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Surface runoff in varying forest cover types in Jangkok Watershed, Lombok Island, Indonesia

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Abstract. *Markum, Rahman FA. 2024. Surface runoff in varying forest cover types in Jangkok Watershed, Lombok Island, Indonesia. Biodiversitas 25: 753-761.* Forests in the Jangkok Watershed play an important role in controlling ecological functions and hydrological cycles in Lombok Island, West Nusa Tenggara, Indonesia. This research aims to evaluate the amount of surface runoff in the Jangkok Watershed by looking at various types of forest cover, namely Primary Forest (PF), Disturbed Forest (DF), Candlenut Agroforestry (CA), Mahogany Woodlot (MW), Multistrata Agroforestry (MA) and Simple Agroforestry (SA). The research area was located at altitudes between 250-650 meters above sea level with a slope of 7-43%. Data collected on each type of forest cover included: vegetation characteristics, surface runoff, slope and rainfall. The result shows vegetation cover in the studied area varies from moderate to very dense with coverage ranging from 50-90%. The vegetation in PF, DF and MA are characterized by very diverse vegetation, while that in UM, CA and SA it is quite homogeneous. The amount of Surface runoff coefficient varies across forest cover types with PF being the lowest (0.6-1.4%), followed by DF (0.6-1.7%), MA (0.6-1.7%), MW (0.6-2.1%), SA (1.0-2.2%) and CA (1.8-4.3%). Factors that are considered influential in determining the magnitude of surface runoff at the research location are the physical properties of the soil, rainfall intensity, vegetation type, structure and density, and land slope. The findings of this study suggest that more complex vegetation has important role in minimizing surface runoff, highlighting the importance of preserving and protecting this forest type to maintain hydrological function of watershed.

Keywords: Forest, Jangkok, surface runoff, watershed

INTRODUCTION

Forest plays an important role as a regulator to maintain hydrological functions and cycles in watershed (Chaubey et al. 2021). The importance of forest in hydrological system can be indicated by the high rate of soil infiltration and high soil biological activity (Basche and DeLonge 2019; Suprayogo et al. 2020), and the abundance of plant roots and the thickness of litter (Liu et al. 2018), making it is easier for rainwater to flow into deeper soil layers (van Noordwijk et al. 2020). Soil infiltration rates are strongly influenced by land use, density of ground cover vegetation (Amiri et al. 2023), rain intensity (Hou et al. 2019; Ren et al. 2020), interception of rain by the plant canopy, rainwater hitting power, landscape drainage and soil structure (Leung et al. 2018; Nöldeke et al. 2021). The higher soil infiltration rate can cause less water to flow as surface runoff (Zhao et al. 2018; Ren et al. 2020; Wang et al. 2020).

Conversion of forest into other land uses can cause changes in watershed hydrology (Demissie 2022; Dogan and Karpuzcu 2022). The decreasing vegetation cover due to such conversion increases the energy of rainwater falling onto the ground and thereby increases surface runoff (Le Bissonnais et al. 2018; Chen et al. 2020), causing damage on the soil surface. The loss of forest cover also results in the decrease in soil macroporosity and infiltration rate of rain water, decreasing the quality of soil physical properties (Hernández-Crespo et al. 2019). In the long run, the reduction of hydrological functions of watershed due to forest conversion might enhance the risks of soil erosion, landslide and flood.

The more water that flows in the form of surface runoff, the less water that infiltrates into the soil. Increased surface runoff also increases the loss of topsoil (Dos Santos et al. 2017; Fortugno et al. 2017), as well as soil organic content and nutrients (Wolka et al. 2021; Sadeghi et al. 2022). The actual condition of surface runoff in an area is one of the factors that need to be considered in watershed planning and management because the level of surface runoff has an impact on the condition of forest cover, which has implications for management strategies and programs (Li et al. 2022). Land use change from forest into non-forest lands has its own characteristics which can be indicated by differences in plant species diversity (Helen et al. 2019; Srivastava et al. 2020), plant density (Peters et al. 2019; Felipe-Lucia et al. 2020), carbon stocks (Law et al. 2018), soil organic content (Ramesh et al. 2019; Soleimani et al. 2019). Such differences ultimately influence the amount of surface runoff (Anand et al. 2018; Guzha et al. 2018).

One of the areas that has an important ecological role on Lombok Island, Indonesia is the Jangkok Watershed, where the forest area based on the decision of the Minister of the Environment of the Republic of Indonesia with

SK.304/MenLHK/PDASHL/DAS.0/7/2018 has an extent of 20,571 ha. Nonetheless, this watershed is pressured by conversion from forest into various land uses, resulting changes in vegetation cover. In the period of 14 years (1995-2009), natural forest in Jangkok reduced by 22% (8087 ha), while secondary forest increased. There was also increase on shrub, settlement and crop area by 25%, 28% and 35%, respectively (Markum et al. 2013). Previous research on this area have been focused on biodiversity (Shavira et al. 2020), plant species diversity and carbon stocks in various types of forest cover (Markum et al. 2013), and the social economy and the ecological function of the Sesaot forest (Markum et al. 2021). No study has been conducted to look at the impacts of forest changes on surface water runoff in the Jangkok Watershed.

Therefore, this study aimed to evaluate the amount of surface runoff in various types of forest vegetation cover in the Jangkok Watershed, Lombok Island. In doing so, we investigated several variables related to vegetation cover, namely forest vegetation type, density of vegetation, slope, rainfall, soil texture and soil organic content. We expected the results of this study can be used to develop strategies to support sustainable natural resource management in Jangkok Watershed and Lombok Island to more broadly.

MATERIALS AND METHODS

Study period and area

The research was carried out in November 2022-January 2023. The research location was in Jangkok Watershed (116º20'-116º31'E and 8º43'-8º49'S) which has altitude between 250-650 meters above sea level (Figure 1). Administratively, Jangkok Watershed is located in West Lombok District and Mataram City, West Nusa Tenggara Province, Indonesia.

Data collection procedures

We established observation plots to measure surface runoff on six types of forest cover, namely: Primary Forest (PF), Disturbed Forest (DF), Mahogany Woodlot (MW), Candlenut Agroforestry (CA), Multistrata Agroforestry (MA) and Simple Agroforestry (SA). For each forest type, we established three observation plots, resulting a total of 18 observation plots. Tools used in the research included apron (gutter), chinometer, ombrometer, measuring cup, jerry can or plastic bottle, 30 cm wide zinc, water scoop, ruler, and plastic hose of 1 cm in diameter.

The general shape of the observation plot is rectangular, following the direction of the slope. The top and sides of the plot were lined with zinc with a height of 30 cm, where some zincs were planted vertically into the ground to avoid water entering from outside the plot. Each plot had a water storage tank (apron) with a capacity of 125 mm. The apron was covered with plastic to prevent rain water entering it. If the apron was full, the surface runoff flowed into the ombrometer and part of the flow in the chinometer flowed into the jerry cans/plastic bottles via the chinometer splitter (Figure 2). We measured the amount of rainfall, volume of water in the apron (gutter) and the volume of water through the chinometer stored in the jerry can. Observations and data collection were carried out at 8-10 am every day for 92 days from November 2022 to January 2023.

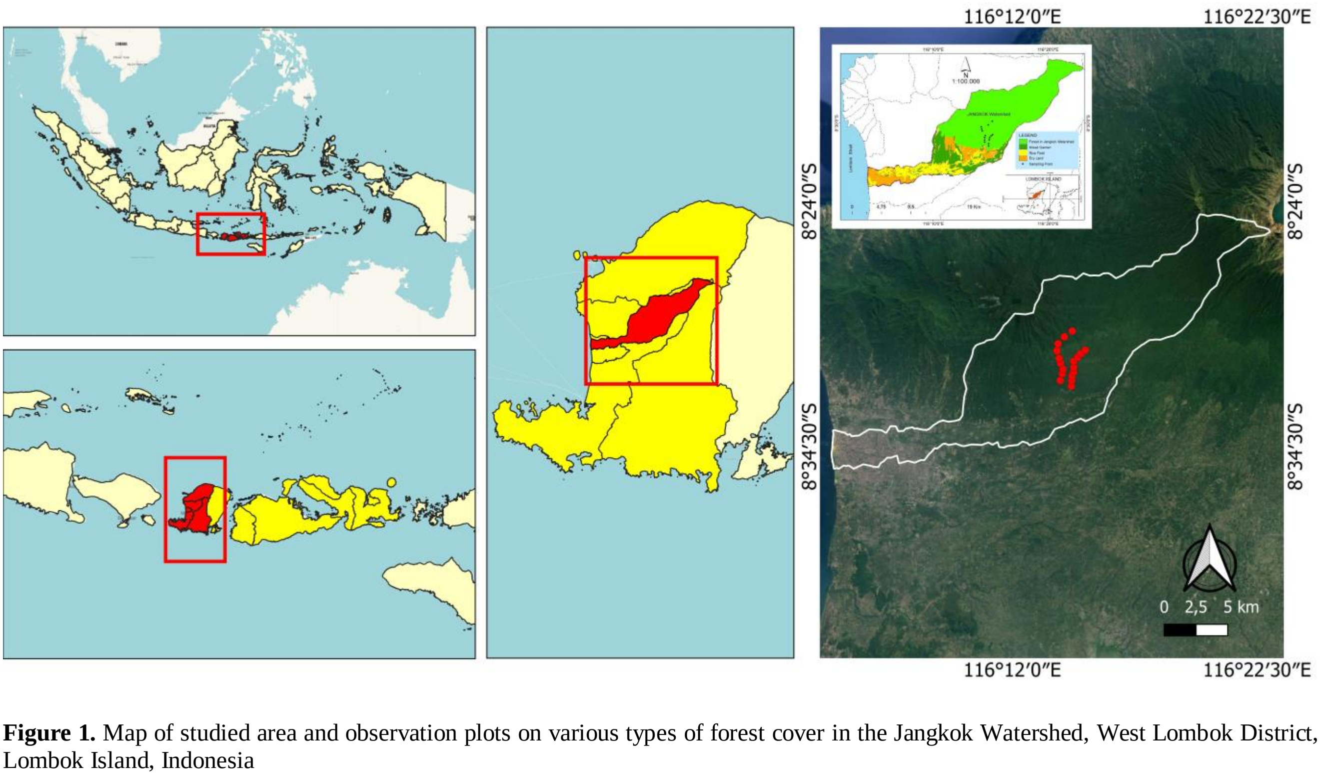

Figure 1. Map of studied area and observation plots on various types of forest cover in the Jangkok Watershed, West Lombok District, Lombok Island, Indonesia

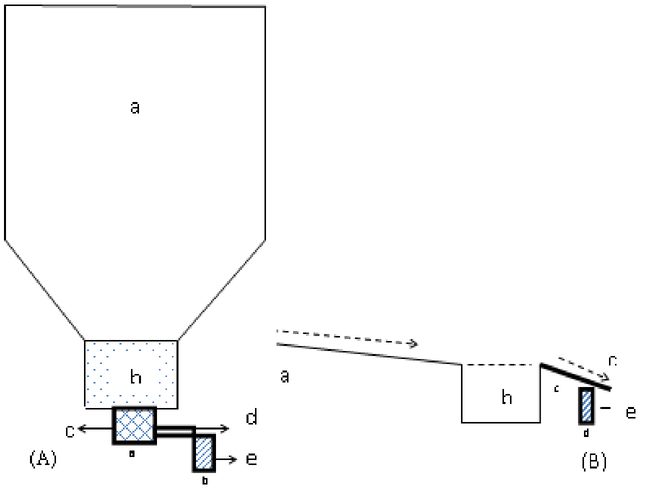

Figure 2. Surface runoff observation plot, top view (A) and side view (B). Notes: a: plot; b: apron; c: chinometer; d: splitter; e: plastic bottles/jerry cans

Data analysis

Volume of surface water flow

The total volume of water collected in the apron and collected in jerry cans via the chinometer describes the surface runoff that occured in each plot. Surface runoff data was calculated using the surface runoff coefficient. Surface runoff for each rain event was calculated by formula (Dariah et al. 2004):

$$Rt = Rg + (Rc \times Fc)$$

Where, Rt: Total surface runoff volume; Rg: Volume of surface runoff collected in the apron; Rc: Volume of water stored in the jerry can; Fc: Conversion factor, which is a value that represents the volume of water that passes through.

Surface runoff coefficient

Surface runoff coefficient was calculated by the following formula:

$$\text{Surface Runoff Coefficient (SRC)} = (Rt/Rh) \times 100\%$$

Where, SRC: Surface runoff coefficient (0-100%); Rt: Total surface runoff volume (mm); Rh: Total volume of rainwater on the plot (mm).

RESULTS AND DISCUSSION

Types of forest cover

Based on the results of observations, forest cover is classified as dense to very dense with vegetation cover ranging from 50-90%. Some forest cover is only dominated by one type of tree, for example in MW and CA, and SA, while PF, DF, and MA have a diverse tree species composition (Table 1).

Rainfall

Rainfall at the research location during November 2022 - January 2023 ranged from 503 mm to 838 mm per month, with the total of 1.851 mm for three months (Figure 3). The highest amount of rainfall is found in PF and the lowest in SA, while the number of rainy days ranges from 20-26 days per month, where MA and SA have a greater number of rainy days compared to other land uses.

From the results of observations in all research plots during November 2022 for the first 6 days of rain, it shows that surface runoff never flows through the chinometer, so that the amount of water collected in the observation apron never exceeds 125 mm (Figure 4).

Surface runoff

The result of measurement shows that Primary Forest (PF) has the smallest surface runoff value (3.61±0.880%) compared to other forest cover types. On the other hand, Multistrata Agroforestry (MA) has the largest surface runoff value (10.16±4.279%). Apart from the type of forest cover, the surface runoff coefficient value is also likely to be caused by the influence of rainfall and land slope factors obtained in each observation plot with values between 0-100% (Table 2).

Relationship between rainfall and surface runoff

The highest daily rainfall intensity was recorded in November 2022 in Primary Forest (PF) at 120 mm with the largest rainfall distribution (60%) found in rainfall between 0-20 mm, this condition can illustrate that the higher the rainfall will increase surface runoff. The relationship between CH and surface runoff has a sufficient level of correlation (R2), namely between 0.59-0.67. Meanwhile, various types of land cover in the Jangkok Watershed have varying values for each land use (Figure 5). The amount of rainfall in PF is higher than other land uses. One of the contributing factors is the greater amount of rainfall with a rainfall value of more than 80 mm compared to other land uses.

Based on Figure 5, it confirms that the surface runoff coefficient value in the PF, DF, MA, MW forest cover is in the range of 0-5% at the CH interval 0-100 mm/day. Meanwhile in CA and SF, LP is in the range of 0-9% at the same CH interval. The relatively higher LP values in the two forest covers (SF and CA) are due to sparser vegetation cover compared to other forest covers (PF, DF, MA and MW). Vegetation cover can be seen from the different plant biomass values. The research results of Markum et al. (2013) illustrate that there are differences in the amount of plant biomass between the six covers, each of which is (in tonnes/ha) PF: 375, DF: 178, MW: 389, CA: 118, MA: 95, and SA: 11.

Table 1. Classification and description of forest cover type in Jangkok Watershed, Lombok Island, Indonesia

Forest Cover Type	Canopy/Vegetation Cover		Tree Height (m)	Description of Vegetation
	%	Category		
Primary Forest (PF)	80-90	Very dense	15-25	Trees are very diverse, multi-stratum (5 strata). Strata 1-2 consists of trees with a height of 15-30 m (DBH>30 cm), the third stratum consists of trees with a height of 5-15 m (DBH=5-30 cm), the fourth stratum consists of shrubs and vines, the fifth stratum consists of ferns.
Disturbed Forest (DF)	80-90	Very dense	10- 20	Same as PF, but the height of the main plant (strata 1-2) is lower.
Mahogany Woodlot (MW)	70-85	Dense	15-25	The dominant plant (stratum 1) is *Swietenia mahagoni*, stratum 2 consists of *Coffea arabica* and fruit tree species, and stratum 3 consists of shrubs and ferns.
Candlenut Agroforestry (CA)	65-75	Quite dense	15-25	The dominant plant (stratum 1) is *Aleurites moluccanus*, stratum 2 is a mixture of *Erythrina variegata*, fruit tree species, *Musa paradisiaca*, and stratum 3 is ferns, grasses and shrubs.
Multistrata Agroforestry (MA)	70-80	Dense	10-25	Stratum 1 consists of *Swietenia mahagoni* and *Durio zibethinus* with a height of 20-30 m, stratum 2 consists of *Artocarpus heterophyllus* and *Erythrina variegata*, stratum 3 consists of *Theobroma cacao* and *Coffea arabica*, stratum 4 consist of shrubs.
Simple Agroforestry (SA)	40-50	Less dense	5-20	Stratum 1 consists of *Aleurites moluccanus* and *Erythrina variegata*, stratum 2 consists of *Albizia chinensis*, *Musa paradisiaca* and fruit plants (*Durio zibethinus, Garcinia mangostana, Persea americana, Artocarpus heterophyllus, Nephelium lappiceum, Arenga pinnata, Coffea canephora,* and *Theobroma caca*), stratum 3 consists of bushes and grass.

Table 2. Surface runoff on various forest cover types in Jangkok Watershed, Lombok Island, Indonesia

Forest Cover	Total Rainfall (mm/month)	Average of Slope (%)	Surface Runoff Coefficient (%)	Average of Surface Runoff (%)±Standard Deviation
Primary Forest (PF)	2207	21.33	0.6-1.4	3.61±0.880
Disturbed Forest (DF)	1746	21.33	0.6-1.7	5.67±1.994
Mahogany Woodlot (MW)	1704	26.33	0.6-2.1	5.76±2.374
Candlenut Agroforestry (CA)	1913	15.67	1.8-4.3	6.58±2.174
Multistrata Agroforestry (MA)	1934	22.67	0.6-1.7	10.16±4.279
Simple Agroforestry (SA)	1553	20.67	1.0-2.2	7.58±2.642

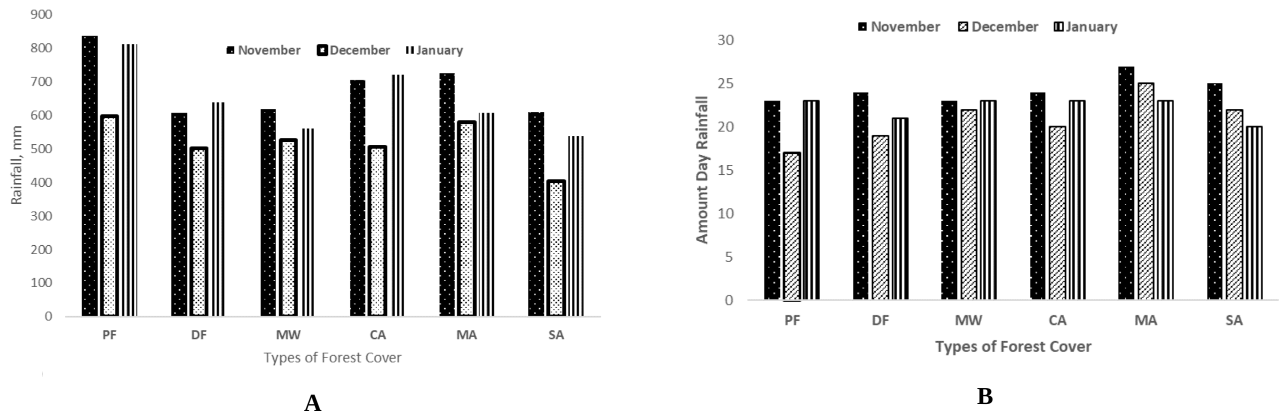

Figure 3. Amount of rainfall (A) and number of rainy days (B) in Jangkok Watershed, Lombok Island, Indonesia. Notes: PF: Primary Forest; DF: Disturbed Forest; CA: Candlenut Agroforestry; MW: Mahogany Woodlot; MA: Multistrata Agroforestry; SA: Simple Agroforestry

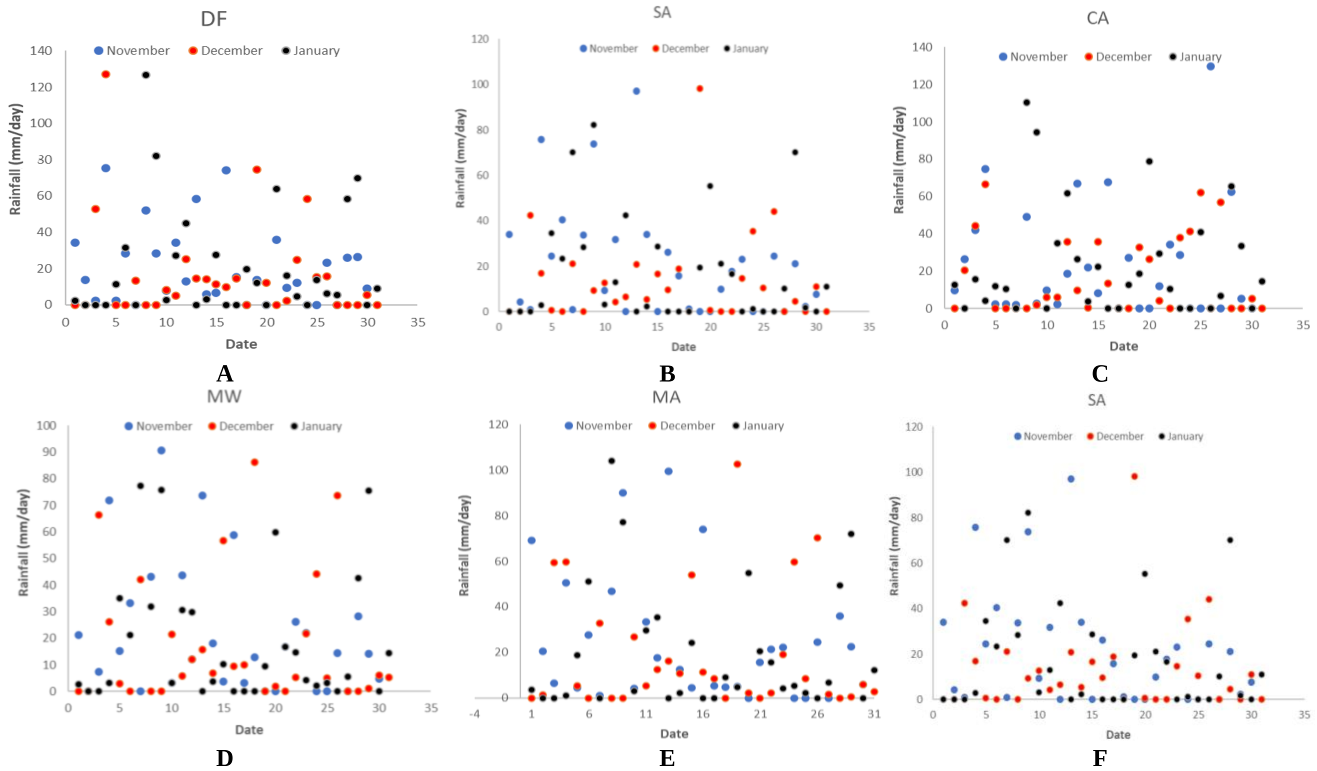

Figure 4. Distribution and rainfall in various types of forest cover in Jangkok Watershed, Lombok Island, Indonesia during November 2022-Januari 2023. A. PF: Primary Forest; B. DF: Disturbed Forest; C. CA: Candlenut Agroforestry; D. MW: Mahogany Woodlot; E. MA: Multistrata Agroforestry; F. SA: Simple Agroforestry

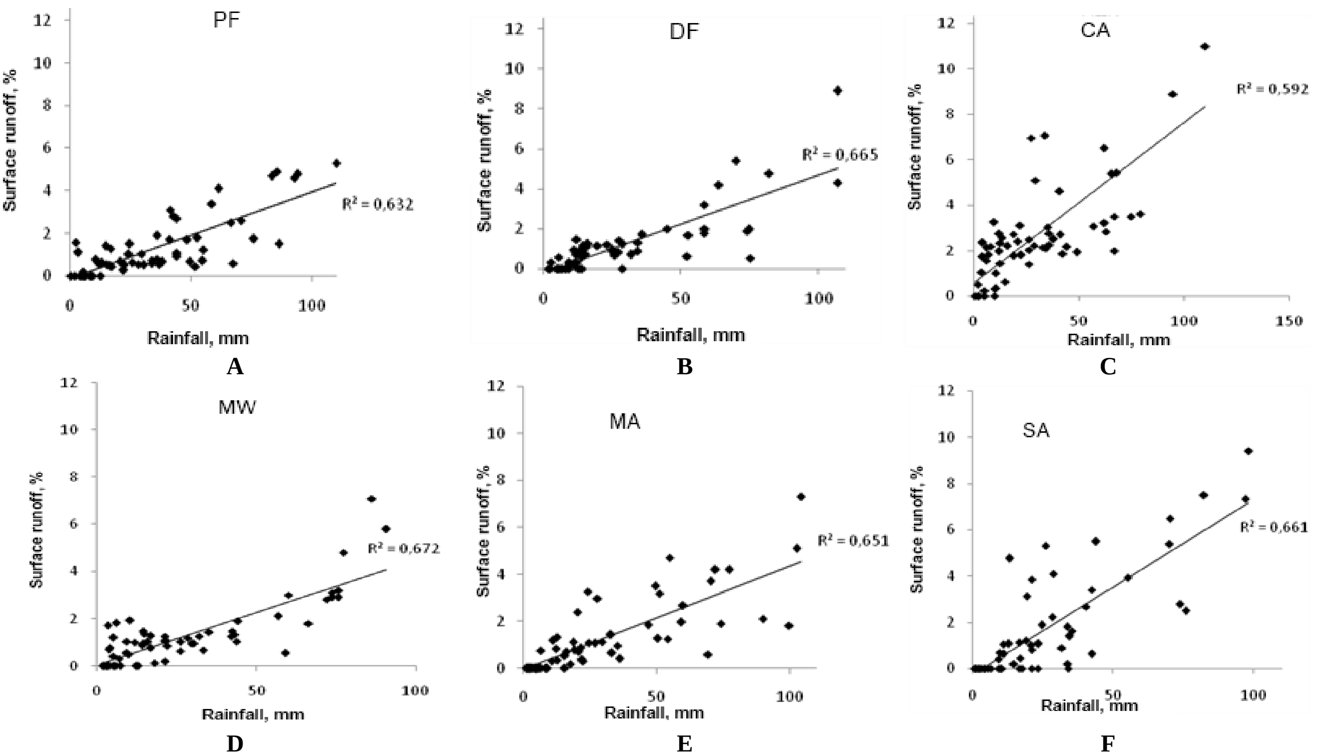

Figure 5. Relationship between rainfall and surface runoff in various land uses in Jangkok Watershed, Lombok Island, Indonesia. A. PF: Primary Forest; B. DF: Disturbed Forest; C. CA: Candlenut Agroforestry; D. MW: Mahogany Woodlot; E. MA: Multistrata Agroforestry; F. SA: Simple Agroforestry

Discussion

The results of the research show that the vegetation in the Jangkok Watershed forest area has a dense canopy and is composed of multi-tiered plant structures (multistrata) which have a good ability to retain rainwater and reduce surface runoff. This is supported by the study by Ai et al. (2017) in the steep slope forest area of the Chinese Loess Plateau which found that forest with various strata (trees, shrubs, and grass) inhibits surface runoff and sedimentation.

Primary forest and disturbed primary forest in Jangkok Watershed (locally called Sesaot forest) have very dense vegetation, resulting the ground surface has a low light intensity. The space between the ground surface and the vegetation cover above is very short (1.0-1.5 m) due to the large number of vines and shrubs. Mahogany woodlot and candlenut agroforestry have dense canopy cover, but the difference is that they have quite a large space between the ground surface and the canopy (5-10 m), because the vegetation cover is dominated by one type of mahogany or candlenut tree. Meanwhile, multistrata agroforestry have more varied plant species (Negash et al. 2022) with a more multi-tiered plant structure, such as in primary forest and disturbed primary forest, thus allowing for greater resistance of rain water to reach ground surface.

Candlenut agroforestry is dominated by *Aleurites moluccanus*, which has a large canopy width (5-10 m), but has relatively small leaves and branches that are not dense, so there is more open space than in multistrata agroforestry forests. This condition allows sufficient sunlight under the stands, facilitating several types of multipurpose tree species and food crops, such as cassava (*Manihot esculenta*) and chilies (*Capsicum annuum*), to grow well. Simple agroforestry has a less dense canopy cover (50-60%), but underneath it grows lots of shrubs and grass.

Based on the classification of the United States Department of Agriculture (USDA), Sadovskї and Ivanova (2020) and Igaz et al. (2020), the soil texture in the Jangkok Watershed area is classified as sandy clay loam and sandy loam. These sandy soils have large size with macro pore space, high porosity and and low water holding capacity, resulting in they are well aerated, easily absorbs water and have fast percolation and good drainage (Kay 2018). In the study area, the high water absorption ability is especially prominent in the simple agroforestry because it contains a high sand component (Le Bissonnais et al. 2018; Pourmohammadali et al. 2019).

Time and forest types show similar rainfall intervals with different surface runoff distributions in November 2022, December 2022, and January 2023. The cumulative distribution of surface runoff values increases over time. This condition can result in a process of soil saturation which is influenced by constant rainfall intensity and has an effect on increasing surface runoff. In addition, the results show that rainfall patterns are not always directly proportional to surface runoff values in various types of forest cover in the Jangkok Watershed. This can be seen in conditions where increasing rainfall intensity tends to produce higher surface runoff, compared to rainfall that falls intermittently (Miao et al. 2020; Dunkerley 2021; Islam et al. 2021). On the other hand, rainfall with high intensity and falling in a short period of time is more at risk of producing higher surface runoff compared to low intensity rainfall over a longer period (Yang et al. 2021; Carrà et al. 2022; Wei et al. 2023).

Surface water runoff in Jangkok Watershed across various forest types can be influenced by the slope, rainfall and vegetation characteristics. This is supported by Qur'ani et al. (2022) that forest with slopes of 0-8% produce greater infiltration rate values than those with slopes of 8%-23%. In addition, Azuka and Igué (2020) and Jourgholami et al. (2020) reported that the density and planting layout in forest areas can influence the length of surface flow paths. As reported by Virlayani et al. (2021) the speed of surface water runoff in sub-watershed forest areas of Malang District is 56.33 mm/second in the area without vegetation, 54.00 mm/second in the straight planting system, and 52.83 mm/second in the zig-zag planting system.

In November 2022, the surface runoff value in all forest types is the smallest, compared to the other two months, even though this month has the highest amount of rainfall. The total surface runoff increases in December 2022 and the highest surface runoff is in January 2023. The low surface runoff in November 2022 is caused by the condition of the soil which is still relatively dry, because the rainy season has just begun that month. Dry soil conditions have pores that are still filled with a lot of air and the soil is still not saturated, so water can quickly be absorbed into the soil (Azuka and Igué 2020; Jourgholami et al. 2020). This result is in line with the research by Kabelka et al. (2019) in hop garden Solopysky Village, Czech Republic and Parhizkar et al. (2021) in Saravan Forest Park, Guilan province, Iran that wet or dry soil conditions during rain greatly influence the amount of surface runoff, where in dry soil conditions many soil macro pores are filled with air which allows a lot of rainwater infiltrates.

The surface runoff value across forest types in the Jangkok Watershed ranges 3.61±0.880%-10.16±4.279%. The surface runoff value on PF, DF, MW, and CA, which ranges 3.61±0.880%-6.58±2.174%, is relatively small which can be influenced by differences in vegetation types, structure and density, period and intensity of rain, slope and physical properties of the soil in each forest cover type in the Jangkok Watershed. The surface runoff value for the Jangkok Watershed is lower than the research results of Anggiarini and Anggraheni (2023) in the Mampang watershed area, East Jakarta with a surface runoff value of 61%. Meanwhile, a study by Suhartanto et al. (2012) in the Sesaot forest which uses modeling based on river discharge data collected with automatic water level recorder, obtained an average of surface runoff value is 16%. The large difference is expected because the location of automatic water level recorder research site is in the downstream area of the Sesaot forest.

Surface runoff will increase with increasing rainfall period and intensity (Ran et al. 2012; Wei et al. 2014; Nasiry et al. 2023). On the other hand, the surface runoff value is not always linear with the amount of rainfall that occurs in the Jangkok Watershed forest area. This can be caused by the length of raining period. The tendency is shorter raining period causes the amount of surface runoff to be greater, so that the distribution of data on rainfall values and their relationship with surface runoff values is quite varied between the amount of rainfall and surface runoff.

Surface runoff coefficient Jangkok Watershed varied across various forest types with the lowest values is in primary forest (0.6-1.4%), followed by disturbed forest (0.6-1.7%), multistrata agroforestry (0.6-1.7%), mahogany woodlot (0.6-2.1%), simple agroforestry (1.0-2.2%) and candlenut agroforestry (1.8-4.3%). This result is in accordance with research by Wang et al. (2016) in the North Shaanxi forest area with a slope of 11°-40° showing the lowest surface runoff values in homogeneous forest vegetation. In addition, Feng et al. (2016) reported that the type of forest vegetation found in the northern part of Yan'an China can influence surface runoff and the artificial grassland is an appropriate choice on land slope gradients between 5°-15°.

There are several factors that are considered influential in determining the value of surface runoff at the research location, including: physical properties of the soil (Hernández-Crespo et al. 2019; Kreiling et al. 2021; Yin et al. 2021; Amiri et al. 2023), rainfall intensity (Morbidelli et al. 2018; Hou et al. 2019; Ewane and Lee 2020), vegetation cover and structure (Wang et al. 2016; Ai et al. 2017), litter (Lee et al. 2018; Shi and Schulin 2018; Wolka et al. 2021), and land slope (Chen et al. 2018; Ding et al. 2022; Kulik and Gordienko 2022).

Land use changes might affect litter thickness which can influence the amount of surface runoff. The higher the litter thickness, the higher the soil organic matter, which also tends to be followed by a decrease in surface runoff. This especially occurs in the Primary Forest (PF), Disturbed Forest (DF), Mahogany Woodlot (MW), multistrata agroforestry (MA and) and Simple Agroforestry (SA). Soil organic content and litter thickness influence the amount of surface runoff and soil infiltration (Evans et al. 2020; Le et al. 2020; Saputra et al. 2022). The result of this research is in line with the report by Hairiah et al. (2004) in the Sumberjaya Lampung forest area which found litter thickness between 1.24-2.5 Mg/ha. Litter thickness at the research location is 1.8-5.8 Mg/ha which is included in the high category. Apart from that, denser plants are also able to increase soil organic content, thereby increasing soil fertility and supporting sustainable land management practices (Wolka et al. 2021; Li et al. 2022; He et al. 2023).

In conclusion, the high and low values of surface runoff obtained in the Jangkok Watershed forest area in various forest types (i.e., primary forest, disturbed forest, candlenut agroforestry, mahogany woodlot, multistrata agroforestry, and simple agroforestry) can be caused by vegetation type, structure and density, period and intensity of rain, slope, and physical properties of the soil. Nonetheless, the findings of this study suggest that a more complex vegetation, such as in primary and disturbed forest, have important roles in minimizing surface runoff, implying the importance of preserving and protecting this forest type to maintain hydrologycal function of watershed.

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