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The Impact of Land Use Change on Hydrological Response in Watersheds Batang Merao

Ollga Febiola
Akademi Teknik Adi Karya

Abstract

Land-use change significantly alters watershed hydrology, affecting runoff generation, infiltration capacity and flood frequency. This study investigates the impact of land-use change on hydrological response in the Batang Merao watershed, Sungai Penuh City, using satellite-derived land-cover interpretation (Landsat/Sentinel series) and public statistical data for the period 2000–2025. A mixed-methods approach combined multi- temporal land-cover estimation with descriptive hydrological analysis of rainfall-runoff indicators. Results indicate a notable reduction in forest cover and a concurrent increase in built-up and agricultural areas, corresponding to higher surface runoff and more frequent peak discharge events during the rainy season. The study recommends integrated watershed management emphasizing riparian restoration, green infrastructure, and tighter land-use controls to mitigate flood risk. These findings contribute practical guidance for urban planning and watershed conservation in similar tropical highland settings.

Keywords: Land-Use Change; Hydrological Response; Flooding

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INTRODUCTION

The Batang Merao Watershed, located in Sungai TFull City, Jambi Province, plays an important role in providing water for domestic, agricultural, and regional ecological needs. In the last two to three decades, the area has experienced significant development pressures and land-use changes. Local urbanization, expansion of residential areas, and land conversion to small-scale plantations and intensive agriculture have resulted in reduced forest cover and catchland. This phenomenon not only changes the character of the landscape, but also affects basic hydrological processes such as infiltration, evapotranspiration, and surface flow. Land-use changes have a direct impact on the hydrological response of watersheds. Modern hydrological theory states that an increase in impervious surface area reduces infiltration capacity and accelerates runoff rates, resulting in higher peak discharge and shorter concentration times (Beven, 2012). In tropical areas such as Batang Merao, seasonal intense rainfall combined with land change can increase the frequency and intensity of flooding. At the local level, data reports and community observations show an increase in local flooding events in some downstream settlements since 2005, with peak occurrences prominent during the heavy rainy season. The city's BPS and regional planning documents indicate the growth of settlements on the riverbanks and the main stream area. In addition, sand mining activities and agricultural practices that do not pay attention to soil conservation also accelerate erosion and sedimentation, thereby reducing the capacity of river channels.

Formulation of Problems and Research Objectives This research focuses on the analysis of land-use changes in the Batang Merao watershed during the period 2000–2025 and its impact on the hydrological response. The formulation of the problems raised includes: (1) What is the pattern of land use change in the Batang Merao watershed in the period 2000–2025? (2) What is the relationship between land-use change and hydrological indicators such as peak discharge, runoff coefficient, and concentration time? (3) What management strategies are effective to reduce the risk of flooding in this region. The objectives of this study are: (1) Identify and describe trends in land use change in the period studied; (2) Examine the impact of these changes on hydrological responses descriptively; and (3) Develop recommendations for conservation policies and actions relevant to the local context. Theoretical Basis Land use change affects hydrological aspects through several mechanisms: reduction of vegetation cover reduces evapotranspiration losses and above-surface storage capacity; replacement of natural soil with an impermeable surface (concrete, asphalt) increases surface runoff; and soil erosion increases sediment which reduces the capacity of river channels (Wang et al., 2020). The framework of this study is based on the cause-and-effect relationship between land change and hydrological variables, taking into account local climatic factors (seasonal rainfall) and the physical conditions of the watershed such as slope and soil type.

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RESEARCH METHODS

Type of research This research is descriptive-qualitative with the support of secondary quantitative data. A semi-quantitative approach was used to estimate changes in land cover area based on the interpretation of multi-temporal satellite imagery. The location of the study was conducted in the Batang Merao watershed, which is located at the approximate coordinates of S 2°03'–S 1°42' and E 101°13'–E 101°32'. This area includes a more hilly upstream and a flatter area around the Kota Sungai TFull settlement. Data Sources and Collection Techniques 1. Satellite Imagery: Landsat (ETM/OLI) and Sentinel-2 for 2000, 2010, 2020, and 2025 (interpreted). The images were processed for land cover classification using a visual-analytical approach and limited field verification (ground truthing). 2. Statistical Data: Land use and demographic statistics from BPS Kota Sungai TFull (2000–2022).

Hydrometeorological Data: Monthly rainfall from the nearest BMKG station, documentation of local flood events, and technical reports of government agencies. The types of data used include spatial data (land cover maps), time-series quantitative data (land area per class, rainfall), and qualitative data (limited interviews and field reports). Data Analysis The analysis includes: (a) classification of multi-temporal land cover changes and quantification of land changes per period; (b) creation of summary tables and graphs of change trends; (c) Descriptive analysis of hydrological indicators—describes changes in infiltration, runoff, and peak discharge based on theoretical relationships and empirical evidence (flood documents and field observations). No full computational hydrological modeling (e.g. SWAT) because the focus of this study is a qualitative impact study supported by simple quantitative estimation.

RESULTS AND DISCUSSION

The results of image classification and data analysis show a consistent trend of land use change over the period 2000–2025. The table below summarizes the estimated area change by land category (forest, agriculture/plantations, residential, wetland/other).

Table 1. Estimated Land Use Changes in the Batang Merao Watershed (2000–2025)

Category	2000 (Ha)	2010 (Ha)	2020 (Ha)	2025 (Ha)	Change 2000–2025 (%)
Forest	12500	10800	9375	8500	-32.0
Plantation/Agriculture	8200	8750	9100	9600	+17.1

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Paddy	4500	4650	4800	4700	+4.4
Settlements	2000	2750	3560	4200	+110.0
Others (open, road)	1300	1500	1665	1750	+34.6

Analysis shows that the reduction in forest area and the increase in residential and plantation areas have direct implications for hydrological responses. Theoretically, reduced vegetation cover reduces the infiltration and water storage capacity of the soil profile, thereby increasing the proportion of rainwater that becomes surface runoff (Beven 2012; Wang 2020). In Batang Merao, this combination shortens the concentration time and increases peak discharge during intense rainfall events. Empirical evidence from field documents and flood event records indicates an increase in the frequency of flooding in downstream settlements, particularly in Hamparan Rawang District and the Bungkal River. Similar studies in tropical watersheds indicate that rapid land use changes related to urbanization tend to double flood risks if not balanced by adequate drainage systems and upstream conservation (Li et al. 2019; Rustiadi et al. 2023).

Furthermore, sand mining activities in several segments are also known to increase the supply of sediment—driving siltation and reducing channel capacity. Recommended mitigation approaches include strengthening riparian zones, replanting upstream vegetation, implementing green infrastructure in urban areas (swales, infiltration wells, permeable paving), and enforcing land-use regulations along riverbanks. From a policy perspective, integrating spatial planning with watershed management should be a priority to reduce community exposure and vulnerability to flooding (Beven 2012). Land use

change also impacts water quality. Increased agricultural and residential land area contributes to nutrient and pollutant loads, including total suspended solids (TSS) and dissolved organic matter. Water quality monitoring studies in similar areas show an increase in the Pollution Index along with land use change (Dewata et al. 2024).

In Batang Merao, qualitative data and limited samples indicate increased sedimentation events, accelerating channel siltation. Quantitative calculations such as estimating increases in runoff coefficients or changes in peak discharge require further modeling (e.g., SWAT, HEC-HMS). However, based on hydrological rules of thumb and comparative studies, a 10–20% increase in impervious surface in subwatersheds can increase peak discharge by several tens of percent under intense rainfall events (Wang 2020). Therefore, land use change management is key to risk reduction. Implementation of regular spatial monitoring (every 5 years) and upstream restoration programs are highly recommended.

CONCLUSION

Land use changes in the Batang Merao watershed between 2000 and 2025 show a decrease in forest area and an increase in agricultural and residential land. These changes have resulted in increased surface runoff, reduced infiltration, increased sedimentation, and increased flood frequency in downstream areas. Key recommendations include riparian rehabilitation, implementation of green infrastructure, enforcement of spatial planning regulations, and regular spatial monitoring.

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