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Land Use Change, Hydrological Responses and Water Balance of Upstream Ciujung Watershed

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ABSTRACT

Ciujung Watershed is an important land located in Banten Province, Indonesia. The Upstream Ciujung Watershed has seen numerous changes in land usage. Before implementing the best watershed management practices, we must first gather knowledge about the watershed's features. This report seeks to provide information about the characteristics of the Upstream Ciujung Watershed, covering land-use changes, hydrological responses, and water balance. Land use changes were analyzed using satellite imagery from 2016 and 2021, with changes traced using ArcGIS and Excel; hydrological response method for flow regime coefficient (FRC) and annual flow coefficient (AFC) in the 2012−2016 and 2017−2021 periods. Water balance was analyzed by calculating water demand in 2021 and availability water from 2012−2021. The study found that deforestation occurred between 2016 and 2021. Primary forest, secondary forest, and production forest area fell by 51 ha, 1,073 ha, and 3,119 ha, respectively, while dryland agricultural area increased with a mix of shrubs, plantations, and settlements, contributing to the alteration in the watershed. The FRC and AFC values from 2012 to 2016 were 49 (poor) and 0.32 (moderate). Meanwhile, the FRC and AFC for 2017–2021 were 60 (moderate) and 0.30 (moderate). The water balance of the Upstream Ciujung Watershed in 2021 indicates a water surplus of 663,739,545 m^3/year, while the dry season in September shows a shortfall of −5,468,643 m^3/month.

Keywords: annual flow coefficient, flow regime coefficient, hydrological function, watershed management

INTRODUCTION

Watershed is a natural system that undergoes complicated hydrological biophysical processes as well as socioeconomic activity (Ministry of Environment and Forestry 2014). Watershed sustainability was a significant strategic problem since it concerns human rights to natural resources. Population growth, which coincides with increased community activities and needs, frequently has a negative impact since it violates environmental sustainability standards. The Directorate General of PDAS-KLHK 2019 stated that 14,01 million hectares of land were crucial, with Java accounting for 15.2%. The increase of essential land indicates watershed deterioration since it reduces the watershed's hydrological function. According to the Strategic Plan in KLHK Document 2020−2024, there were 108 key watersheds in Indonesia, with some being prioritized for restoration, such as the Ciujung Watershed.

Ciujung Watershed is a cross-provincial watershed under Citarum-Ciliwung Watershed management. Most of the watershed management was included in Banten Province, with a tiny portion located in Bogor Regency in West Java. Since 2019, it has been designated as the restored watershed (Ditjen PDASHL 2020). This watershed problem resulted from an imbalance in natural resource management and consumption. According to Heriyanto (2018), during the 2013 rainy season, the discharge peak of Pamayaran Dam increased to 2,600 m³/s for 14 h. As a result, the Jakarta−Merak toll road stretch downstream from the Ciujung Watershed was entirely flooded. Another report claimed that Lebak, Pandeglang, and Serang Regencies are in the flood and drought disaster prone zone with a high index. In 2019, the Meteorology, Climatology, and Geophysics Agency (BMKG) declared Pandeglang and Lebak Regencies to be on drought alert (Kurniasari 2021).

The hydrological phenomena that occurred in the Ciujung Watershed has prompted many stakeholders in Banten Province to quickly begin watershed management activities; this calamity occurred because this watershed's hydrological function was not performing properly. According to Sulaeman (2016), the Ciujung River's flow rate increased by 16.2% because of land cover changes in the watershed. Another report found that the Upstream Ciujung sub-watershed's carrying capacity was very poor, with a score of 140.5 (Naitkakin 2021). Based on these data, the watershed's hydrological function will have an impact on the water balance of the majority of Banten Province and Bogor Regency population.

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According to Government Regulation No. 37 of 2012 on Watershed Management, monitoring and evaluation of watershed management are required to acquire information on watershed performance that may be utilized as a foundation for future watershed management planning. As a result, information about the current state of the Ciujung Watershed must be documented to establish watershed management policies. The goal of this research was to examine land use changes, hydrological responses, and water balance in the Upstream Ciujung Subwatershed.

METHODS

This study was conducted from Maret 2022 to December 2022 in the Upstream Ciujung Watershed, which is in 5°57'14"−6°4'20" South Latitude and 106°01'00"−106°29'03" East Longitude. Upstream Ciujung Watershed covers 136,505.6 acres. Figure 1 shows flow rate data acquired from the Jembatan Rangkas II River Flow Measurement Channels. Global positioning system (GPS), camera, and office stationery were used. The materials used were SPOT 6 Satellite Imagery of 2016 and SPOT 7 of 2021, Google Earth, Topographic Map of Indonesia (RBI), Land Use Maps of 2016 and 2021, daily river discharge data 2012−2021, rainfall data 2012−2021, and demographic data of 2021, which included population data, rice field area data, number and type of livestock data, number and type of industry data, and area of aquatic pond data. ArcGIS 10.4 with BFI+ and Microsoft Excel 2010 were used to analyze research data.

Land Use Change Analysis

Land use trends were investigated by interpreting SPOT 6 satellite photos from 2016 and SPOT 7 from 2021 using on-screen digitalization techniques. Land cover classifications in satellite imagery were based on RBI maps and Google Earth, while land use was classed using the 2014 RSNI standards. Land use data for 2016 and 2021 were obtained by spatial analysis and then overlayed on the two land use maps. The tracking of land use change was studied using pivot table techniques in Excel 2010.

Hydrological Response Analysis

The hydrological response analysis approach employed the flow regime coefficient (FRC) and annual flow coefficient (AFC) factors. FRC compares the maximum daily river flow (Q_{max}) to the minimum flow (Q_{min}) throughout a year. To calculate the Q_{max} and Q_{min} values, we used average daily river flow data from 2016 to 2021. This analysis was carried out to compare the hydrological responses to land use changes in both years. Another hydrological approach was AFC, which compares direct surface runoff to rainfall. The estimate utilized river flow discharge data from the Jembatan Rangkas II RFMC from 2012 to 2021. Using the BFI+ baseflow separation tools program, the direct surface runoff was separated from the subsurface flow value. Rainfall data was collected from 8 stations dispersed throughout the Upstream Ciujung Watershed and analyzed using the Thiessen Polygon method.

Water Balance Analysis

Water balance analysis evaluated the relationship between water demand and supply in a subwatershed

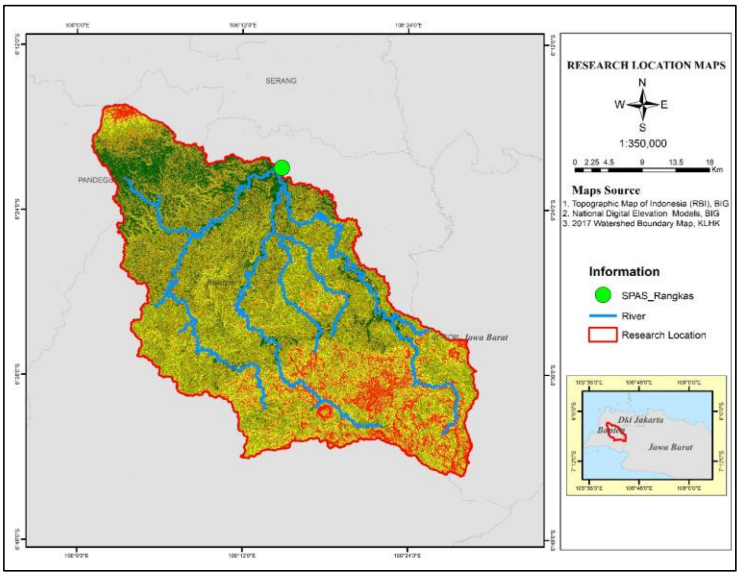

Figure 1 Research site map.

(SNI 2015). This study calculated water needs for five sectors: residential, agriculture, fisheries, livestock, and industry. Water demands are computed by multiplying the weighted population of each sector by the water use guidelines outlined in SNI 6728.1-2015. Water availability was computed using an 80% dependable discharge (Hatmoko *et al*. 2012), which was then converted to monthly water availability till 2021.

RESULTS AND DISCUSSION

Land Use Changes

Table 1 shows land use trends from 2016 to 2021, with dryland shrubland agriculture increasing by 3.6%. Meanwhile, forest land, including primary dryland forest, secondary dryland forest, and production forest, fell by 51 ha, 1,073 ha, and 3,119 ha, respectively. Furthermore, dryland agriculture and rice fields have reduced by 606 ha and 187 ha, respectively, whereas regional development in the Ciujung has boosted land usage for plantations and residential areas by 25 ha and 162 ha. Land-use changes from 2016 to 2021 (Figure 2) were evaluated geographically and quantitatively. The matrix in Table 2 demonstrates that deforestation occurred in the Upstream Ciujung Watershed, with much of it converted into agricultural land, plantations, and residential areas.

Land use changes in the Upstream Ciujung Watershed have left just about 17% of forest, despite Law No. 41 of 1999 requiring a minimum forest area of 30% of the watershed area. The watershed is intended to function as a buffer zone for the overall Ciujung Watershed environment. As a result, deforestation in the Upstream Ciujung Watershed will affect watershed function. Sulaeman (2014) revealed that the rate of deforestation has a substantial impact on the hydrology of the Ciujung Watershed.

Hydrological Response

The hydrological response of a watershed is one of its tasks in water resource management. Data from the Jembatan Rangkas II RFMC for the 2012−2016 and 2017−2021 periods show that the average daily discharge for the Upstream Ciujung Watershed was 62.41 m^3/second and 52.23 m^3/second, respectively. The decrease in discharge was caused by rainfall (Figures 3a and 3b). The average rainfall from 2012 to 2016 was 2,235.85 mm, and the average rainfall from 2017 to 2016 was 2,014.31 mm.

Watershed health indicators can be assessed using the ratio of maximum and minimum discharge or the Flow Regime Coefficient (Pantow *et al*. 2013). Table 3 explains that the FRC was 49 from 2012 to 2016, and

Table 1 Land use changes in Upstream Ciujung Watershed

	2016 (ha)	2021 (ha)	Changes (ha)	(%)
Primary dryland forest	1916.9	1865.6	−51.3	0
Secondary dryland forest	8235.5	7162.3	−1073.2	−0.8
Production forest	17534.6	14414.7	−3119.9	−2.3
Open land	222.6	222.6	0	0
Plantation	6248.6	6273.7	25.2	0
Dryland agriculture with shrub	71980.8	76831.1	4850.3	3.6
Residential area	6265.5	6427.8	162.3	0.1
Dryland Agriculture	11673.5	11067.2	−606.3	−0.4
Rice Paddies	12399.8	12212.8	−187	−0.1
Wallow	27.7	27.7	0	0
Sum	136505.6	136505.6		

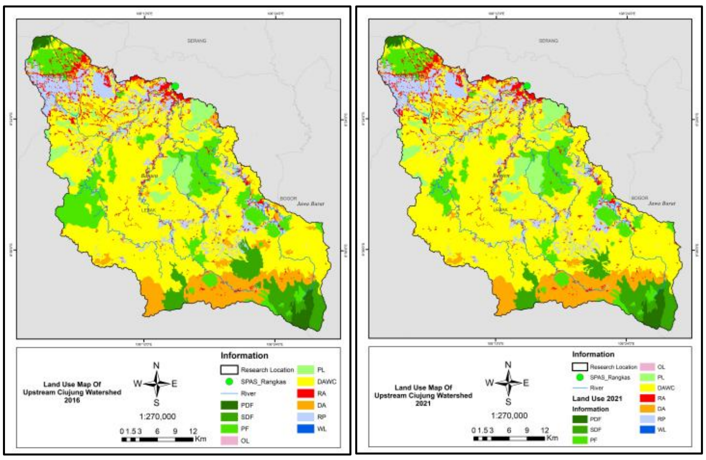

Figure 2 Land use change conditions in the Upstream Ciujung Watershed 2016−2021.

Table 2 Matrix of land use changes in Upstream Ciujung Watershed

2021 (ha)	2016 (ha)										Total
	PDF	SDF	PF	OL	PL	DAWC	RA	DA	RP	WL	
PDF	1866										1866
SDF		7162						0			7162
PF		32	14372						11		14415
OL				223							223
PL					6242			16	16		6274
DAWC	51	870	2906			71849		853	301		76831
RA			5			78	6265	20	59		6428
DA		170	122			38		10732	4		11067
RP		2	129		6	15		52	12009		12213
WL										28	28
Sum	1917	8236	17535	223	6249	71981	6265	11674	12400	28	136506

Remarks: *PDF: Primary dryland forest. SDF: Secondary dryland forest. PF: Production forest. OL: Open land. PL: Plantation. DAWC: Dryland agriculture with shrub. RA: Residential area. DA: Dryland agriculture. RP: Rice paddies. WL: Wallow.

A)

B)

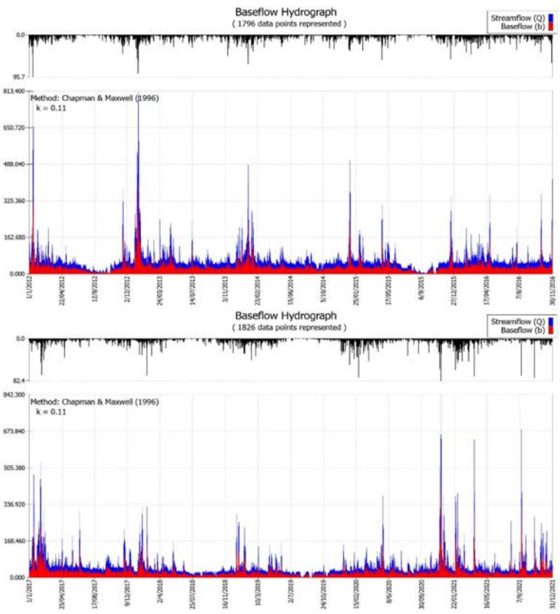

Figure 3 Subsurface flow hydrograph. surface flow and rainfall (a) 2012−2016 and (b) 2017−2021.

Table 3 FRC of Upstream Ciujung Watershed

Discharge (m^3/s)	Year	
	2012−2016	2017−2021
Q_{Max}	607	527
Q_{Min}	12	9
FRC	49	60
Rate	Low	Middle

60 from 2017 to 2021. According to the Minister of Environment and Forestry Regulation No. 61/2014 on Watershed Monitoring and Evaluation, an increase in the FRC value indicates a worsening watershed quality in reacting to the watershed hydrological system. The FRC from 2012 to 2016 was classified as low, while the subsequent period was classified as moderate. Land use changes in the Upstream Ciujung Hulu Watershed have an impact on hydrological response, particularly where the dry season discharge to rainy season discharge ratio is quite high. The surface flow rate increases during the rainy season as forest land cover decreases between 2016 and 2021. During the dry season, increased agricultural land use affects the total amount of water in the river and even the availability of groundwater. This circumstance suggests that the land cover in the Upstream Ciujung Watershed has been unable to adequately manage water, increasing the risk of drought during the dry season and floods during the rainy season. A similar situation exists in the Kerala Watershed and the Tapang Subwatershed, where forest conversion to agricultural and plantation land raises FRC by 15% and 20%, respectively (Sasikumar & Remya 2014, Sandhyavitri *et al*. 2015).

AFC is a significant diagnostic variable in detecting a watershed's hydrological response to a certain rainfall event (Norbiato *et al*. 2009, Utami 2020). To calculate the AFC value of the Upstream Ciujung Watershed, subterranean flow and direct surface flow were separated. The recession coefficient utilized was 0.111. Using the Chapman & Maxwell (1996) technique (Duncan 2019), the average baseflow index was 0.50. Table 4 shows the AFC value for the Upstream Ciujung Watershed.

The Upstream Ciujung Watershed had an AFC of 0.32 from 2012 to 2016 and 0.31 from 2017 to 2021. According to the Ministerial Regulation of Environment and Forestry No. 61/2014 on Watershed Monitoring and Evaluation, the AFC falls into the intermediate category. Despite being in the same class group, the 2017−2021 period saw a lower ratio of direct surface flow to rainfall than the 2012−2021 period. According to Zhang *et al*. (2017), in addition to watershed surface characteristics, climate parameters such as rainfall intensity and evaporation potential influence total annual water discharge. Heavy and sustained rainfall reduces the surface's ability to transfer water to the subsurface. Water that flows off the surface will swiftly flow into the river if the surface basin is filled.

Water Balance

The overall water needed for the Upstream Ciujung Watershed was 465,083,178 m^3/year (Table 5). Water consumption is highest in agriculture, but lowest in fisheries. In the agricultural industry, water is required for irrigation, particularly in rice fields. The analytical results suggest that the water need for 2021 is 393,818,616 m^3/year. Water usage in the fishing sector is only approximately 861,658 m^3/year. This is because ponds for fish farming are uncommon in the Upstream Ciujung Watershed. This is also consistent with Kurniasari's (2021) research, that fisheries operations are more commonly carried out along the coast or downstream of the watershed. The next greatest water needs are from the industrial sector (11,796,571 m^3/year), households and cities (21,479,054 m^3/year and 36,150,241 m^3/year), and cattle (977,036 m^3/year).

The overall water availability in the Upstream Ciujung Watershed, as estimated by the Jembatan Rangkas II RFMC, was 1,128,822,723 m^3/year. The watershed had an 80% dependable discharge from 2012 to 2021, ranging from 55 m^3/second to 11 m^3/second. The highest water availability was in January, at 147,393,627 m^3/month, while the lowest was in September, at 30,779,984 m^3/month.

The Upstream Ciujung Watershed water balance considers five sectors' water needs: agricultural, residential, fisheries, livestock, and industry, as well as water availability based on an 80% dependable discharge. Water balance analysis was performed to establish the amount of water surplus and deficit. According to the analysis results, this watershed will have a 663,739,545 m^3/year water surplus in 2021. Figure 4 depicts oscillations in the levels of water surplus and deficit in the watershed. From October to August, water needs remained (surplus) each month. However, in September, there was a water shortage of −5,468,643 m^3/month. Although rainfall decreased from June to September, water needs were excess in

Table 4 AFC of Upstream Ciujung Watershed

Discharge (m^3/s)	Year	
	2012−2016	2017−021
Rain (mm)	11179.26	10071.55
Direct run off (mm)	3611.41	3021.04
AFC	0.32	0.30
Rate	Moderate	Moderate

Table 5 Water needs and water available of Upstream Ciujung Watershed

Month	Water needs of Upstream Ciujung Watershed (m^3)						Water needs Total (m^3/month)	Water available Total (m^3/month)
	Irrigation	Household	Urban	Livestock	Industry	Fisheries		
Jan	35.979.483	1.819.264	3.061.906	82.754	999.163	72.982	42.015.552	147.393.627
Feb	33.660.982	1.701.892	2.864.363	77.415	934.701	68.273	39.307.628	123.248.399
Mar	34.349.676	1.819.264	3.061.906	82.754	999.163	72.982	40.385.746	110.693.817
Apr	34.827.408	1.760.578	2.963.135	80.085	966.932	70.628	40.668.766	123.918.019
May	35.991.268	1.819.264	3.061.906	82.754	999.163	72.982	42.027.337	124.265.859
Jun	33.249.787	1.760.578	2.963.135	80.085	966.932	70.628	39.091.145	89.360.374
Jul	17.344.086	1.819.264	3.061.906	82.754	999.163	72.982	23.380.156	61.271.879
Aug	32.727.370	1.819.264	3.061.906	82.754	999.163	72.982	38.763.439	40.087.617
Sep	30.407.270	1.760.578	2.963.135	80.085	966.932	70.628	36.248.628	30.779.984
Oct	36.005.999	1.819.264	3.061.906	82.754	999.163	72.982	42.042.068	61.646.260
Nov	33.263.395	1.760.578	2.963.135	80.085	966.932	70.628	39.104.753	90.456.935
Dec	36.011.892	1.819.264	3.061.906	82.754	999.163	72.982	42.047.961	125.699.953
Sum	393.818.617	21.479.055	36.150.241	977.036	11.796.571	861.658	465.083.178	1.128.822.724

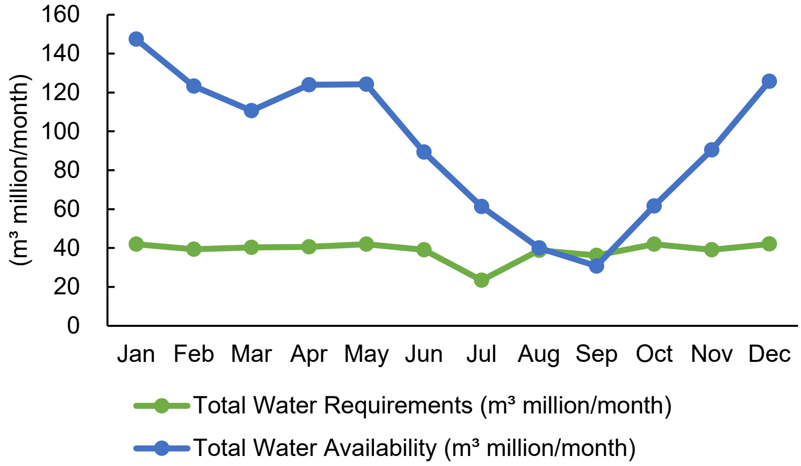

Figure 4 Water balance of the Upstream Ciujung Watershed in 2021.

June, July, and August until September, when they became deficit.

CONCLUSION

Land usage in the Upstream Ciujung Watershed altered from 2016 to 2021. Deforestation for agricultural and other land uses has an impact on the hydrological response of the watershed. The hydrological response of the FRC and AFC was considered good from 2012 to 2016, but in the next period, 2017−2021, it declined to moderate. The watershed's water balance remains in excess, indicating that water needs can still be satisfied, albeit water deficits do arise at the conclusion of the dry season.

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