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Dynamics of land cover change on hydrological conditions using the soil and water assessment tool model in the Tiworo watershed

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ABSTRACT

Land cover changes in watersheds can affect various hydrological aspects, such as river flow, sedimentation, and water quality. Land cover changes from forests to farmlands or settlements can cause significant changes in local hydrological cycles. This study aims to analyze the dynamics of land cover change and its impact on the hydrological conditions in the Tiworo watershed. The study was conducted in the Tiworo watershed, covering Muna and West Muna Regencies, with an area of 25,445.84 Ha. Using the soil and water assessment tool (SWAT), the results of the study for the period from 2017 to 2022 showed no groundwater flow. This condition reflects a potential issue with the groundwater parameters in the model or a lack of groundwater recharge during this period. However, as rainfall increases, groundwater loss is influenced by land conversion to settlements and the mixing of dryland agriculture with shrubs, ponds, and rice fields. The magnitude of surface runoff, the decrease in lateral flow (interflow), water yield, and the reduction in infiltration processes increased the fluctuations in Qmax (m^3/s), Qmin (m^3/s), and the flow regime coefficient (KRA) in the Tiworo watershed.

Keywords: land cover change, tiworo watershed, hydrological parameters, loss of groundwater, fluctuations in maximum flow rate and minimum flow rate.

INTRODUCTION

The Tiworo watershed in Muna Regency and West Muna Regency is essential for supporting the region's social, economic, and ecological life. However, in recent decades, the conversion of forestland to farmland, plantations, and settlements has led to various environmental problems, especially those related to hydrology. This land cover conversion can change the hydrological characteristics of the watershed, such as surface flow, infiltration, and evaporation. Research shows that land cover changes have the potential to increase surface flow and reduce infiltration, which can ultimately reduce the quality and quantity of available water. This impact can also exacerbate a region's flooding risk and soil erosion [Putra et al., 2022].

Changes in land cover in watersheds can affect various hydrological aspects, such as river flow, sedimentation, and water quality. Land cover changes, especially from forests to agricultural or residential land, can significantly change local hydrological cycles [Zhang et al., 2020]. Hydrological parameters such as erosion and sedimentation are influenced by climate change and deforestation, which directly impact the hydrological balance of watersheds. These factors are crucial in analyzing hydrological dynamics in the Tiworo watershed, particularly concerning the increased risk of flooding and erosion due to land cover changes [Pindi and Jayakumar, 2023]. Decreased forest cover often increases surface flow and decreases soil infiltration capabilities, increasing the risk of flooding and soil erosion. Previous studies have shown that land conversion can change river flow patterns, increase flood frequency and intensity, and reduce river water quality [Li et al., 2021]. The soil and water assessment tool (SWAT) model is an effective tool for modeling the impact of land cover change on hydrology in watersheds. SWAT predicts river flow, water quality, and soil erosion under various land use scenarios [Zhang et al., 2020]. Recent studies have shown that the SWAT model has been successfully used to evaluate the impacts of land use changes in various watersheds, accurately reproducing hydrological functions, estimating soil erosion rates, and providing an efficient tool for water resource management [M'barek et al., 2021]. SWAT is not only able to identify changes in flow patterns and water quality but also provides useful information for water resource management planning (Gu et al., 2022; Babaremu, 2024) Implementing this model allows for an in-depth analysis of how land cover changes affect hydrological processes in different regions. [Li et al., 2019; Khadka et al., 2023]

According to [La Baco et al., 2022], the Tiworo watershed in the Muna and West Muna districts faces critical problems related to land cover change, with significant conversion of forestland into agricultural land and settlements. Studies on the Tiworo watershed have shown that this conversion impacts increasing surface flow rates and decreasing water quality. The critical land in this area reaches 5,956.29 ha, and the critical potential land reaches 16,644.65 ha, indicating that land cover changes have significantly affected the environmental quality. It is essential to identify the changes that occur and their effects on the water balance in an area. In addition, this understanding is crucial in developing sustainable land management strategies to minimize the negative impact of land conversion and maintain the balance of the ecosystem as a whole [Pawitan, 2004; Sari et al., 2024].

This study aims to analyze the dynamics of land cover change and its impact on hydrological conditions in the Tiworo watershed via the SWAT model. This research aims to understand better how land cover changes affect hydrology and provide recommendations for better water management. An in-depth analysis using the SWAT model will allow for a more precise evaluation of the impacts of different land cover change scenarios, and the results will be particularly relevant for the planning and management of water resources in the region. [Anaba et al., 2017; Salim et al., 2019]. This study is expected to contribute to scientific knowledge about the impact of land cover change in the tropics. These findings can be a reference for future studies in similar regions.

METHOD

This study will be carried out in the Tiworo watershed (Figure 1), Muna and West Muna Regencies, with an area of 25,445.84 Ha, which is in direct contact with ten subdistricts, namely, the Muna Regency with four subdistricts consisting of the Kabawo, Lohia, Kontunaga, Tongkuno, and West Muna Regencies with six subdistricts, namely, the Barangka, Lawa, Saweregadi, Tiworo Islands, Tiworo Tenga, and Wadaga Districts. This research will be carried out from May 2022 to August 2023. The tools used in this study include ArcGIS 10.8 software with additional SWAT detection, a global positioning system (GPS), the Google Earth Engine, and digital cameras. The materials used in the research are primary data obtained from field observations and secondary data obtained from various sources. The secondary data are in the form of the results of the analysis of Landsat Image 8, which displays the land cover in 2012, 2017, and 2022. The Tiworo watershed map from 2012–2022 was obtained from BPDASHL Sampara. DEM (digital elevation model) data from the Geospatial Information Agency, soil type data and attributes from RePPProt 1987, rainfall and daily discharge data from the Tiworo watershed from the Kendari River Region Center (BWS IV Kendari), and climatological data from NASA's MERRA-II satellite, which can be accessed through https://power.larc.nasa.gov/data-access-viewer/.

Data analysis

The research consisted of collecting maps and data, processing data on land cover changes, managing SWAT hydrological model data, and analyzing SWAT models to determine the dynamics of land cover changes in the hydrological conditions of the Tiworo watershed. The analysis of land cover change in this study uses spatial analysis. Spatial analysis was conducted via SPOT satellite imagery via ArcGIS 10.8 software to obtain maps of land cover changes in 2012, 2017, and 2022. Before conducting spatial analysis, the interpretation of satellite images is first carried out with on-screen digitation [delineation on the computer screen]. The goal is to classify land cover classes. The land cover classes are determined based on the Indonesian terrain map from the Geospatial Information Agency. After the classification of land cover classes, an overlay was carried out

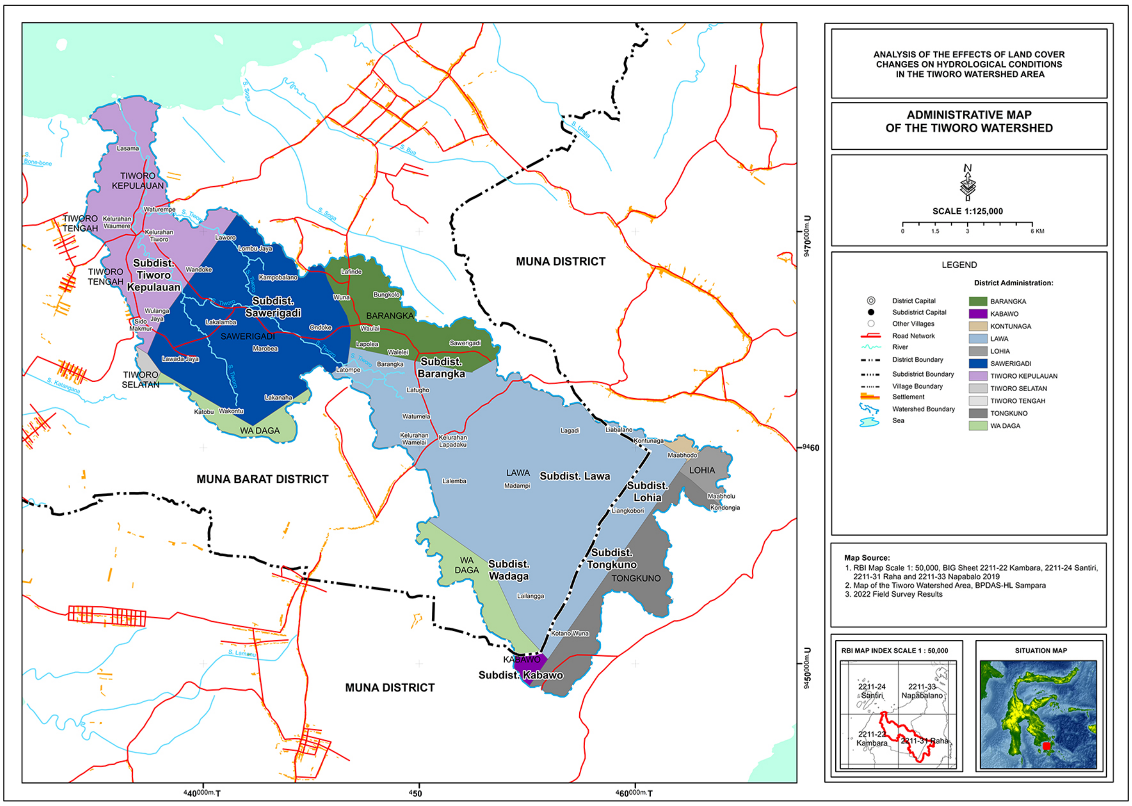

Figure 1. Map of the Tiworo watershed area

from the 2012, 2017, and 2022 land cover maps to obtain a map of land cover change for 10 years.

Land cover changes

Land cover analysis was performed by correcting the Landsat 8 digital image using the Indonesian terrain map as a reference. The research location (clipping) was determined based on the Tiworo watershed boundary map. Furthermore, the interpretation of the Landsat 8 image was carried out via supervised classification to identify land cover classes that are by the input of the SWAT model, such as settlement (URHD), forest (FRSE), rice field (RICE), dry land agriculture (AGRR), open land (BARR), plantation (FRST), shrub (RNGB), and water body (WATR) classes. This process includes cropping the image to form a region of interest, using a combination of bands to produce a composite image using three bands of imagery, image interpretation to classify pixels based on spectral values, and image correction to transform the image into map properties in terms of shape, scale, and projection [Deng et al., 2018; Which, 2019]. Field checks are carried out to determine the actual conditions in the field, with the geographical position of the observed object determined via GPS [Adjovu et al., 2023]. Each report is accompanied by a thematic map overlay to analyze changes in land cover from 2012, 2017, and 2022 [Susanti et al., 2020].

SWAT hydrological model

In the SWAT (soil and water assessment tool) model, watershed delineation uses digital elevation model (DEM) data to form river networks. This process divides and limits watersheds based on the predetermined area threshold.

1) The process begins with watershed delineation using DEM data to form river networks. This is carried out automatically through automatic watershed delineation (AWD), which includes determining outlets and river networks.
2) Next, the hydrologic response unit (HRU) is formed by overlaying data and maps of land cover, topography, and soil type.
3) After that, daily climate input data is entered, including rainfall, humidity, temperature, wind speed, and solar radiation. Rainfall and temperature data are typically in text format (.txt) (Son et al., 2022).
4) The SWAT model analysis is performed to generate daily prediction simulations based

on variations in land cover. The outputs of this simulation include surface runoff, baseflow, and daily river discharge. 5) The simulation data provide information about hydrological conditions for different land cover periods, such as 2012 and 2022. These outputs include total water yield (WYLD), surface runoff (SUR_Q), lateral flow (LAT_Q), and groundwater flow (GW_Q) (Li et al., 2023).

5) Additionally, discharge fluctuations in the Tiworo watershed can be further analyzed in terms of the ratio of maximum to minimum discharge (KRA) and the annual flow coefficient.
6) The results of this analysis can be used to plan water resource management and mitigate potential hydrological disasters in the Tiworo watershed, considering changes in land cover over specific periods (Zhang et al., 2020).

RESULTS AND DISCUSSION

General conditions of the Tiworo watershed

The Tiworo watershed (DAS) is located in the Muna and West Muna Regencies, Southeast Sulawesi, with approximately 25,445.84 hectares. Geographically, this watershed has a variety of topography that covers lowlands and hilly areas. The Tiworo watershed area is drained by several rivers, with the Tiworo River being the main river that empties into the Banda Sea in the southeast. A tropical climate with two seasons also influences the Tiworo watershed, namely, the rainy season and the dry season, which significantly affect hydrological conditions; thus, the existence of this watershed is essential because of its role in providing water sources for agriculture and the needs of the surrounding community, but it is also vulnerable to land degradation due to deforestation and unsustainable land use practices. The Tiworo watershed consists of five classes, dominated by flat (71.01%) and sloping (19.07%) slope classes. The percentage of area in the Tiworo watershed according to slope is shown in Table 1.

The forest area in the Tiworo watershed has a cultivation area of 25,039.53 ha or 98.40% and a protected area of 406.31 ha or 1.6% of the total watershed area. This shows that most forest areas have cultivation functions that have the potential for various economic activities but also require attention for sustainability. Moreover, settlements in the Tiworo watershed area are spread across several subdistricts with varying populations. District Tongkuno has the highest population of 15,719 people, followed by Lohia with 14,825 people and Kabawo with as many as 12,991 people. Other subdistricts that are also included in the Tiworo watershed are Barangka 7,377 people, Lawa 8,796 people, Sawerigadi 8,132 people, Tiworo Islands 7,225 people, Central Tiworo 7,658 people, and Wadaga 6,433 people. The community work in the Tiworo watershed area involves mainly farmers with yellow corn, cashews, coconut, cassava, and patchouli crops [BPS Muna Regency 2023 and BPS West Muna Regency 2023]. The percentage of the area of the Tiworo watershed according to the function of the area can be reviewed in Table 2.

Dynamics of cover changes

Analysis of satellite images of land cover changes in the Tiworo watershed from 2012–2022. Each land cover change in the area throughout the year was analyzed. Based on the analysis that has been carried out, the percentage of land cover change that has occurred in the Tiworo watershed can be reviewed in Table 3. Changes in land cover in the Tiworo watershed area during two periods, namely, 2012–2017 and 2017–2022, show significant dynamics that impact local environmental and ecosystem conditions (Figure 2, 3, 4). From 2012–2017, the area of secondary dryland

Table 1. Tiworo watershed area, according to slope

Slope class (°)	Category	Broad (hectares)	Percentage (%)
0–8	Flat	18,165.86	71.01
8–15	Ramps	4,879.92	19.07
15–25	Somewhat steep	1,977.92	7.73
25–40	Steep	510.84	2.00
>40	Very steep	48.95	0.19
Sum		25.445,84	100

Note: BPDASHL Sampara, 2023 (processed).

Table 2. Area of the Tiworo watershed by area function

No.	Area function	Area (ha)	Area (%)
1	Protected areas	406,31	1,60
2	Cultivation area	25.039,53	98,40
Sum		25.445,84	100,00

Note: BPDASHL Sampara, 2023 (processed).

Table 3. Distribution of land cover change

No.	Land closure	Area/Year					
		2012		2017		2022	
		Ha	%	Ha	%	Ha	%
1	Secondary dryland forests	6.252,19	24,57	4.848,59	19,05	3.960,03	15,56
2	Secondary mangrove forest	390,57	1,53	253,48	1,00	243,76	0,96
3	Settlement	1.134,74	4,46	1.168,19	4,59	1.186,10	4,66
4	Plantation	48,98	0,19	48,98	0,19	48,98	0,19
5	Mixed dryland agriculture	16.663,61	65,49	17.993,30	70,71	18.619,63	73,17
6	Paddy	376,28	1,48	376,28	1,48	376,28	1,48
7	Shrubs/bushes	391,57	1,54	426,60	1,68	670,93	2,64
8	Pond	74,73	0,29	217,22	0,85	226,94	0,89
9	Water body	113,16	0,44	113,19	0,44	113,19	0,44
Grand total WIDE		25.445,84	100,00	25.445,84	100,00	25.445,84	100,00

Note: GIS 2023 analysis results.

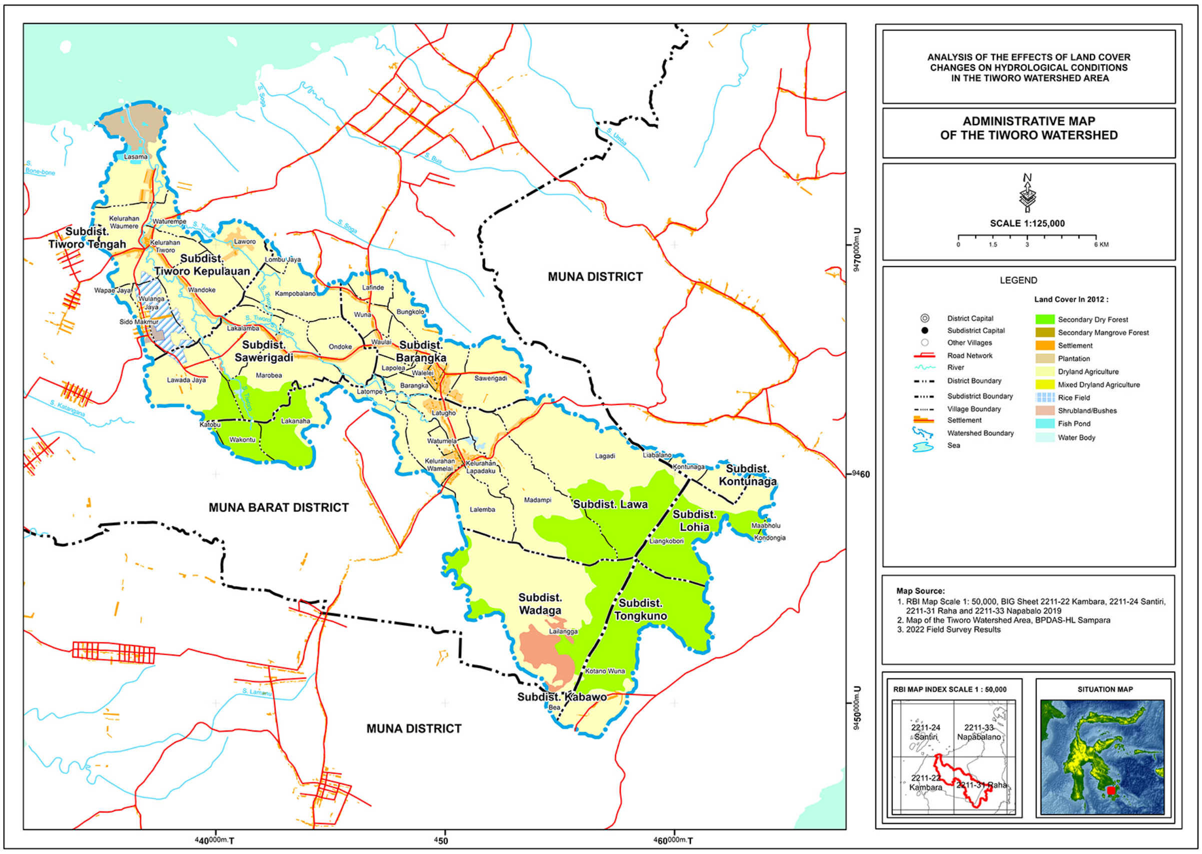

Figure 2. Map land cover Tiworo watershed 2012.

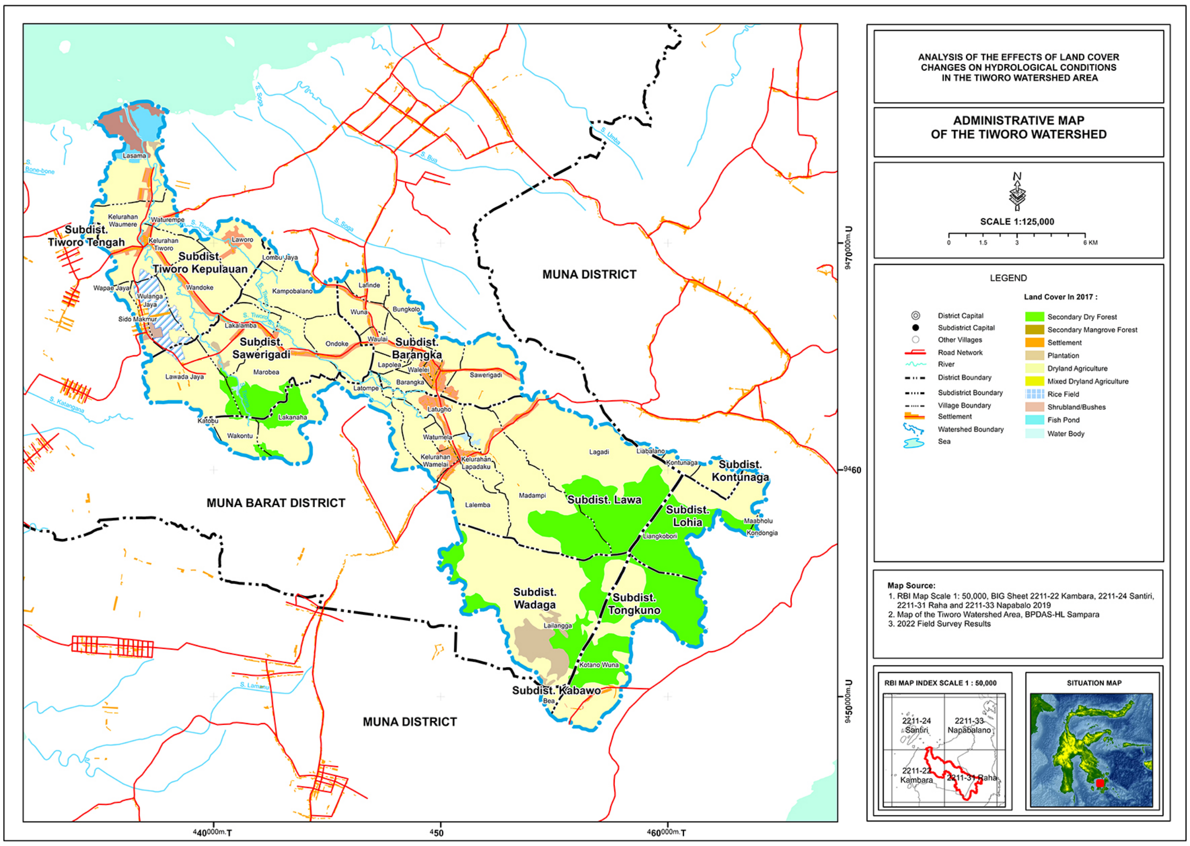

Figure 3. Map land cover Tiworo watershed 2017

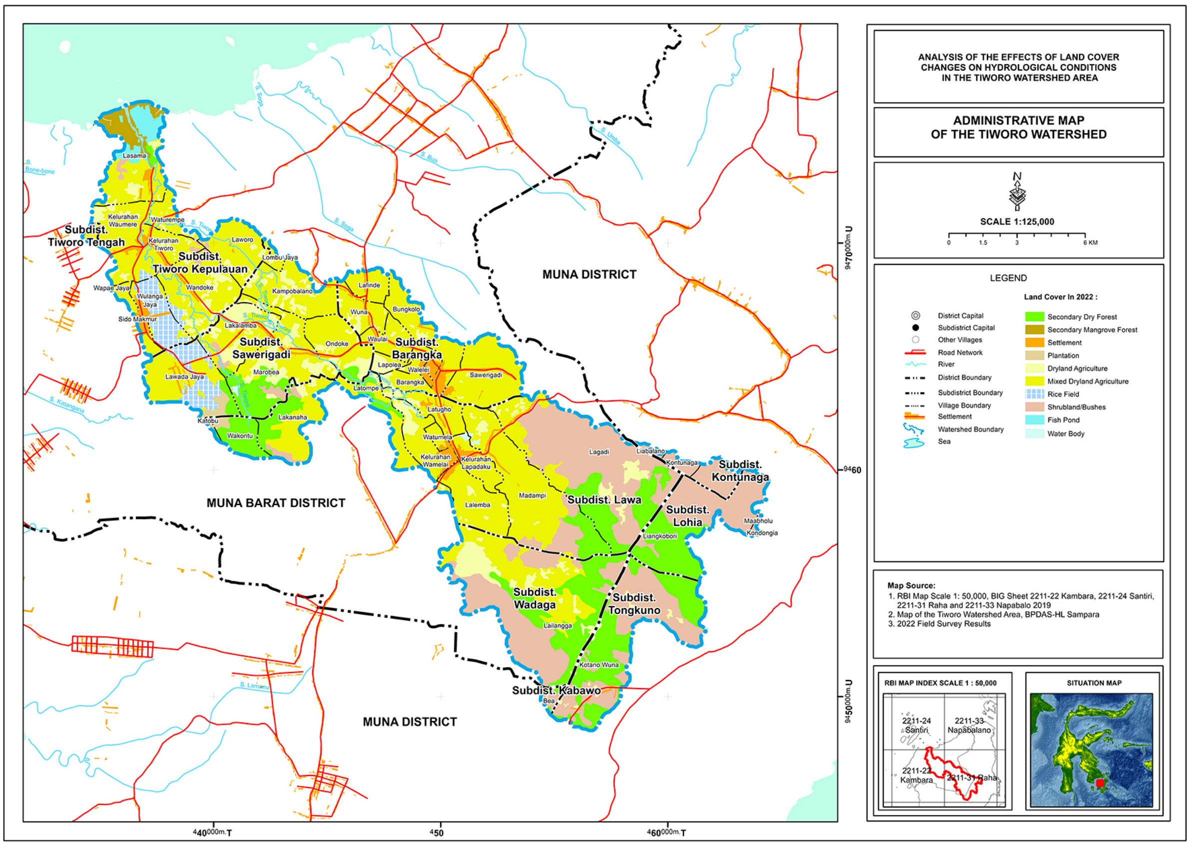

Figure 4. Map land cover Tiworo watershed 2022

forests decreased by 1403.60 hectares. The area of secondary mangrove forests decreased by 137.09 hectares, and significant changes occurred in residential land, where residential areas increased by 33.44 hectares. This expansion reflects an increase in the number of people or urbanization, which has led to the expansion of residential areas. This significant decrease occurred in the area of plantations, which remained stable throughout the study period. This shows that the plantation sector in the Tiworo watershed area has reached its maximum capacity and has not undergone further expansion. The area of agricultural land or mixed dry land has increased significantly, amounting to 1329.69 hectares, and there has been a massive expansion in the agricultural sector, driven by the need for productive land for food crops or mixed plantations. No changes were recorded in the paddy area during the two periods, indicating that the area of paddy fields in the Tiworo watershed was stable. This condition is essential for maintaining consistent and sustainable food production. The area of shrubs or shrubs increased by 35.03 hectares, and the area of ponds increased significantly by 142.49 hectares, which may be related to the increase in economic needs from the fisheries or aquaculture sector. No significant changes were recorded in the water body category during these two periods, with only a tiny increase of 0.03. This shows that there is a strong dynamic of forest cover in the Tiworo watershed area.

However, from 2017–2022, the rate of decline in secondary dryland forest cover decreased compared with that in the previous period, which was 888.56 hectares, and the decrease in the area of secondary mangrove forests was 9.72 hectares. In contrast, it increased by 17.91 hectares for settlements, which was smaller than that in the previous period. This could be due to limited land for further development or a shift in development trends toward verticality or more efficient land use. The rate of increase slowed down in mixed dryland agriculture to 626.33 hectares, and bushes occurred. This increase was more significant, namely, 244.32 hectares. The growth of this shrub or shrub area may be caused by the conversion of agricultural land that is no longer productive or land abandoned after other functional changes. The pond area has hardly increased, increasing by only 9.72 hectares. This may reflect the limitations on land available for pond expansion or stricter policy adjustments regarding using coastal land for ponds to mitigate adverse impacts on mangrove ecosystems and coastal environments; this downward trend remains a concern. There is no change in water bodies such as lakes and rivers, which remain stable in their area. This dynamic reflects more intensive conservation and rehabilitation efforts, although the results have not entirely stopped the forest degradation rate. [Pribadi et al., 2020]. The changes in land cover in the Tiworo watershed from 2012 to 2022 exhibited complex dynamics, and significant land conversion was dominated by the conversion of forests into agricultural land, settlements, and ponds. Agricultural land was developed to meet the social and economic needs of the community. Agricultural commodities include yellow corn plants, cashews, coconuts, cassava, sweet potatoes, and patchouli, whereas the growing fishery commodities include milkfish and shrimp. The increase in residential land cover can indicate population growth in the Tiworo watershed area, with the impact of increasing the economic and social needs of the community, especially the use of rice fields and ponds for food needs. This shows that there is pressure on forest areas due to the expansion of agricultural land and settlements, which affects the carrying capacity of the watershed in absorbing rainwater and maintaining the hydrological balance. [Soma et al., 2021] stated that changes from forestland cover to nonforest land could affect surface flow, increase erosion, and impact overall watershed conditions, including a greater risk of flooding and sedimentation. The distributions of land cover changes can be reviewed in Tables 4 and 5.

Watershed definition

Watershed delineation is carried out via a digital elevation model (DEM) and river network data. The delineation process in this study was carried out by changing the DEM base in the stream definition from the original 25,445.84 ha with 15 subbasins, each having different height characteristics. The highest elevation is in the upstream area, namely, subbasins 14 and 12, with an altitude of 274 m above sea level. In contrast, the lowest elevation is at the outlet point in subbasin 1, with an elevation of -10 m above sea level. This topographic pattern directly affects water flow dynamics in the watershed, where surface flow tends to be concentrated toward the outlet point with the lowest elevation. The division of subbasins, areas, and slopes for each subbasin of the Tiworo watershed is presented in Table 6.

Table 4. Distribution of land cover changes from 2012–2017

		2017 (ha)									
Land closure		1	2	3	4	5	6	7	8	9	Total
2012 (ha)	(1) Secondary forest	4,846.05				1,405.85		0.29			6,252.19
	(2) Mangrove forest		247.44						143.09	0.03	390.57
	(3)Settlements			1,127.97							1,134.74
	(4) Plantations				48.98						48.98
	(5) Agriculture	2.55		33.51		16,581.97		40.15	5.44		16,663.61
	(6) Rice fields						376.28				376.28
	(7) Check					5.41		386.16			391.57
	(8) Ponds		6.04						68.69		74.73
	(9) Water body									113.16	113.16
Total		4,848.59	253.48	1,161.47	48.98	18,000.02	376.28	426.60	217.22	113.19	25,445.84

Note: land cover cross tabulation processing, 2023.

Table 5. Distribution of land cover changes from 2017–2022.

		2022 (ha)									
Land closure		1	2	3	4	5	6	7	8	9	Total
2017 (ha)	(1) Secondary forest	3,940.90				907.70					4,848.59
	(2) Mangrove forest		235.23						18.25		253.48
	(3) Settlements			1,168.19							1,168.19
	(4) Plantations				48.98						48.98
	(5) Agriculture	19.13		17.91		17,695.35		260.91			17,993.30
	(6) Rice fields						376.28				376.28
	(7) Check					16.58		410.02			426.60
	(8) Ponds		8.53						208.69		217.22
	(9) Water body									113.19	113.19
Total		3,960.03	243.76	1,186.10	48.98	18,619.63	376.28	670.93	226.94	113.19	25,445.84

Note: Land cover cross tabulation processing, 2023.

The characteristics of each subbasin strongly influence the hydrological conditions of a watershed. Wide subbasins, such as Subbasin 12, have the potential to serve as good water catchers and support biodiversity, which is essential for maintaining water quality and reducing flood risk. Subbasins 1 and 14, with their significant areas, also contribute to water flow regulation and groundwater storage. Conversely, small subbasins may be more vulnerable to the negative impacts of land-use change, which can disrupt the hydrological balance [Alshammari et al., 2024].

HRU (hydrology response unit)

The HRU is a hydrological analysis unit formed on land cover, soil characteristics, and specific slope classes [Arnold et al., 2012]. The process of forming HRUs is carried out by generating overlay land cover maps, soil type maps, and slope maps that are automatically formed from DEMs via SWAT models. The HRU is spread in the subbasin to describe the biophysical state of each subbasin above. This process results in 181 HRUs with different characteristics for each HRU. The dominant HRU classes in the Tiworo Subwatershed are presented in Table 7.

Based on the analysis of HRUs in the Tiworo subwatershed, 16 HRUs dominate AGRL land cover and WATR with the same soil type (Lc78-3c-4529) and slope classes dominated by flat areas. Settlement development tends to reduce water infiltration, increase surface flow, and increase the risk of flooding and deterioration of

Table 6. Distribution of the Tiworo watershed in the subbasin

Subbasin	Area (ha)	Area (%)	Looseness grade (%)
1	23.521	9.24	0–25
2	11.16	4.39	0–45
3	14.464	5.68	0–25
4	14.91	5.86	0–25
5	14.67	5.76	0–25
6	15.485	6.08	0–45
7	13.118	5.15	0–45
8	16.779	6.59	8->45
9	5.4331	2.13	8->45
10	13.713	5.39	8->45
11	3.5892	1.41	8->45
12	44.414	17.45	8->45
13	0.47967	0.19	8->45
14	26.578	10.44	8->45
15	36.17	14.21	8->45
Total	254.484	100.00	

Note: 2023 analysis results.

Table 7. The dominant HRU class of the Tiworo watershed

HRU	Land cover	Soil type	Slope class %	Broad	
				ha	%
16	AGRL	LC78-3C-4529	0–8	1,422	5.6
27	AGRL	LC78-3C-4529	0–8	936	3.7
33	AGRL	LC78-3C-4529	0–8	1,206	4.7
39	AGRL	LC78-3C-4529	0–8	1,014	4.0
56	AGRL	LC78-3C-4529	0–8	897	3.5
59	AGRL	LC78-3C-4529	0–8	882	3.5
67	AGRL	LC78-3C-4529	0–8	1,091	4.3
71	AGRL	LC78-3C-4529	0–8	985	3.9
126	AGRL	LC78-3C-4529	0–8	1,575	6.2
127	AGRL	LC78-3C-4529	15–25	553	2.2
128	AGRL	LC78-3C-4529	8–15	1,007	4.0
145	WATR	LC78-3C-4529	0–8	736	2.9
153	AGRL	LC78-3C-4529	0–8	1,090	4.3
158	AGRL	LC78-3C-4529	0–8	1,288	5.1
163	WATR	LC78-3C-4529	0–8	576	2.3
166	WATR	LC78-3C-4529	0–8	674	2.6

Note: 2023 analysis results.

water quality. With most HRUs being in flat areas, the potential for waterlogging during high rainfall increases, which can lead to erosion [Gao et al. 2024]. In addition, HRUs associated with water bodies, such as HRUs 145 and 163, contribute to local hydrological systems and require proper management to prevent pollution. This condition requires a land and water conservation-based management approach to maintain the hydrological function of the watershed, especially in the HRU adjacent to the water body, to reduce the negative impact on water quality and the surrounding aquatic ecosystem. [Utami et al. 2020].

Effects of land cover changes on hydrological conditions

Changes in watershed land cover can be reviewed from a hydrological perspective, directly affecting land cover characteristics and the watershed water system. The dynamics of land cover changes in response to the hydrological conditions of the Tiworo watershed were analyzed via the SWAT hydrological model based on precipitation values, surface runoff, flow out, and base flow. The hydrological conditions of the Tiworo watershed can be seen in Figure 5 and Table 8

This study analyzes the impact of land cover changes on hydraulic conditions. Figure 5 and Table 8 shows the SWAT model simulation results, with precipitation values fluctuating from 15,204.29 mm/year in 2012 to 9,690.15 mm/year in 2017 and 40,525.37 mm/year in 2022. This increase in rainfall contributes to the increase in surface flow runoff), which shows a similar pattern; in 2012, it was 6,474.84 mm/year; in 2017, it was 1,799.34 mm/year; and in 2022, it was 16,790.17 mm/year. The base stream value (groundwater) in 2012 was 1,857.15 mm/year, and in 2017 and 2022, there was no groundwater. These results reveal a significant decrease in subsurface flow (groundwater) every year and an increase in the value of surface runoff (surface runoff) every year, resulting in a lack of discharge that seeps into the soil (infiltration), resulting in subsurface flow (groundwater) being lost. The discharge flowing in the surface runoff increases with each period. Lateral flow (interflow) and evapotranspiration influence hydrological systems but are more complex. The lateral flow value (interflow) in 2012 ranged from 23.54 mm/year to 11.67 mm/year in 2017 and 36.22 mm/year in 2022. In addition to evaporation (evapotranspiration) in 2021, which ranged from 57,155.63 mm/year to 30,730.91 mm/year in 2017, and 48,300.72 mm/year in 2022, evapotranspiration (evapotranspiration) plays a vital role in influencing the amount of water available in the soil for runoff and lateral flow. When evapotranspiration is high, more water is lost to the atmosphere through evaporation and transpiration, thereby reducing the amount of water available at the surface and inhibiting water flow

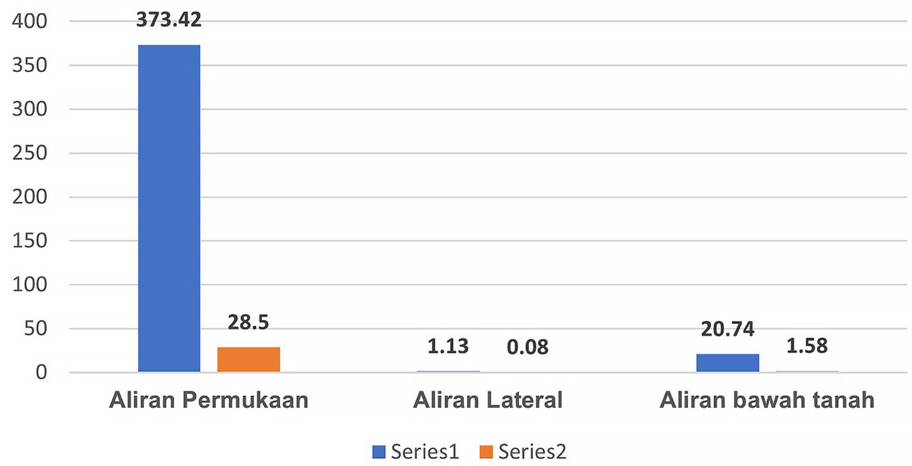

Figure 5. Graph of hydrological conditions for each land cover change in the Tiworo watershed**;** SWAT analysis results, 2023

Table 8. Hydrological conditions of land cover changes in the Tiworo watershed

Hydrology parameters	2012 mm/year	2017 mm/year	2022 mm/year
PREP	15,204.29	9,690.15	40,525.37
SURQ	6474.844	1,799.34	16,790.17
LATE	23.54	11.67	36.22
GW	1,857.15	–	–
PET	57,155.63	30,730.91	48,300.72
WYLD	8,553.19	1,812.06	16,848.01

Note: SWAT analysis results, 2023. PRECIP: rain (precipitation), GW: groundwater (groundwater). SURF: surface flow (surface runoff), PET: evapotranspiration, LATE: lateral flow (interflow) WYLD: water yield (water yield).

into the soil. This reduces the water availability for lateral flows that usually occur when the soil is saturated [Nursaputra Et al., 2023].

Water yield (water yield) during each period of land cover change in the Tiworo watershed: the total water yield from surface flow runoff), lateral flow (interflow), and underground flow (base flow). The more surface flow occurs, the less lateral flow and groundwater are reduced. In 2012, the Tiworo watershed produced water (water yield) from 8,553.19 mm/year to 1,812.06 mm/year and 16,848.01 mm/year in 2017, which indicates that the subangan of water production (water yield) comes from surface flows. These water results show how much precipitation and runoff impact the water available in a given year. [Hatheway, 1999]

The analysis of the SWAT results revealed that land use changes in the Tiworo watershed have an impact on its hydraulic conditions. This affects the area of dryland agriculture, and ponds, shrubs/bushes, and settlements in a watershed (watershed) can result in a high level of land erosion (Salim et al., 2019). The results of the SWAT model analysis in 2012, 2017, and 2022 from a total of 15 surface flow substations (surface runoff), underground flow, water results (water yield), and seven sub-watersheds (9, 10, 11, 12, 13, 14, and 15) lateral flows (interflow) were the most significant contributors to the Tiworo watershed hydrological system. Moreover, from 2017 to 2022, no water was produced by underground flows (groundwater). This condition shows the ability of the watershed hydrological system to replenish groundwater reserves, although precipitation increases significantly to 40,525.37 mm/year. At the study site, most dryland agriculture is mixed with shrubs planted with mixed crops, and the influence is related to vegetation and improper tillage [Soma et al., 2023].

Distribution of HRUs in various land covers dominated by settlements affects the hydrological function of the Tiworo watershed. Land cover significantly impacts surface flow runoff, underground lateral flow (interflow), and water yield (water yield) in settlements, with dryland agriculture mixed with shrubs and rice fields. This influence is related to the increase in agricultural land over 10 years by 2335.55 ha, the increase in shrubs/bushes by 301.35 ha, and the increase in residential area by 51.42 ha. The increase in settlement areas has led to increased surface runoff because residential areas are waterproof. These buildings are generally made of cement, bricks, or concrete, making it difficult to absorb water [Staddal 2016].

The Regulation of the Minister of Forestry No. P.61/Menhut-II/2013 flow regime coefficient (KRA) compares the maximum discharge (Q_{max}) and minimum discharge (Qmin) to indicate whether the watershed functions as a good processor. Table 9 shows the results of the flow regime coefficient criteria based on land cover data from the 2012, 2017, and 2022 periods.

The increase in the value of the flow regime coefficient from 45.79–40.52 in the 2012–2017 period, as well as its increase from 40.52–78.08 in the 2017–2022 period, shows that there was a significant impact of land cover changes on river flow patterns. This change was due mainly to the conversion of forestland to non-forestland, such as an increase in dry agricultural land of 2335.55 hectares, ponds of 409.44 hectares, and settlements of 51.42 hectares. This transformation decreases the soil infiltration capacity, as forestland, which naturally has a high infiltration capacity, functions to absorb less rainwater into the soil [Sari et al., 2024]. As a result, surface flow or runoff increases, especially during the rainy season, which makes discharge fluctuations even greater and increases the flow coefficient, as seen in the 2017–2022 period [Purwitaningsih et al., 2017]. This also impacts the stability of river flows, increasing their susceptibility to flooding and decreasing water quality and groundwater availability due to reduced infiltration [Rau et al., 2015]. These changes emphasize the importance of maintaining forestland cover in watershed management for the sustainability of water resources and maintaining a balance between land use and environmental conservation.

Table 9. Effects of land cover changes on fluctuations in the Tiworo watershed discharge

It	Land cover	River discharge		KRA	Criterion
		Q_{max}(m^3/s)	Q_{min}(m^3/s)		
1.	Land cover 2012	22.37	0.49	45.79	keep
2.	Land cover 2017	16.94	0.42	40.52	keep
3.	Land cover 2022	46.46	0.60	78.08	tall

Note: KRA value processing, 2023.

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

1. From 2017 to 2022, underground flows produced no water. This condition reflects the ability of the watershed hydrological system to replenish groundwater reserves; however, as precipitation increases, the loss of groundwater is influenced by increases in residential land closure and the mixing of dryland agriculture with shrubs, ponds, and rice fields.
2. The magnitude of the surface runoff, the decrease in lateral flow (interflow), the water yield, and the decrease in the water process (infiltration) increased the fluctuations in Qmax (m^3/s), Qmin (m^3/s), and the flow regime coefficient (KRA) of the Tiworo watershed.

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