

Analysis of water regulating ecosystem services in the Upper Ciliwung Watershed from 2015 to 2025 based on vegetation index, morphometric characteristics, and soil properties

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ABSTRACT

The Upper Ciliwung Watershed (DAS) plays a crucial role in regulating water management for downstream areas, particularly flood-prone Jakarta. Population growth in the Greater Jakarta agglomeration and land conversion in the Puncak area have eroded the watershed's ability to perform its water-regulating ecosystem services. This study aims to (1) assess and map the water-regulating ecosystem services (JEPA) of the Upper Ciliwung Watershed in 2015 and 2025, and (2) evaluate the dynamics and formulate management recommendations for flood mitigation. The JEPA assessment was conducted using the Multi-Criteria Evaluation (MCE) method for four parameters: slope gradient, topographic wetness index (TWI), vegetation index (NDVI), and soil depth. This study used 30 m resolution SRTM data, Landsat 8/9 imagery acquired in 2015 and 2025, and BBSDLP soil maps at a scale of 1:50,000. Spatial analysis was performed using ArcGIS Desktop 10.8 software, and reclassification results were obtained using the Natural Breaks method. The results showed that over a decade, JEPA degradation occurred in the Upper Ciliwung Watershed, characterized by an increase in the area of low class from 12,493.90 ha (81.94%) in 2015 to 13,630.20 ha (89.39%) in 2025, while the medium class decreased from 2,644.38 ha to 1,598.94 ha, and the high class decreased from 109.17 ha to 18.31 ha. This degradation indicates a decrease in the watershed's capacity to retain and infiltrate rainwater, thereby increasing the risk of flooding in downstream areas. Management recommendations include greening open areas, implementing agroforestry on agricultural land, tightening spatial planning in residential areas in the Puncak region, and strengthening coordination across administrative regions based on the one river one plan approach.

Keywords: *NDVI; TWI; Upper Ciliwung Watershed; watershed morphometry; water regulating ecosystem services*

INTRODUCTION

A flood is an event where river water overflows from its natural channel into the surrounding area, caused by an increase in discharge that exceeds the river channel's capacity. This increase in discharge can be caused by high rainfall over a certain period or by the breach of a dam in the upstream area, which can cause flash floods. Naturally, a river basin (DAS) is a hydrological system that regulates water from upstream to downstream through an outlet, making the DAS approach highly relevant for flood studies (Asdak, 2018). Floods generally occur in the downstream area of a watershed due to the increasing accumulation of water from various tributaries above it, while the downstream area geomorphologically has a relatively flat relief with a shallower river valley depth, thus increasing the chance of flooding. Therefore, watershed management from upstream to downstream is a strategic issue in flood disaster mitigation (Istiadi & Priatna, 2021).

One of the cities in Indonesia that frequently experiences flooding is Jakarta. As the largest urban area in Indonesia, this metropolitan city is located in the downstream area of the Ciliwung River Basin. Flooding

in Jakarta can be caused by local rainfall, flash flooding from upstream areas, or a combination of both (Harsoyo, 2013). Flooding caused by local rainfall is largely related to high rainfall over the city area and limited urban drainage capacity, while flash flooding is largely determined by rainfall conditions in the upstream area of the Ciliwung River Basin, especially by the condition of water-regulating ecosystem services (JEPA). Through these ecosystem services, rainfall can be controlled so that not all rainfall becomes surface runoff, but rather a large portion is infiltrated into the soil and retained on the land surface. Various studies have shown that the condition of the Upper Ciliwung River Basin ecosystem has changed and degraded over time due to the high rate of land conversion (Arifasihati & Kaswanto, 2016; Handayani & Asyary, 2019; Fitri, 2020). This condition is primarily triggered by demographic pressure from the Greater Jakarta area in utilizing existing land resources in the Upper Ciliwung River Basin (BPDAS Citarum-Ciliwung, 2013). In order to support flood disaster control in Jakarta, JEPA studies in upstream areas are very necessary, especially to determine their conditions and observe development trends over time.

Ecosystem services or environmental services are benefits provided by nature or the environment to meet human needs (MEA, 2005; Government of the Republic of Indonesia, 2009). According to the Millennium Ecosystem Assessment (MEA), ecosystem services are divided into four categories: provisioning services such as food, water, and timber; regulating services such as climate regulation, flood control, and water regulation; cultural services such as recreation and spiritual values; and supporting services such as soil formation and nutrient cycling (MEA, 2005; Costanza et al., 2017; Monk & Priatna, 2022; Priatna et al., 2025). In relation to flooding, the condition of the JEPA in the upstream watershed area is very important to monitor from time to time so that disaster mitigation can be carried out in a measurable and targeted manner. This study will examine the trend of JEPA in the Upper Ciliwung Watershed during the period 2015–2025.

Greater Jakarta (Jabodetabek) is the most densely populated metropolitan area in Indonesia. In 2015, the population of the Greater Jakarta metropolitan area was estimated at around 29 million, increasing to around 33 million by 2025. Meanwhile, the population of Jakarta, the center of metropolitan activity, increased from around 10.18 million to 11.01 million during the same period (BPS, 2017; BPS, 2021; Dukcapil, 2025). Given that humans require space for their activities while land area remains stagnant, pressure for land-use change increases with the rate of population growth. This land-use change occurs not only in lowland areas but also in hilly and mountainous areas, particularly for tourism development (Dewi & Muhtar, 2025). The Puncak area in Bogor Regency, located in the Upper Ciliwung River Basin, is a major target for Jakarta tourists due to its relatively close distance (less than 100 km) and good accessibility, resulting in a very high rate of land conversion from forest and agriculture to built-up land (Saridewi et al., 2014).

The upstream watershed is functionally a rain catchment area (Asdak, 2018), so this area should largely be a protected area. By fulfilling its function as a protected area, the upstream watershed function can be achieved because the degradation of existing ecosystem services can be minimized. Furthermore, the Upper Ciliwung Watershed area is geomorphologically formed by volcanic processes, so the material that makes up this area is rich in pyroclastic material resulting from past volcanic eruptions that is porous. Such material is rich in minerals and can infiltrate rainwater well. Forest vegetation in this area can also withstand rainfall through its canopy density, including litter that accumulates on the soil surface and continues to increase in thickness over time. The nature of the ecosystem that facilitates water infiltration and retention is an important factor in the JEPA assessment. Considering that conditions in the Puncak area have experienced rapid land use changes

(Arifasihati & Kaswanto, 2016), this JEPA study is very necessary for monitoring, mitigation planning, and evaluation of spatial planning so that landslides in the upstream area and flooding in the downstream area can be minimized as much as possible.

This study aims to (1) assess and map the JEPA of the Upper Ciliwung Watershed in 2015 and 2025, and (2) evaluate the condition of the ecosystem services of the Upper Ciliwung Watershed and formulate management recommendations, especially for flood disaster mitigation in the downstream area.

METHODS

Research Location

The research was conducted in the Upper Ciliwung Watershed, which is administratively located in Bogor Regency, West Java Province, covering parts of the Cisarua, Megamendung, and Ciawi sub-districts, and part of Bogor City. Geographically, the Upper Ciliwung Watershed is located at coordinates $106^{\circ}50' - 107^{\circ}00'$ East and $6^{\circ}35' - 6^{\circ}47'$ South, with elevations ranging from 250 m to approximately 3,000 m above sea level, with the highest peak being Mount Pangrango. The research area covers an area of 15,247.45 ha, with an outlet at the Katulampa Dam (Figure 1).

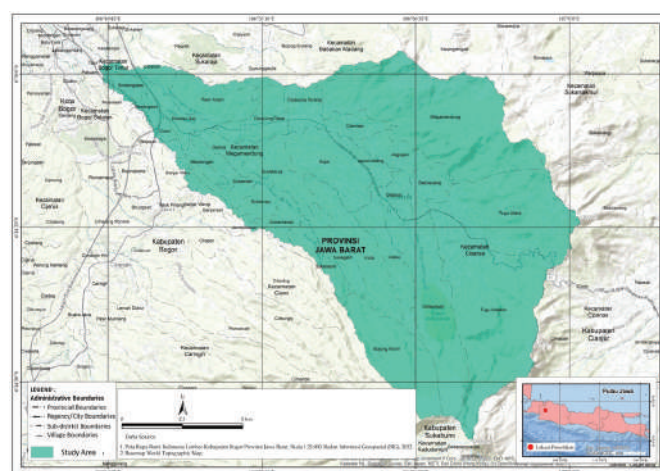


Figure 1. Research the location of the Upper Ciliwung Watershed.

Data Sources and Analysis

Data analysis was conducted to achieve the research objectives using several primary data sources, namely 30-m-resolution SRTM data and Landsat satellite data downloaded from the portal <https://earthexplorer.usgs.gov/>. Landsat data were collected at two points in the year: acquisitions in September 2015 (Landsat 8 OLI) and September 2025 (Landsat 8/9 OLI). September was selected based on the minimal cloud cover during the dry season in West Java. Additional data used were 1:50,000-scale soil depth

maps sourced from the Center for Agricultural Land Resources Research and Development (BBSDL P).

Morphometric analysis was performed from the SRTM data to generate slope parameters and a topographic wetness index (TWI). The Landsat data generated a vegetation index (NDVI). These four parameters were then used to assess the JEPA of the Upper Ciliwung Watershed using ArcGIS Desktop version 10.8 software.

Slope Gradient

Slope gradient is a value that describes the ratio of the difference in height between two points to their horizontal distance. In this case, slope gradient is closely related to water regulation, especially water from rainfall. The lower the slope gradient, the less likely it is to allow water to drain. This means that gentle slopes can hold or retain water so that it does not flow to lower levels quickly, allowing it to infiltrate the ground. Therefore, their function as water regulators is crucial. Slope gradient units can be in degrees, percentages, or radians; in this study, radians were used.

Topographic Wetness Index (TWI)

The Topographic Wetness Index (TWI) is a quantitative method based on geographic information systems (GIS) to map the potential for water accumulation and soil moisture based on the morphometry or morphology of the land surface. The lower the TWI value, the less likely the land surface is to retain water for infiltration into the soil. The TWI value can be derived from DEM data using the following formula developed by Kopecky, Macek & Wild (2021):

$$TWI = \ln(a / \tan \beta)$$

Where:

$\ln$ = natural logarithm.

a = specific catchment area (inflow area at the top of the slope per unit contour length).

β = slope angle in radians.

Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a vegetation index that can be derived from optical remote sensing data such as Landsat. This index is a mathematical combination of satellite imagery channels (generally in the red and near-infrared (NIR) spectral bands) used to analyze and measure vegetation density, health, and greenness. This technique distinguishes vegetation from other objects (land/water), making it highly useful for environmental, agricultural, and drought monitoring.

One commonly used vegetation index is the NDVI, developed by Rouse et al. (1974). In relation to rainwater management, a higher NDVI value indicates a higher

vegetation density, meaning greater retention capacity, whether through leaves, twigs, branches, or litter produced on the soil surface. The resulting root system enriches the soil pores, thereby increasing water infiltration into the soil. NDVI is formulated as follows:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} = \frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)}$$

Note: Band 5 = near infrared (NIR) channel on Landsat 8/9 OLI; Band 4 = red channel on Landsat 8/9 OLI. NDVI values range from -1 to $+1$, with values closer to $+1$ indicating high vegetation density.

Soil Depth

Soil is a material resulting from the weathering of rocks and organic matter over a long period of time. Theoretically, soil formed from the same parent material will have the same basic characteristics. The Upper Ciliwung Watershed, the study area, shares a similar morphogenesis: it was formed by volcanic processes, resulting in the primary constituent material consisting of lava and pyroclastic flows, primarily originating from Mount Pangrango. However, the depth of the soil varies considerably depending on topographic conditions, particularly slope gradient.

Related to JEPA analysis, soil depth is a crucial factor because it reflects the soil's capacity to receive infiltrated water. The deeper the soil, the greater its capacity to transmit water, thus reducing the formation of overland flow (or runoff). In this study, soil depth data were taken from the BBSDL P and categorized into three categories: shallow, deep, and very deep. For the JEPA analysis, the shallow category was given a score of 1, the deep category a score of 2, and the very deep category a score of 3.

Water Regulation Ecosystem Services (JEPA)

In this study, ecosystem services were assessed using the Multi-Criteria Evaluation (MCE) method, where each parameter is weighted equally (equal weighting), while the score is determined based on the value of each pixel. Thus, JEPA is the sum of the weights and scores of each parameter, consisting of the vegetation index (NDVI), slope gradient, topographic moisture index (TWI), and soil depth. The JEPA formula is as follows:

$$JEPA = (w \times sV) + (w \times sS) + (w \times sT) + (w \times sD)$$

Where:

JEPA = water regulation ecosystem services.

w = weight of each parameter (assuming equal weighting).

s = parameter score.

V = vegetation index (NDVI).

S = slope gradient.

T = TWI.

D = soil depth.

The obtained JEPA values were then reclassified into three classes, namely low, medium, and high, using the Natural Breaks (Jenks) method as available in ArcGIS Desktop 10.8 software. This method was chosen because it can identify the most natural dividing value based on the data distribution, so that the classification reflects the statistical structure of the data objectively (Jenks, 1967).

Evaluation and Recommendations

The evaluation of the JEPA assessment results was conducted through an analysis of changes in the JEPA class area between 2015 and 2025. Recommendations were developed based on the impact of changes in the JEPA area on flood mitigation capacity in the Upper Ciliwung Watershed and its downstream areas.

RESULTS AND DISCUSSION

The water regulation ecosystem service (JEPA) in this study was influenced by four parameters: slope gradient, topographic wetness index (TWI), vegetation index (NDVI), and soil depth. To evaluate the dynamics and trends of ecosystem services over time, a comparison was made between the 2015 and 2025 JEPA. The conditions of these four parameters in the study area are described below.

Slope Gradient

The slope gradient of the study area is depicted in Figure 2, which is the result of an analysis of 30-m-resolution SRTM DEM data. Slope gradients are displayed in grayscale with radian units. White represents areas with steep or steep slopes, while black represents areas with shallow to gentle slopes. Based on the distribution pattern of these hues, the watershed boundaries in the north, east, and south are dominated by steep slopes, reflecting hilly and mountainous landforms with higher elevations.

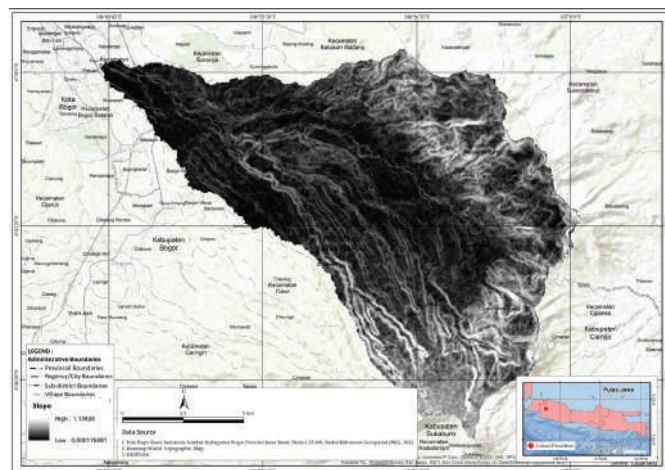


Figure 2. Map of the slope gradient of the Upper Ciliwung Watershed.

Meanwhile, the central area features darker hues, reflecting relatively flat areas with lower elevations. Overall, the basinal shape (watershed) of the study area is clearly defined, with river flow oriented toward the western outlet. This slope distribution pattern is a key determinant of water management, as steep slopes tend to accelerate surface runoff, while gentle slopes allow water to infiltrate the ground (Yuswandi et al., 2024).

Topographic Wetness Index (TWI)

A topographic moisture analysis, or TWI (Topographic Wetness Index), was performed using 30-m-resolution SRTM DEM data, and the results are presented in Figure 3. White reflects high TWI values, indicating a high capacity to accumulate, retain, and infiltrate rainwater falling on the land surface. Black, on the other hand, reflects a low capacity of the land surface to accumulate and infiltrate water.

The TWI pattern shows that the distribution of high TWI values follows the pattern of river valleys or concave land surfaces, as well as flat slopes at relatively lower elevations than the surrounding terrain. Meanwhile, areas with darker hues are located on hill ridges or areas with very steep to steep slopes. This distribution pattern indicates that water accumulation capacity in the Upper Ciliwung Watershed is concentrated along the drainage network and lowlands, consistent with the theory of Beven and Kirkby (1979) regarding the spatial distribution of soil moisture based on topography.

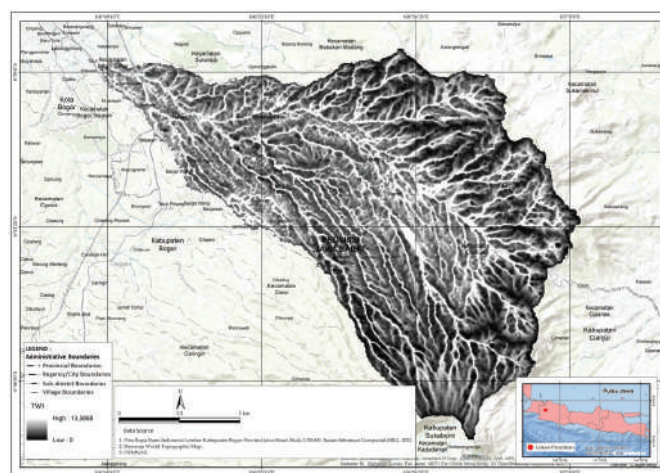


Figure 3. Topographic Wetness Index (TWI) map of the Upper Ciliwung Watershed.

Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI), derived from Landsat 8/9 data (30 m resolution), was taken from two time points in 2015 and 2025 to examine trends in change over a decade. These changes reflect the extent to which human activities have impacted ecosystems and the services they provide to humans,

including the resulting natural hazards, particularly flooding in downstream areas.

The Landsat imagery used to assess the NDVI was acquired in September 2015 and September 2025, with minimal cloud cover and shading during the dry season. Areas covered by clouds and shading were not analyzed for NDVI, so the effective area used to assess ecosystem services is slightly smaller than the watershed area.

From the NDVI analysis, black reflects low values or low vegetation density, while white reflects high values. Low values appear to dominate the study area in both 2015 and 2025, while high values occupy a smaller area around the hilly areas (Figure 4). The pattern of decreasing vegetation density between 2015 and 2025 indicates land use change, particularly from forest and garden vegetation to built-up areas and intensive agricultural land. This finding aligns with several previous studies reporting a trend of green land conversion in the Puncak region (Arifasihati, Y., & Kaswanto, 2016).

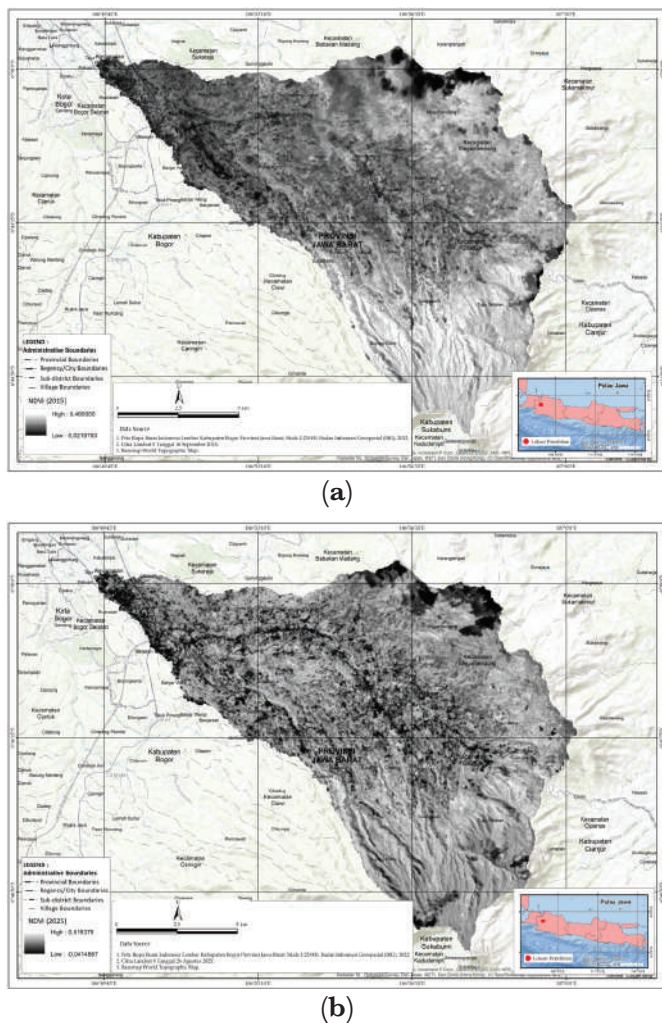


Figure 4. NDVI conditions in the Upper Ciliwung Watershed (a) in 2015 and (b) in 2025.

Soil Depth

As a rainwater catchment area, the Upper Ciliwung Watershed (DAS) is largely located on the lower slopes of Mount Pangrango. This type of volcano is a stratovolcano, like other volcanoes along tectonic plate boundaries. This type of volcano is rich in pyroclastic material consisting of ash, sand, and gravel interspersed with lava flows. This volcanic material forms the soil in the study area. The resulting soil type is generally porous, meaning it has a high capacity to transmit rainwater through infiltration and percolation. Therefore, springs often emerge on the middle and lower slopes of this type of volcano, flowing to the surface. The thicker the soil layer, the greater its capacity to store groundwater.

The distribution of soil depth based on a 1:50,000 scale soil map from BBSDLP shows that the depth pattern follows the landform within the watershed. In hilly areas with steep to very steep slopes, soil depth tends to be shallow, while in relatively flat lower areas, soil depth tends to be deeper. This is in accordance with the geomorphic processes that occur in the watershed, namely the dominant erosion process in the upper area (upland) and the dominant deposition process in the lower area (lowland) (Figure 5).

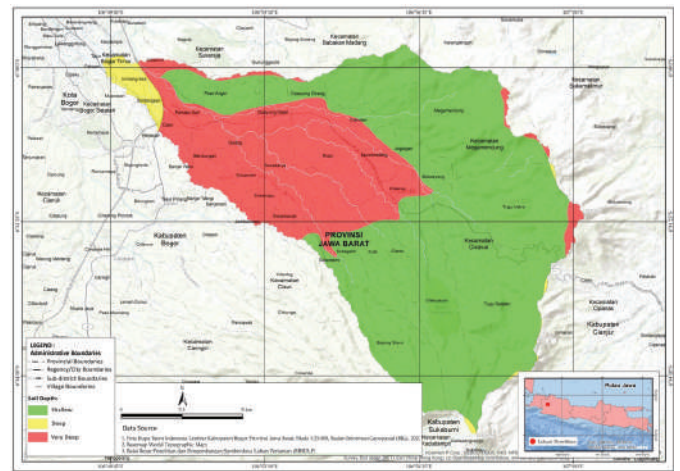


Figure 5. Soil depth map in the Upper Ciliwung Watershed.

Water Regulation Ecosystem Services (JEPA) in 2015

Based on the parameter conditions in the Upper Ciliwung Watershed as mentioned above and the JEPA formulation explained in the Research Methods Chapter, a spatial depiction of the 2015 JEPA was obtained, as presented in Figure 6. In this figure, ecosystem service values are discretely classified into low, medium, and high classes.

Figure 6 shows that low-class ecosystem services were predominantly distributed on lower slopes in 2015, with some in the northern part. Medium-class ecosystem services were distributed primarily in the southern part or in hilly areas, and high-class ecosystem services were

also distributed, although with the smallest area. The distribution of these JEPA classes can be seen in Table 1.

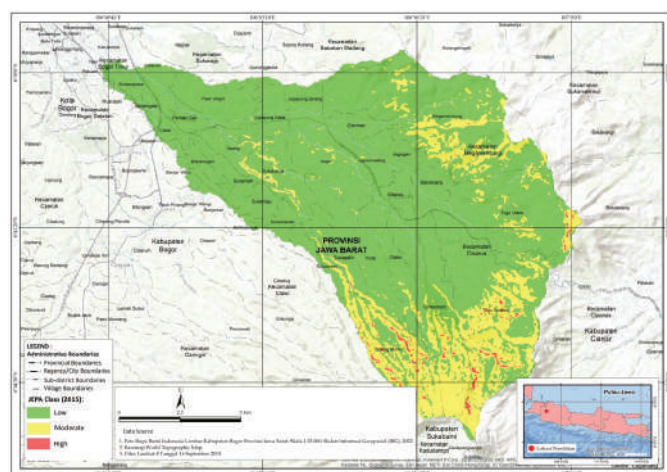


Figure 6. Condition of Water Regulating Ecosystem Services (JEPA) in the Upper Ciliung Watershed in 2015.

Table 1. Area of JEPA class in the Upper Ciliung Watershed in 2015.

JEPA Class	Area (ha)	Percentage (%)
Low	12,493.90	81.94
Medium	2,644.38	17.34
High	109.17	0.72
Total	15,247.45	100.00

Water Regulation Ecosystem Services (JEPA) in 2025

The JEPA in 2025 was assessed to determine the actual condition because ecosystem services can change over time according to the dynamics of changes in their parameters. In this case, some parameters are relatively permanent or can change over very long periods of time, namely topographic parameters such as slope gradient and topographic wetness index (TWI), as well as soil depth. Conversely, highly dynamic parameters are land cover and use, which are driven by human activities. In this study, land cover/use is represented by vegetation density through the vegetation index (NDVI).

Vegetation was chosen to represent land cover and use because of its important role in water regulation. It can retain rainwater that falls on the earth's surface (retention), either through the canopy or through litter accumulated under trees or on the ground surface. This prevents rainwater from immediately becoming surface runoff but is retained and slowly infiltrates the soil. Furthermore, vegetation also plays a role in increasing infiltration capacity through its root growth and activity. The distribution pattern of ecosystem service classes in 2025 is similar to that in 2015, but their extent appears to have changed, with many medium-class ecosystem services located on the southern side having shifted to

low-class (Figure 7). The extent of each class can be seen in Table 2.

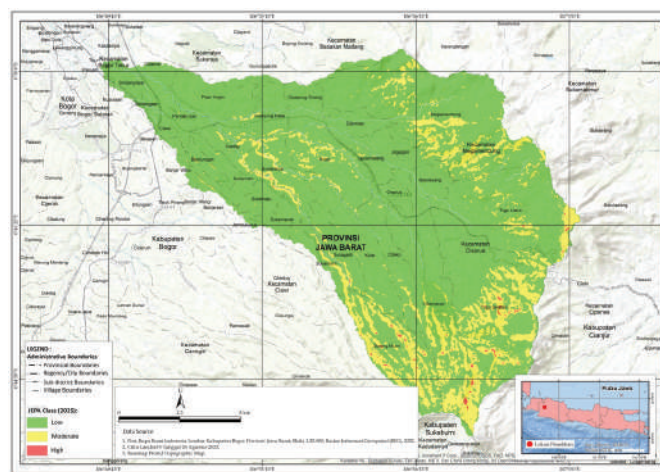


Figure 7. Condition of Water Regulating Ecosystem Services (JEPA) of the Upper Ciliung Watershed in 2025.

Table 2. Area of JEPA class of the Upper Ciliung Watershed in 2025.

JEPA Class	Area (ha)	Percentage (%)
Low	13,630.20	89.39
Medium	1,598.94	10.49
High	18.31	0.12
Total	15,247.45	100.00

Evaluation of Water Regulation Ecosystem Services 2015–2025

Based on Tables 1 and 2, it can be seen that the area of each ecosystem service class changed over the decade (2015–2025), with low classes tending to increase, while medium and high classes tended to decrease (Figure 8).

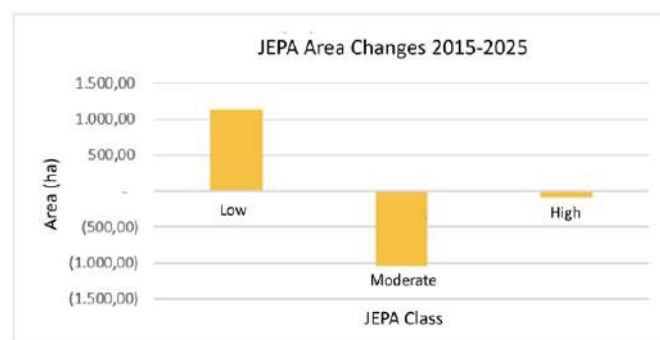


Figure 8. Changes in the area of JEPA in the Upper Ciliung Watershed 2015–2025.

Over the course of a decade, the area of low-grade JEPA in the Upper Ciliung Watershed increased by 1,136.30 ha, while the area of medium-grade and high-grade floodplain decreased by 1,045.44 ha and 90.86 ha, respectively. This indicates that the Upper Ciliung Watershed is experiencing degradation over time related to JEPA. This decline means that the volume

of rainfall falling within the watershed that infiltrates into the soil is decreasing, while the volume converted to surface runoff is increasing. The main threats from this phenomenon are flooding in downstream areas, in this case Jakarta and its surroundings, as well as the threat of soil erosion (critical land) and hydrological drought (drought), including reduced spring discharge if extreme climate change occurs in the middle and upper Ciliwung Watershed.

Over the past decade, major flooding in Jakarta linked to the overflowing Ciliwung River occurred in early 2020 and early 2025, with the Katulampa Dam reaching Alert Level 1 and causing significant flooding in several areas of Jakarta (BNPB, 2020; BNPB, 2025). This indicates that a watershed is a hydrological system interconnected between upstream, midstream, and downstream areas, requiring comprehensive watershed management from upstream to downstream. If a watershed is divided into different administrative regions, cooperation between these administrative regions is essential for disaster mitigation (Istiadi & Priatna, 2021), spatial planning, and policy coordination. Population growth in upstream areas and the increase in built-up land in the Puncak area are also contributing factors to the increase in low-grade JEPA (Handayani & Asyary, 2019; Saridewi et al., 2014).

Management Recommendations

Based on the trend of changes in JEPA values over the decade (2015–2025) in the Upper Ciliwung Watershed, several recommendations can be made for disaster mitigation, both for upstream and downstream areas. The main threat to downstream areas is flooding, which can endanger residents, especially in the densely built-up Jakarta area. The primary recommendation based on this analysis is to increase the NDVI value as an indicator of vegetation density. One way to increase the NDVI value is to reforest upstream areas, particularly in and around Puncak. Specific recommendations based on land use type and field observations are as follows.

Residential Areas: implementation of green open space (RTH) of a minimum of 30% of the plot area as mandated by Law Number 26 of 2007 concerning Spatial Planning, construction of infiltration wells and biopore holes in each household to increase rainwater infiltration, tightening of building permits (IMB) and a moratorium on the construction of new villas in the Puncak area as mandated by Presidential Regulation Number 60 of 2020 concerning the Jabodetabekpunjur Spatial Planning, as well as planting shade vegetation along roads and public spaces as part of green infrastructure.

Agricultural Land Areas: Implementation of agroforestry systems that combine staple crops with woody perennials such as coffee, avocado, or cloves to increase canopy density and soil infiltration capacity; implementation of soil and water conservation

techniques such as bench terraces, ridge terraces, and drainage channels on sloping land; utilization of organic mulch to reduce surface runoff and increase soil organic matter content; and implementation of organic or semi-organic farming to improve soil quality and water retention capacity.

Forest and Conservation Areas: Strengthening protection of the Mount Gede Pangrango National Park (TNGGP) and surrounding protected forest areas through routine patrols and law enforcement against encroachment; rehabilitation of forests and critical land through planting programs with local tree species with dense canopies and deep roots; and development of a payment for ecosystem services scheme involving upstream communities as managers or service providers and downstream water users as service payers.

Riparian Areas and River Boundaries: Establishing and enforcing river boundaries in accordance with Government Regulation Number 38 of 2011 concerning Rivers, which is a minimum of 5 meters from the left and right banks of embanked rivers for rivers in urban areas and 100 meters for large rivers outside urban areas; planting riparian vegetation with strong-rooted tree species such as bamboo and banyan to prevent riverbank erosion; and restoring degraded riparian ecosystems.

Institutional and Governance Aspects: Strengthening cross-administrative coordination between the Bogor Regency Government, the Jakarta Provincial Government, and relevant Ministries through a watershed forum facilitated by the Citarum-Ciliwung Watershed Management Center; implementing the one river, one plan principle in spatial planning and water resource management; integrating data and a remote sensing-based ecosystem service monitoring system periodically (at least every five years) as a basis for policy evaluation; and strengthening local community participation in watershed management based on local wisdom and a collaborative approach.

CONCLUSION

This study yielded two main findings. First, the water regulation ecosystem services (JEPA) of the Upper Ciliwung Watershed have been successfully assessed and mapped for 2015 and 2025 using the integration of four parameters through a Multi-Criteria Evaluation (MCE) approach: slope gradient, topographic moisture index (TWI), vegetation index (NDVI), and soil depth. In 2015, the JEPA was dominated by low-class land with an area of 12,493.90 ha (81.94%), followed by medium-class land with an area of 2,644.38 ha (17.34%), and high-class land with an area of 109.17 ha (0.72%). In 2025, the dominance of low-class land increases to 13,630.20 ha (89.39%), while the medium-class and high-class land decreases to 1,598.94 ha (10.49%) and 18.31 ha (0.12%).

Second, the evaluation results indicate the occurrence of JEPDA degradation in the Upper Ciliwung Watershed over a decade, marked by an increase in the area of low-class areas by 1,136.30 ha and a decrease in the area of medium and high classes by 1,045.44 ha and 90.86 ha, respectively. This degradation indicates a decline in the watershed's capacity to retain and infiltrate rainwater, which has implications for increasing the threat of flooding in downstream areas, especially Jakarta and its surroundings. Management recommendations include reforestation of residential areas with green open space and infiltration wells, implementation of agroforestry on agricultural land, strengthening protection of conservation areas, restoration of riparian vegetation, and strengthening cross-regional coordination based on the principle of one river, one plan. Further research is recommended to integrate climate parameters and distributed hydrological models to predict the hydrological response of the watershed to various management scenarios.

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