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Analysis of the Effect of Land-Use Change on Flood Discharge in the Dendeng Watershed, Kupang City

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A B S T R A C T

Land-use change in urban areas can alter infiltration capacity and increase surface runoff. This study aims to identify land-use changes in the Dendeng Watershed (DAS) of Kupang City in 2014 and 2024 and to analyze their effects on flood discharge. The analysis employed maximum daily rainfall data from El Tari Meteorological Station and Kupang Class II Climatological Station, Landsat 8 imagery for land-use interpretation, QGIS for spatial analysis, the Mononobe method for rainfall intensity, and the Nakayasu Synthetic Unit Hydrograph (SUH) for flood discharge estimation. The results show that vegetation coverage decreased from 12.67 km^2 to 8.02 km^2, built-up areas increased from 20.46 km^2 to 21.00 km^2, and open land increased from 12.35 km^2 to 16.71 km^2. The composite runoff coefficient increased from 0.357 to 0.377, while peak hydrograph discharge increased from 1.452 m^3/s to 1.531 m^3/s. Design flood discharge also increased; for the 25-year return period, it increased from 41.007 m^3/s to 60.416 m^3/s, while for the 100-year return period, it increased from 52.791 m^3/s to 83.438 m^3/s. These findings indicate that declining vegetation cover and increasing built-up and open areas intensify the runoff response of the Dendeng Watershed. Spatial planning control, protection of recharge areas, and vegetation rehabilitation are therefore required to reduce the increasing flood risk in Kupang City.

INTRODUCTION

Flooding is one of the hydrometeorological problems that frequently develop in urban areas. The magnitude of flood discharge is determined not only by rainfall but also by changes in the physical characteristics of a watershed resulting from spatial development and land utilization. The expansion of settlements, road networks, and various urban facilities can transform natural land into relatively impervious surfaces, thereby reducing the ability of the soil to absorb rainfall (Asdak 2010; Arsyad 2010).

Land-use change affects the processes of interception, infiltration, surface storage, and runoff. As vegetation decreases and built-up areas expand, the proportion of rainfall converted into surface runoff tends to increase. This condition is reflected in an increase in the runoff coefficient and can consequently increase peak river discharge (Suripin 2004; Triatmodjo 2008).

The Dendeng Watershed is one of the main watersheds in Kupang City and plays a strategic role in the urban hydrological system. The Dendeng River not only conveys runoff from upstream to downstream areas but is also utilized as a raw water source through the SPAM Kali Dendeng water supply system. Accordingly, changes in the hydrological condition of the watershed have direct implications for both flood control and water-resource management.

Kupang City has a semi-arid climate characterized by a relatively short rainy season. High-intensity rainfall over short durations has the potential to generate substantial runoff, particularly when it occurs in a watershed experiencing an increase in impervious surfaces. During the 2014–2024 period, urban development within the Dendeng Watershed is presumed to have triggered substantial changes in land use.

Previous studies conducted in various watersheds in Indonesia have demonstrated that changes in land cover affect increases in flood discharge. Wisanggeni et al. (2024) demonstrated that land-cover changes in the Central Government Core Area of IKN increased flood discharge, whereas Ocktaviani, Badrun, and Cangara (2025) identified increases in runoff coefficients and flood discharge in the Saddang Watershed. However, the characteristics of the Dendeng Watershed, which is situated in a semi-arid region and is undergoing urban development, require a specific evaluation based on local conditions.

Based on these considerations, this study aims to: (1) identify and analyze land-use changes in the Dendeng Watershed in 2014 and 2024; and (2) analyze the effects of land-use changes on the runoff coefficient and flood discharge. The results of this study are expected to provide input for spatial-use control, watershed conservation, and flood-control planning in Kupang City.

RESEARCH METHODS

The study was conducted in the Dendeng Watershed, Kupang City, East Nusa Tenggara. The study integrates spatial and hydrological analyses. QGIS was used to obtain land-use information and the area of each land-use class, whereas hydrological analysis was conducted to determine design rainfall, rainfall intensity, effective rainfall, and flood discharge using the Nakayasu SUH.

Figure 1. Location of the Dendeng Watershed study area

The data used consisted of maximum daily rainfall data for the 2005–2024 period from El Tari Meteorological Station and Kupang Class II Climatological Station, physical characteristics of the watershed, and Landsat 8 imagery representing conditions in 2014 and 2024. The rainfall data were divided into two groups, namely Period I (2005–2014) and Period II (2015–2024), to examine changes in hydrological characteristics between the two periods.

Areal rainfall analysis was conducted using the arithmetic method. Statistical parameters were calculated to determine the appropriate probability distribution. The Normal, Log-Normal, Log-Pearson Type III, and Gumbel distributions were evaluated, after which their goodness of fit was assessed using the Chi-Square and Smirnov–Kolmogorov tests. The resulting design rainfall was subsequently converted into rainfall intensity using the Mononobe equation.

The composite runoff coefficient was calculated based on the area composition and coefficient values of each land-use type, using the general formulation Cgab = Σ(CiAi)/ΣAi. Changes in the C value between 2014 and 2024 were used to identify changes in the watershed's capacity to infiltrate rainfall.

Flood discharge was analyzed using the Nakayasu SUH. The parameters calculated included lag time (tg), effective rainfall duration (tr), time to peak (Tp), hydrograph parameters, recession time T_{0.3}, peak discharge Qp, ordinates of the rising and falling limbs, river-network density, and baseflow. To minimize the dominance of rainfall variability, the study also applied cross-simulation of rainfall data between the two analysis periods so that changes in discharge could be evaluated in relation to changes in land use.

RESULTS AND DISCUSSION

Land-Use change

Image interpretation indicates a substantial change in the composition of land utilization over the course of one decade. The areas of vegetation and agriculture decreased, whereas built-up areas and open land increased. These changes demonstrate a shift in surface functions from areas that are relatively capable of retaining and infiltrating water toward areas with lower infiltration capacity.

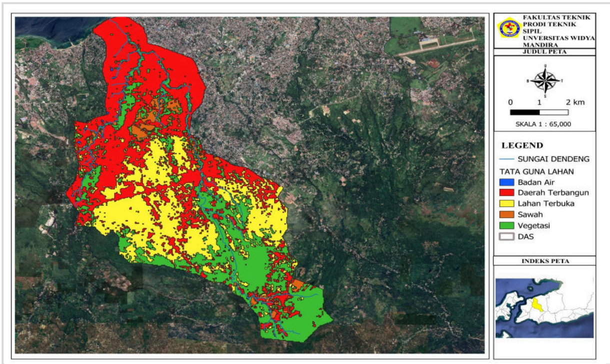

Figure 2. Land-use map of the Dendeng Watershed in 2014

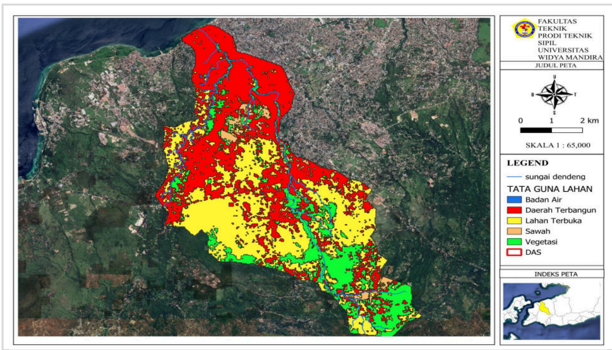

Figure 3. Land-use map of the Dendeng Watershed in 2024

Table 1. Land-use changes in the Dendeng Watershed, 2014–2024

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Land Type	2014 (km^2)	2024 (km^2)	Change (km^2)	Change (%)
Agriculture	1.99	1.73	-0.26	-13.07
Water Bodies	0.05	0.06	+0.01	+20.00
Vegetation	12.67	8.02	-4.65	-36.70
Built-up Areas	20.46	21.00	+0.54	+2.64
Open Land	12.35	16.71	+4.36	+35.30

Vegetation decreased by 4.65 km^2, or 36.70%, from its 2014 condition. This represents the largest change in terms of areas that function to support infiltration and water retention. At the same time, open land increased by 4.36 km^2, or 35.30%, while built-up areas increased by 0.54 km^2, or 2.64%. The expansion of built-up areas increases the extent of surfaces that are difficult for water to penetrate, while the increase in open land can accelerate surface runoff formation when soil conditions are compacted or vegetation is sparse.

Changes in the Runoff Coefficient

The calculation results indicate that the composite runoff coefficient of the Dendeng Watershed increased from 0.357 in 2014 to 0.377 in 2024. The increase of 0.020, or approximately 5.60%, indicates that a greater proportion of rainfall is being converted into surface runoff. Physically, this change is consistent with the decline in vegetation and the expansion of built-up areas and open land.

A C value of 0.377 conceptually indicates that approximately 37.7% of effective rainfall has the potential to contribute to surface runoff, consistent with the assumptions of the runoff coefficient employed. The remainder undergoes infiltration, interception, evaporation, or temporary storage within the watershed. The change in the C value is an important indicator because this parameter directly enters the determination of effective rainfall and subsequently affects flood discharge.

Nakayasu SUH and peak discharge

Under the 2014 land-use conditions, the peak discharge obtained from the Nakayasu SUH was 1.452 m^3/s. After the runoff coefficient changed in accordance with the 2024 conditions, the peak discharge increased to 1.531 m^3/s. The increase of approximately 5.44% indicates that the watershed response became faster and greater to the same or comparable rainfall event.

Table 2. Changes in key hydrological indicators

Indicator	2014	2024	Change
Runoff coefficient	0.357	0.377	+5.60%
Qp Nakayasu SUH (m^3/s)	1.452	1.531	+5.44%
Q25 (m^3/s)	41.007	60.416	+47.328%
Q100 (m^3/s)	52.791	83.438	+58.055%

Effects on design flood discharge

Land-use changes have a greater impact when analyzed in terms of design flood discharge. For the 25-year return period, discharge increased from 41.007 m^3/s to 60.416 m^3/s, or 47.328%. For the 100-year return period, discharge increased from 52.791 m^3/s to 83.438 m^3/s, or 58.055%. These increases demonstrate that changes in the surface characteristics of a watershed can amplify the consequences of extreme rainfall events.

The greater increase in design discharge compared with the increase in the runoff coefficient indicates that hydrological response results from the interaction of various parameters, including rainfall distribution, effective rainfall, hydrograph shape, time to peak, and baseflow. Therefore, interpreting the effects of land-use change cannot rely solely on changes in land area but must be related to the entire process of transforming rainfall into runoff.

These findings are consistent with studies conducted in other watersheds, which have reported that the conversion of vegetated land into built-up areas increases runoff and flood discharge (Wisanggeni et al. 2024; Ocktaviani, Badrun, and Cangara 2025). However, in the Dendeng Watershed, this effect is particularly important because Kupang City is located in a semi-arid region: short rainy periods can generate intensive rainfall events, while urban growth reduces opportunities for infiltration within the limited available time.

Implications Of the study findings

The findings of this study have implications for watershed management and spatial planning in Kupang City. First, the remaining vegetated areas need to be preserved, particularly in portions of the watershed that function as recharge areas. A 36.70% decline in vegetation over one decade demonstrates the need to control land conversion and rehabilitate areas that have already experienced degradation.

Second, the expansion of built-up areas should be accompanied by the implementation of environmentally oriented drainage concepts. Infiltration wells, detention/retention ponds, green open spaces, permeable pavements, and runoff control at the site scale can be employed to maintain the infiltration functions lost as a result of development. This strategy is relevant because the increase in the runoff coefficient has been demonstrated to coincide with an increase in peak discharge.

Third, the design-discharge results indicate the need to evaluate the capacity of rivers and drainage systems in flood-prone locations, particularly if land-use changes continue. Integrating spatial-planning data with hydrological and hydraulic models will assist in establishing priority mitigation zones and determining the infrastructure requirements for flood control.

Fourth, the presence of the SPAM Kali Dendeng as a raw water source requires watershed management to consider water quantity and quality simultaneously. Conservation efforts in upstream areas will not only be beneficial for reducing peak runoff but will also help maintain recharge functions and the sustainability of water resources.

CONCLUSION

Land-use changes in the Dendeng Watershed during 2014–2024 were characterized by a decrease in agricultural land from 1.99 km² to 1.73 km² and vegetation from 12.67 km² to 8.02 km², whereas built-up areas increased from 20.46 km² to 21.00 km² and open land increased from 12.35 km² to 16.71 km². These changes reduced the surface infiltration function of the watershed.

The composite runoff coefficient increased from 0.357 to 0.377, and the peak discharge of the Nakayasu SUH increased from 1.452 m³/s to 1.531 m³/s. Design flood discharge also increased substantially, with Q25 increasing from 41.007 m³/s to 60.416 m³/s and Q100 increasing from 52.791 m³/s to 83.438 m³/s. Thus, land-use changes were demonstrated to contribute to an increase in the runoff response and flood discharge of the Dendeng Watershed.

Spatial-use control, protection of recharge areas, vegetation rehabilitation, and the implementation of environmentally oriented drainage should form part of the flood-mitigation strategy in Kupang City. Future research is recommended to employ higher-resolution imagery, longer hydrological data series, as well as distributed hydrological models and two-dimensional hydraulic simulations to map inundation depth and extent in greater detail.

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