and forest areas began to be converted to settlements (Figure 3).

Figure 3 Inggramui Village settlement adjacent to a steep hill without vegetation (left), a residential area adjacent to a steep hill with vegetation (right)

Figure 3 shows a house building adjacent to a steep slope. The threat of landslides is high. Considering the area has a rather steep and very steep topography, when it rains, the water easily flows on the soil surface. It erodes the top layer of soil and causes the soil to shift/move in large numbers because nothing is able to bind the soil. On the other hand, the area with a rather steep and very steep topography, if it is well maintained (designated as protected forest/protected areas), will maintain soil fertility, protect the soil from the threat of landslides, and provide water, particularly during the dry season.

Hardiyatmo (2012) discovered that topography is very influential on rainfall. If it rains on a steep surface without vegetation, a runoff will arise and flow downstream or to a lower place. Excessive flow cannot be accommodated by the river, causing flooding. In areas with a flat topography to slightly concave, water is easily concentrated and inundated, and if the amount of water is greater, then flood is inevitable (Marfai 2011). One of the flooded locations has built an embankment (Figure 4), but the embankment is not fully able to cope with flooding. Many embankments were built in flooded areas, but because the upstream watershed had a lot of land conversion, water with great speed was able to destroy the embankment, eventually, it broke, and the flood reoccurred.

Figure 4 The flooded area where the embankment has been built

Land Use

The increasing crowded urban areas have led to an increase in land use for residential, agricultural, and water needs. Types of land use around Wosi watershed are divided into 7 groups which are dominated by settlements, as shown in Table 4.

Table 4 Topography and Land Use Functions in the Wosi Watershed

Topography	Use land	Non-forest area (ha)	Forest area (ha)	Percentage (%)	
				Non-forest	Forest
Steep	Primary dryland forest	-	83.15	-	3.54
Steep	Secondary dryland forest	-	773.26	-	32.95
Steep	Bushes /scrub	-	27.64	-	1.17
Flat and Steep	Settlement	697.90	-	29.74	-
Flat and Steep	Open land	3.94	-	0.16	-
Flat	Mixed dryland farming	707.07	-	30.13	-
Flat	Airport	53.35	-	2.27	-
Total		1,462.26	884.05	62.32	37.68

Source: BPDASHL Remu Ransiki 2019

The type of land use as forest based on Table 4 is still above 30%. It is suitable to protect and maintain watershed is at least 30% based on law Number 41 of 1999. The forest cover includes primary dry land forest, secondary dry land forest, and shrubs/shrubs covering an area of 884.05 hectares (37.68%), while the non-forest area is 1,462.26 hectares (62.32%). The forest area of 37.68% is expected to be able to protect and maintain the diversity of flora and fauna, bio-geophysics, and the carrying capacity of natural resources.

Along with the development of Manokwari City as the capital of West Papua Province, the area continues to experience forest land conversion. As Figure 5, the upper Wosi Watershed has been cut off. Some areas are still shaped like a hill where landslides may occur. In fact, in 2012, some of the cities of Manokwari, which are adjacent to the watershed, experienced major floods. City development that does not follow the regency’s spatial plan will cause not only a major flood but also landslides. The conversion of land to built-up land is around 28.02 ha (39.5%), resulting in a decrease in groundwater, landslides, and an increase in surface water discharge (Dewi and Rudiarto 2014).

Figure 5 The planned upstream watershed for the built-up area has been partially leveled (left). Some of the lands is still steep and made like a ladder (right)

Impact of Watershed Characteristics on Hydrology

Mahmud et al. (2021a) found out that the carrying capacity of the Wosi Watershed is categorized as bad and is one of the watersheds in Manokwari Regency that must be restored. Water discharge is a very important part of hydrological parameters to evaluate the extent to which rainfall affects surface runoff, river water level, and river capacity. Meanwhile, the FRC is an inseparable part of the water discharge, as shown in Table 5.

Table 5 FRC and AFC values in the Wosi watershed

Year	Max of water discharge ($m^3\ s^{-1}$)	Min of water discharge ($m^3\ s^{-1}$)	FRC	Evaluation	Total water discharge ($m^3\ year^{-1}$)	Total rainfall in the watershed ($mm\ year^{-1}$)	AFC	Evaluation
2016	1.23	0.06	20.53	low	13,038,081.4	48,044,540.9	0.27	low
2017	2.37	0.04	60.57	moderate	12,909,855.2	53,176,793.8	0.24	low
2018	3.73	0.02	232.29	very high	30,749,926.9	33,162,321.5	0.93	very high
2019	7.1	0.01	710	very high	16,018,933.6	67,450,857	0.23	low
2020	6.98	0.02	349	very high	15,986,897.4	66,630,438	0.23	low

Table 5 shows the trend of increasing differences in water flow. The value of FRC from 2016 to 2020 is dominated by very high. This shows that there is a decrease in the carrying capacity of the watershed to receive, absorb, and drain rainwater into the river. According to Mahmud et al. (2021a), if the FRC is low, the water flows throughout the year without showing a significant water level. The flow of water is not only in the rainy season but continues to flow even during the dry season. On the other hand, if the FRC is very high, it means that the flow of river water is easy to change, sometimes low or even very high, which can cause flooding. This indicates that the river flow is bad, because the ability of forests and land to absorb, store, receive rainwater, and release water is bad. Rain intensity, vegetation cover, soil type, slope, and land management techniques are related to the ability of the watershed to receive, store, discharge, and drain water.

River flow is an important part of determining the extent to which surface runoff, river water level, river capacity, and sediment affect rainwater input/input. The annual flow coefficient indicates what percentage of rainfall is a runoff in the watershed. Table 5 also shows that AFC always changes starting from low and very high but is dominated by low. A low AFC means that the watershed's carrying capacity is good, while a very high AFC indicates that the watershed's carrying capacity has decreased.

The increasing rainfall is not always accompanied by an increase in water discharge if there is low rainfall intensity, even distribution of rain, and good canopy cover. More crowns and a wider distribution will reduce the canopy runoff and the flow of stems to reach the soil surface (Mahmud et al. 2019a). When it reaches the ground surface, the water will seep, and if it is saturated, it will become surface runoff. The better the water flow, this indicates that more water flows from the water springs than from the surface runoff. The government and environmentalists must be aware of the community land use to always implement soil and water conservation and follow the spatial plans of Manokwari Regency.

Flooding Management and Mitigation

Recently, there have been massive land use changes in Manokwari Regency for human settlement, local and central government official administration, village development programs, national infrastructure program of a seaport, airport, and roads, industrial expansion, Mahmud et al. (21019a). Forest cover areas conversion into palm oil plantations (Mahmud et al. 2019a), Maruni’s forest kart-cover area into cement industries (Mahmud et al. 2020), and Wosi protected forest area into a settlement, and commercial sectors (Mahmud et al. 2021b) have been influenced the hydrological system of Manokwari City and regency. These land use changes supported by the biogeographical characteristic recorded from this research are supposed to generate the occurrence of flooding in Manokwari Regency and town.

Two types of flooding management and mitigation worldwide acknowledge for the tropical area are structural and non-structural systems or measures (Samu and Kentel 2018). Urbanus et al. (2021) stated that management for flooding could be divided into actions, prevention/mitigation, response/intervention, and recovery. Structural mitigation emphasizes the structural and physical in-stream and off-stream such as building water dams, checking dams, groundsill, river normalization, river pass, and others. Non-structural mitigation ranges from law and regulation enforcement, land use policy, replantation, watershed management, public and community awareness, campaign, and education.

Structural and non-structural mitigation could be conducted parallelly to reduce the flooding risk in Manokwari Regency, ranging from making water sanitation/drainage, waterways, and sewer water at the settlement areas, and building retaining walls, gravity walls for the area with a steep slope. Replantation, warning system, flooding leaflets mitigation campaigns, and community involvement are various non-structural mitigation.

CONCLUSION

The Wosi watershed has a very wet tropical climate type/climate type A (0.028) which is dominated by rain/wet months (>100 mm). Its morphometric is a triangular-shaped watershed with 4 rivers, namely Rendani 1 River, Rendani 2 River, Kentek River, and Kali Dingin River. Furthermore, this watershed has flat slopes covering an area of 970.58 hectares and steep slopes occupying an area of 1.366,91 hectares. Land use is dominated by non-forest, with an area of 1,462.26 hectares (62.32%). Meanwhile, the coefficient of flow regime (FRC) is categorized as low, medium, and dominated by very high. Very high FRC means that river water flow changes quickly, sometimes low or even very high, which can cause flooding. The result of the assessment of AFC is categorized as low and very high. A low AFC value means that the carrying capacity of the watershed is good, while a very high AFC indicates that the carrying capacity of the watershed has decreased.

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