

## Conservation Zone Delimitation Based on Physical Properties in Langsa Watershed, Aceh Province

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### ABSTRACT

Watershed zoning is essential for regional development, specifically the conservation aspect. Langsa is a city in Aceh province that has no watershed zoning map as a basis for development. Therefore, this study aims to delimit the conservation area in the Langsa River Basin, Aceh Province, based on three factors, which include rainfall, slope, and vegetation density. The data used are Digital Elevation Models (DEM), Langsa City rainfall, and satellite imagery from Landsat 8 OLI TIRS. Furthermore, the data was obtained online from the website of Badan Informasi Geospasial also known as Geospatial Information Agency, the United States Geological Survey, and Badan Pusat Statistik or Central Bureau of Statistics. The data was processed using the Quantum GIS 3.16 application with scoring and weighted overlay. In this study, the Langsa watershed was divided into three areas, namely cultivation, buffer, and conservation. The cultivation area dominates the Langsa watershed with a sloping morphology, moderate rainfall, and moderate vegetation density. Also, the conservation area has a high morphology with high rainfall and vegetation density, while that of the buffer has characteristics that falls between the cultivation and conservation areas. Each zone namely cultivation, buffer, and conservation has respective areas of 63.75 km<sup>2</sup>, 4.84 km<sup>2</sup>, and 3.55 km<sup>2</sup> with different land use priorities. For example, the cultivation zones are prioritized for agricultural and urban areas. Buffer is separated for perennials, while conservation zones are for protected forests or national parks.

**Keywords** : Langsa Watershed; Conservation Area; Buffer Area; Cultivation Area

### 1. Introduction

River has a crucial role in meeting several human needs, such as household, environmental sanitation, agriculture, industry, tourism, sports, defense, fisheries, power generation, and transportation. Similarly, its influence on nature significantly determines the life of animals and plants (Leclerc & Grégoire, 2017; Wu, 2018; Xia & Dong, 2019). The tendency to exploit human livelihoods in watershed has resulted in a diminishing functioning of river ecosystems. This is characterized by physical changes in the watershed, such as narrowing, siltation, river pollution, and flood risk (Mutia et al., 2020; Roba et al., 2021; Sihombing et al., 2021). Over time, population growth has increased, which caused the watershed area to be densely populated by human activities, such as logging, public facilities, trade, and services (Nasrudin et al., 2019). An essential aspect in mapping watershed conservation is the assessment of river conditions and selecting the area based on the degree of damage using

technology. This study aimed to conserve the watershed as an effort to control and preserve the environment based on the function of each area, such as the upstream, middle, and downstream. The control and preservation aspects include protection, utilization, and maintenance of watershed ecosystems sustainably through technology.

According to [Bismark et al. \(2007\)](#), conservation activities are part of watershed management and depend on human behavior towards nature, beliefs, and the ability to protect wildlife without compromising the basic life necessities. The basic concept of conservation is to maintain the availability of natural resources. Therefore, watershed conservation is defined as an effort to preserve the environment, which includes protection, maintenance, and information regarding various efforts to save the ecosystem and its environment based on the roles and functions of each area. The purpose of watershed management is to control the connections and trade-offs between natural resources and the environment around the watershed, as well as human activities in order to preserve environmental functions and community welfare ([Setyowati, 2014](#)).

Langsa City has a river that stretches from the southwest to the northeast with about 6.9 km ([Mutia et al., 2020](#)), but its watershed area has not been accurately determined due to its natural conditions. Also, the Geospatial Information Agency called *Badan Informasi Geospasial* has not released a watershed map for this place. [Debie et al. \(2019\)](#) and [Wang et al. \(2018\)](#) found that the watershed is a very important ecosystem for water protection and related landscape problems for conservation. However, the lack of community knowledge and less stringent government regulations make it difficult to conduct further analysis of ecological zoning in this aspect ([Jiang et al., 2022](#); [Sihombing et al., 2021](#)). The Langsa watershed has become a serious concern for the government and educational institutions. This is reinforced by the turbid condition of the Langsa river water due to sedimentation, high erosion rates, and flood disasters that occur yearly ([Ardiansyah & Sumunar, 2020](#)). This makes [Sun et al. \(2020\)](#) conclude that detailed planning is required to create comprehensive management, such as zoning of watershed conservation areas in Langsa City. In this current study, the Langsa watershed area is divided into three zones, namely conservation, buffer, and cultivation. This helps to observe, analyze, and evaluate problems in the main areas that represent the origin of the flood disaster ([Sihombing et al., 2021](#)). It is important to note that these three zones are interconnected thereby making this study to be very critical and urgent. Consequently, this helped the government, NGOs, and educational institutions utilize the watershed conservation zone as a reference for ecological development in the Langsa watershed in order to solve problems related to clean water scarcity and flood disasters ([Roba et al., 2021](#)).

One of the studies on ecological area zoning was conducted by [Liu et al. \(2015\)](#), at the upstream and midstream of the Tarim River Basin in China. The study solved drought problems in the upper and middle Tarim Watershed using a comprehensive zoning method of ecosystem service functions with two categorical aspects, namely quantity and magnitude of change or quality. This helps to quantitatively analyze the spatial and temporal distribution of the four indicators, as well as the characteristics of increasing and decreasing spatial aggregation. Furthermore, the QGIS reclassification tool was employed to classify areas having more than two essential zones as high-quantity ecosystem services. This is consistent with [Jiang et al. \(2022\)](#) that proposed a network-based framework for ecological zoning taking Yunnan Province, China as a case study. The results showed five ecological zones, which include protection, enhancement, corridor construction, restoration, and non-ecological network.

From the studies mentioned above, no mapping has been performed in relation to the zoning of watershed ([Jothimani et al., 2022](#)). As such, this present study serves as a reference for further investigations on watershed conservation. According to [Funan et al. \(2022\)](#) and [Wang et al. \(2022\)](#), the Langsa watershed zoning map is very important as a follow-up to control land suitability for the three zones. [Indarto \(2020\)](#) identified that the importance of the watershed position as a comprehensive

planning unit is the basic requirement for maintaining a balance when using forest, land, and water resources. [Srinivas et al. \(2020\)](#) added that the lack of precise watershed management often exacerbates ecosystem degradation. This implies that comprehensive planning is needed to establish a management approach, specifically related to the zoning of conservation areas in the Langsa watershed. Therefore, this study aims to delimit the conservation area in the Langsa River Basin, Aceh Province.

## 2. Methods

This study was conducted in Langsa City, which is located on the east coast of Aceh province at positions 4°24'35" - 4°33'47" N and 97°53'14" - 98°04'42" E, with an area of 262.41 km<sup>2</sup> as shown in [Figure 1](#). To identify the Langsa watershed, an analysis was performed through the Digital Elevation Model (DEM) extraction ([Ali et al., 2020](#); [Ardiansyah & Sumunar, 2020](#)). [Figures 2 and 3](#) show the delimitation procedures for the Langsa watershed and its result, respectively. This procedure was conducted because no official map of the Langsa watershed was released by the government or other authorized institutions. In addition, watershed delimitation is very important to focus on areas useful for watershed-based regional development planning in Langsa City. The data used were obtained from the following sources:

- (1) The topographical Map of Indonesia was collected from the BIG website ([BIG, 2001](#)). This data was utilized for the delimitation of the Langsa watershed boundary.
- (2) The image of DEM Langsa City was obtained from the Geospatial Information Agency ([BIG, 2022](#)) also known as *Badan Informasi Geospasial* (BIG). This data was employed for creating the Langsa watershed boundary and its topographic map. It is important to note that DEM is processed using Strahler Order and Upslope Area analysis in the QGIS application in order to create the Langsa Watershed map. Consequently, high accuracy vector data was produced based on the morphology displayed by the DEM image using interpolation. In the analysis, rainfall data obtained from several weather stations were employed in order to produce an isohyet and rainfall distribution map.
- (3) Landsat 8 OLI TIRS image was obtained from the United States Geological Survey ([USGS, 2022](#)). [Table 1](#) shows the Landsat 8 image specifications data that was utilized for creating a vegetation density map for the Langsa watershed using Normalized Difference Vegetation Index (NDVI) analysis. Furthermore, the NDVI analyzes vegetation density based on visible and near-infrared sunlight reflected from plants. The map shows areas with high, medium, and low vegetation density ([Amiri & Pourghasemi, 2022](#)). Each level of vegetation density has a different index value, such as high vegetation density with a score of  $0.45 < \text{NDVI} < 0.58$ , medium of  $0.33 < \text{NDVI} < 0.45$ , and low with  $\text{NDVI} < 0.33$ .

Table 1. Specifications of Landsat 8 Imagery used in this study

No	Specifications
1	Location : Langsa City
2	Date Acquisition : January 30 <sup>th</sup> 2021
3	Cloud Cover : 20%
4	Spatial Resolution : 30 m
5	Temporal Resolution : 16-day repeat cycle

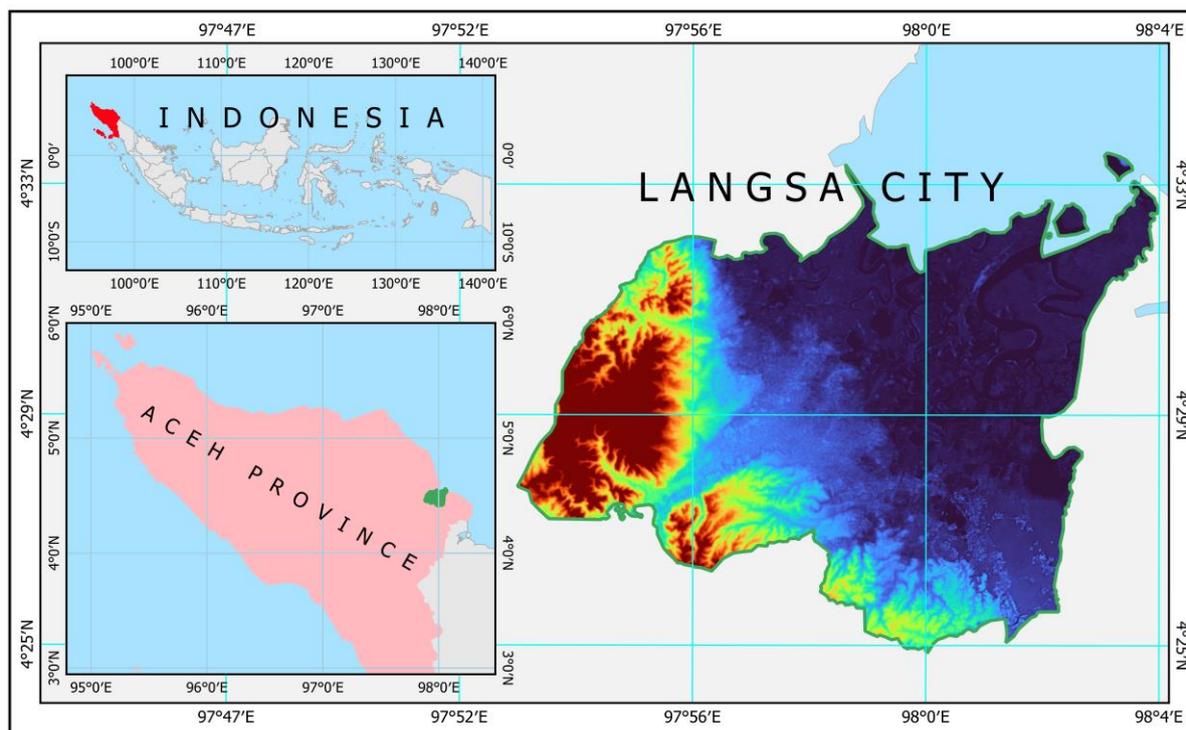


Figure 1. Study location in Langsa City, Aceh Province, Indonesia.

Data analysis was conducted using Quantum GIS (QGIS) 3.16 application with an open-source license. An assessment and weighted overlay technique were employed between three maps, namely rainfall, vegetation density, and slope (Asdak, 2020; Bismark et al., 2007; Suprayogi et al., 2015). It is important to note that these three maps were employed in the zoning system of this study location, and was tested with overlay techniques as well as area assessment using the QGIS application. Furthermore, they are categorized based on scores and weights analyzed using the overlay technique as shown in Table 1. The scores and weights are processed in order to divide the watershed into conservation (Lin et al., 2020), buffer (Bismark et al., 2007), and cultivation areas (Mello et al., 2021). Each region has different characteristics, for example, the conservation areas have very high human use limits, while the cultivation is used for settlement and agriculture. The buffer zone is a transitional area with intermediate characteristics between the conservation and cultivation areas.

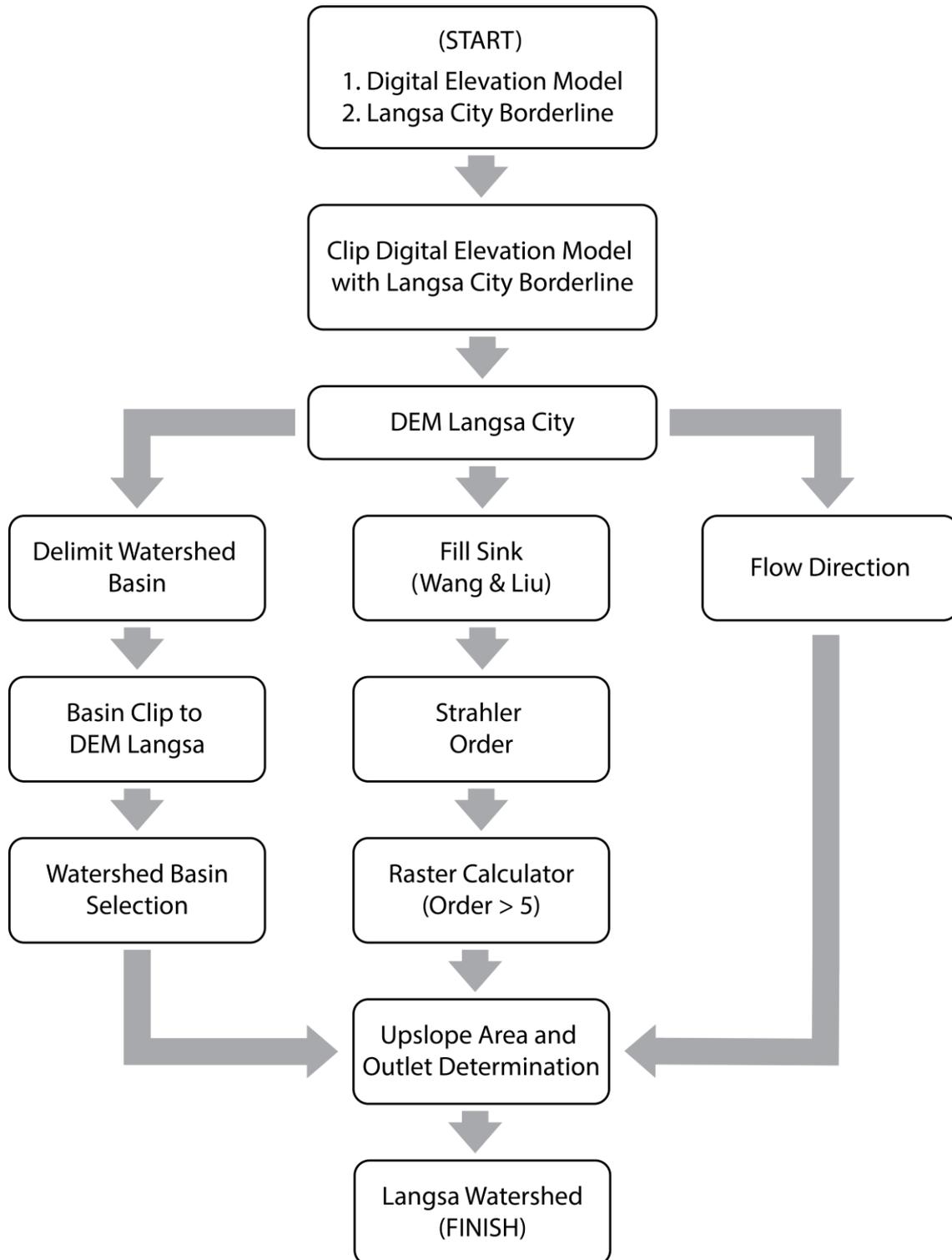


Figure 2. Langsa watershed delimitation procedure

Table 2. Score and weight for overlay technique

Category/Class	Score	Weight
<b>Slope</b>		
1. Flat	1	40%
2. Sloping	2	
3. Slightly Steep	3	
<b>Rainfall</b>		
1. Low	1	40%
2. High	4	
<b>Vegetation Density</b>		
1. High	1	20%
2. Medium	2	
3. Low	3	

Source: Suprayogi et al. (2015)

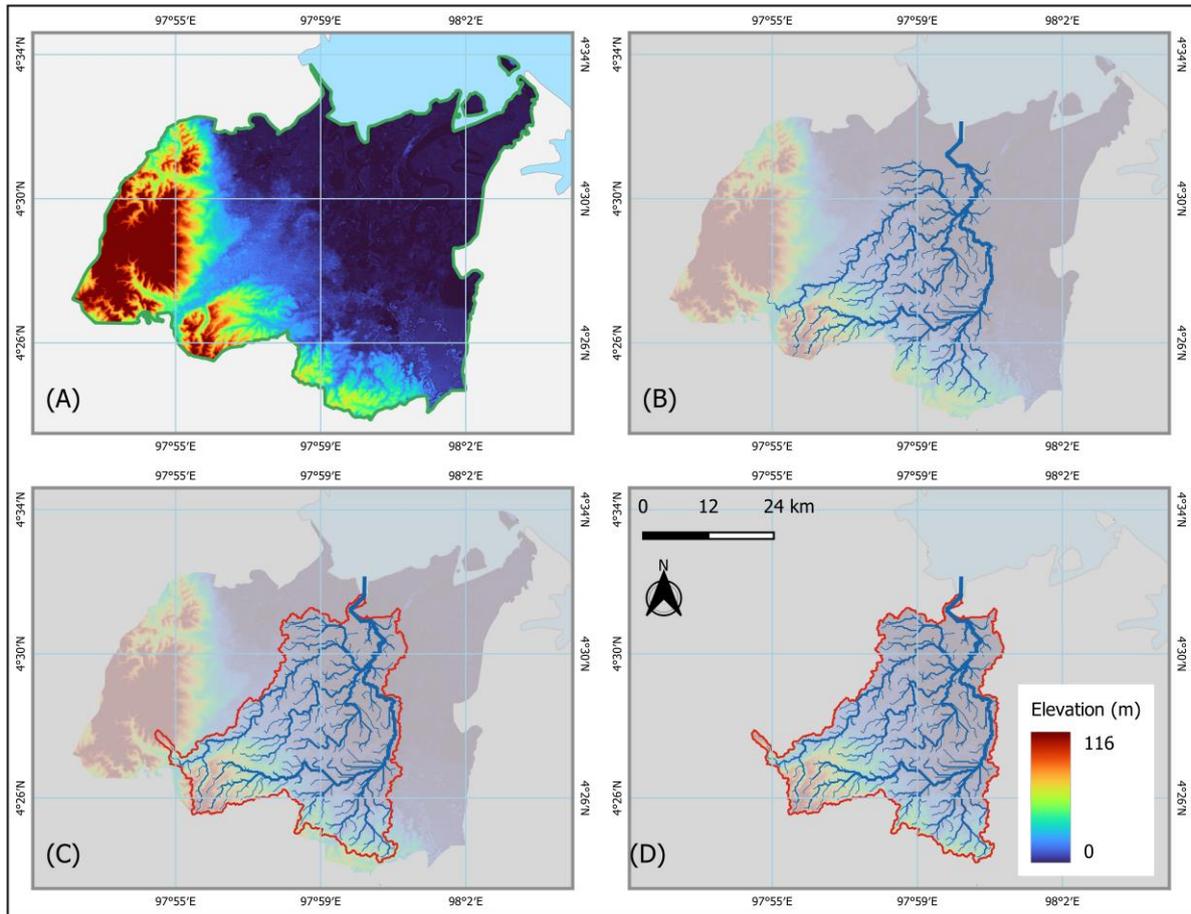


Figure 3. Langsa watershed delimitation from DEM Extraction through basin selection, fill sink (Wang and Liu) and flow direction analysis. (A) Clipped DEM by the administrative boundary of Langsa City; (B) Analysis of fill sink and flow direction to produce river nets; (C) Analysis of watershed basin yields watershed boundaries; (D) The final result of the analysis showed the periphery of the Langsa watershed.

### 3. Results and Discussion

It is important to reiterate that this study presents a conservation zoning map based on three parameters, namely slope, rainfall, and vegetation density. [Bharath et al. \(2021\)](#) observed that the slope of the river is an essential factor to investigate as it controls the water flow rate from upstream to downstream. Furthermore, the watershed's slope describes the elevation change level at a given distance along the main direction of the river. The results of data analysis from DEM images showed the slope's average value is 0-8%, indicating that the Langsa watershed's gradient is homogeneous. Moreover, in some areas, it is between 8-15% and 15-25%. It has been observed that slope is an essential factor to consider because it controls the flow rate of river water from upstream to downstream. This denotes that the watershed's slope is the level of elevation change at a certain distance along the main flow direction.

The Langsa watershed rainfall data obtained from the Central Statistics Agency (BPS) in 2021 was processed with the Quantum GIS 3.16 application in order to produce a rainfall distribution map using interpolation analysis. This is used for processing data points in areas on the rainfall map and the results showed that the highest average monthly rainfall was 339 mm/month, while the lowest was 113 mm/month. In addition, the highest rainfall distribution was recorded in the peak areas of the Langsa watershed. The place has high erosion intensity when it rains heavily throughout the day. Meanwhile, [Chen et al. \(2019\)](#) stated that low rainfall occurred in areas with sloping to flat topography, and are not affected by flooding even when it rains heavily all through the day.

The vegetation density level was determined by analyzing the NDVI, and the result showed the percentage of vegetation density, living plants or Leaf Area Index, the active radiation fraction for photosynthesis absorption, photosynthetic capacity, and the estimate of CO<sub>2</sub> absorption ([Jothimani et al., 2022](#); [Patowary & Sarma, 2018](#)). Furthermore, the vegetation density in the Langsa watershed is a plant area with good conditions, high leaf biomass, canopy, and high chlorophyll vegetation. The dark green area that represents the vegetation is upstream of the Langsa watershed and it has a stronger near-infrared reflectance. The result of NDVI is seen in the index value for determining the vegetation density of Langsa Watershed, which varies from low, medium, to high levels. [Figure 4](#) shows the slope map, monthly rainfall, and vegetation density.

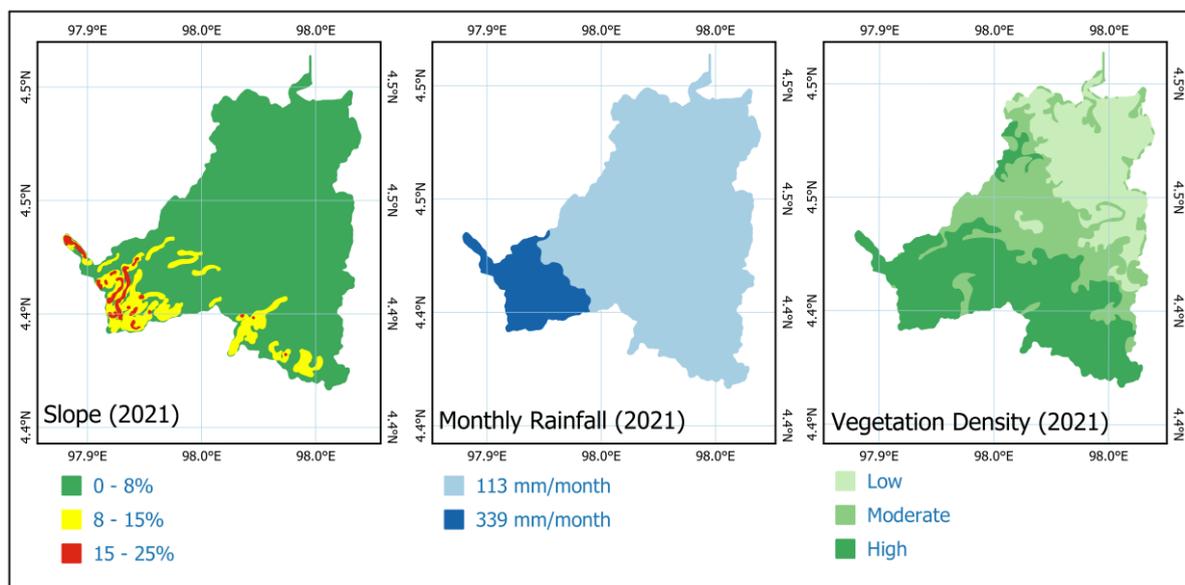


Figure 4. Slope, rainfall, and vegetation density are the determinants of conservation zoning in the Langsa watershed. The three maps are overlaid to produce the zoning of the Langsa watershed conservation area.

From the [Figure 4](#), the zoning system was reviewed based on the characteristics of each overlaid map and then adjusted to the watershed ecosystem's features, namely upstream, middle, and downstream areas as shown in [Figure 5](#). It was observed that the Langsa watershed was divided into 3 zones for conservation efforts, which include conservation ([Liu et al., 2015](#)), the buffer ([Bismark et al., 2007](#)), and cultivation ([Mello et al., 2021](#)). The conservation area, represented by dark green color belongs to slope class III with 15-25% moderate value, high rainfall of 339 mm/year, and a total area of 3.55 km<sup>2</sup>. In addition, the place has a high density and is located upstream of the Langsa river. The buffer area has 8-15% fairly steep slope, belongs to class II, and has high lattice rainfall of 339 mm/year. It also has moderate vegetation density with an area of 4.84 km<sup>2</sup>, and is located in Langsa Lama District which is not far from the conservation. Meanwhile, the light green cultivation area belongs to slope class I with 0-8%, low relative rainfall of 113.67 mm/year, and a low vegetation density. This place has an area of 63.75 km<sup>2</sup> and is located almost throughout the Langsa watershed.

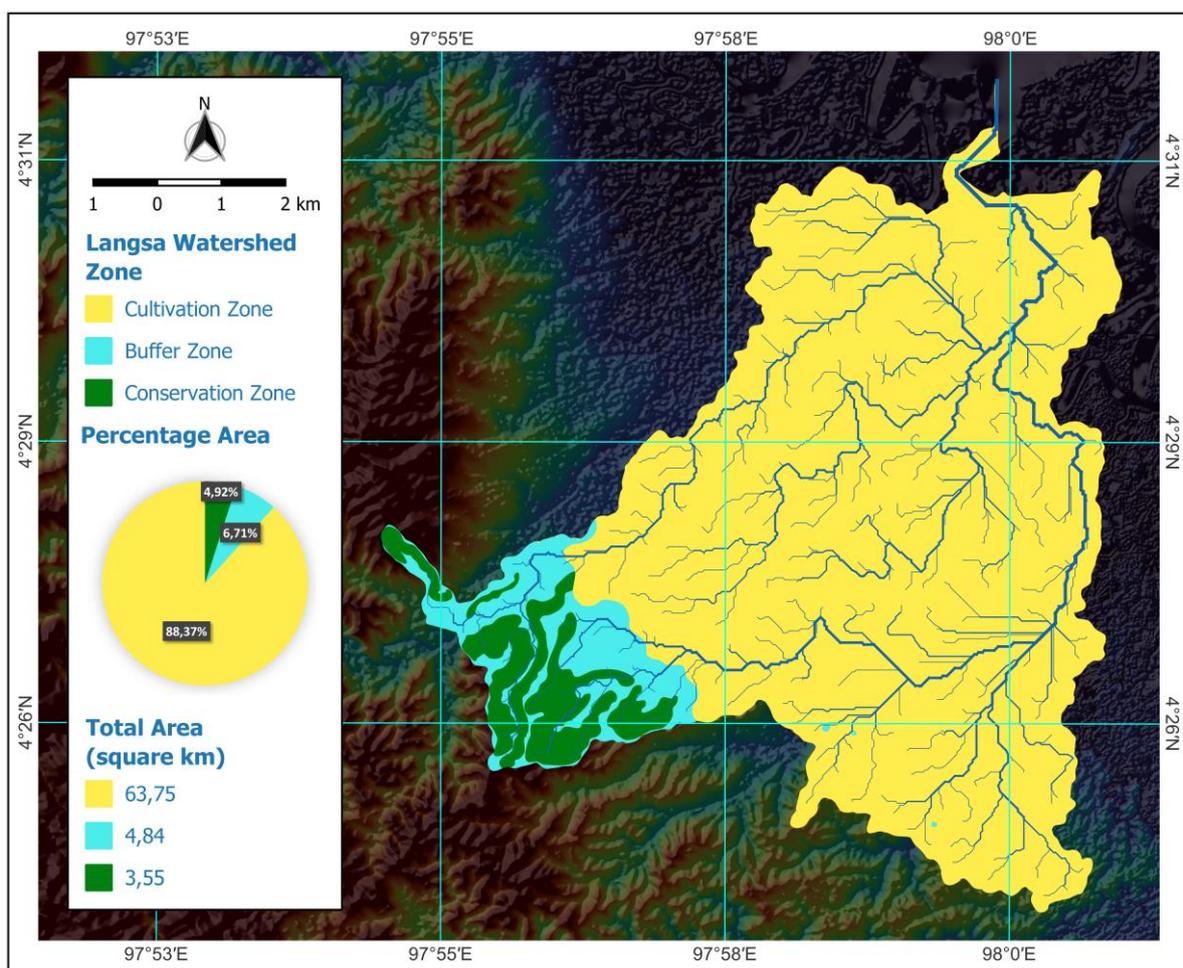


Figure 5. Zoning of conservation areas in the Langsa watershed. The figure shows that the Langsa watershed needs to be dominated by cultivated areas because most of the morphology of the Langsa watershed is flat and sloping. In comparison, the rainfall in the Langsa watershed is overwhelmed by low intensity.

According to [Asdak \(2020\)](#), conservation areas tend to have a high drainage density, without flood, and a forest stands vegetation type with water catchments. The ecosystem in the upstream

watershed is the most critical part because it protects the entire place. This indicates that changes in land use/building construction in the area is likely to have both negative and positive impacts on the whole watershed. This makes the place to always be the planning focus in managing the unitary watershed.

The Langsa watershed conservation area is located upstream of the river. Based on [Patowary & Sarma \(2018\)](#), the upstream feature is a fairly steep morphology that affects erosion intensity, such as the runoff and erosion rate of the hill. It was observed that there is no change in the flow when the number of slopes increases and even tends to be horizontal. This is because the amount of rain often limits runoff, hence the slope value causes water to move faster and takes less time to reach the ground surface, resulting in frequent overflow.

It is important to note that zoning was used for spatial planning in the watershed-based Langsa City. According to [Appiah & Asomani-Boateng \(2020\)](#), watershed-based spatial planning reduces the negative impacts of human-made development, such as river pollution, flooding, and clean water crises. Langsa City is lowland and homogeneous area with rivers and a reasonably dense network. It has the same climate as the territory of Indonesia, including two seasons, namely the rainy and the dry season, which is influenced by monsoons. The watershed in the location has a parallel river flow pattern with two tributaries converging at a point downstream. Based on [Sihombing et al. \(2021\)](#), this flow pattern has great potential for flooding the downstream.

Figure 6 shows the upstream status of the Langsa watershed, with a river width of 12 m. Even though the vegetation density was very high as shown in [Figure 6A](#), the exploitation of sand mining material is still widespread according to [Figure 6B](#). The exploitation of sand mining reduces vegetation density and the water absorption capacity of the soil in the upstream area. This condition is certainly not caused by watershed-based regional planning and therefore, needs to be followed up conservatively.



Figure 6. River conditions in the Langsa watershed conservation area, which is located upstream. (A) Vegetation density upstream is very high. (B) There are sand mining activities upstream that harm the ecosystem.

The buffer zone is adjacent to the core area and protects the ecosystem from adverse environmental influences. Furthermore, it significantly maintains the sustainability of river functions, has good water flow absorption, protects habitats, and secures from natural disasters, such as floods. It was observed that the river's width in the buffer area was 17 meters with an uneven riverbed. This is formed due to the distribution of flow velocity, sedimentation, and erosion processes. [Figure 7](#) shows the condition of the river contained in the buffer zone. In [Figure 7B](#), settlements are on the river banks, even when the vegetation density is high. Therefore, there is a need to specially monitor human activities in buffer zones in order to preserve the river ecosystem ([Ahmad Abdo & Prakash, 2020](#)).



Figure 7. River conditions in the Langsa watershed buffer area with an average river width of about 17 m. (A) River conditions in the buffer zone with sloping morphology. (B) Residents' houses can be found in the buffer zone adjacent to the riverbank.

The cultivation zone primarily develops and manages resources in an area, including natural, human, and artificial. The Langsa watershed cultivation area is located in the river's downstream area that flows into the sea. Furthermore, river located in the zone tends to be comprehensive and have varying river depths which are deeper than buffer areas. The cultivation area needs to be managed appropriately under conservation principles and supported by annual and seasonal cultivation for the City to independently produce all the primary needs from community cultivation.

The Langsa watershed cultivation area has tremendous potential for river silting. It was observed that the accumulated sediment tends to be higher over time and therefore reduces the river's capacity for large-intensity rainwater, specifically during the rainy season. This causes a natural disaster called flooding in the downstream watershed. It even becomes a seasonal disaster in the Langsa watershed every rainy season. Figure 8 shows the physical conditions in the cultivation area.



Figure 8. River conditions in the Langsa watershed cultivation area that located in the downstream area. (A) River conditions in the cultivated area with a homogeneous flat morphology. (B) The community uses the land for agricultural purposes (rice field).

The condition of the cultivation area in the Langsa watershed, located in the downstream region is seen in the [Figure 8](#). It was observed from [Figure 8A](#) that the flat and homogeneous land morphology decreased the river flow velocity, while [Figure 8B](#) shows where the people use river water for irrigation in agriculture, particularly for cultivating rice. The agricultural land in the cultivation area is vulnerable

to land conversion into settlements. This reduces the adequate distribution of rain and irrigation water, as well as the soil absorbing rainwater in the rice field, which further exacerbates the erosion and sedimentation occurrence in the downstream watershed. A more concise explanation of the conservation zoning in the Langsa watershed is seen in Table 3.

Table 3. Characteristics of cultivation, buffer, and conservation zone

Area	Characteristics	Utilization	Location
Cultivation Zone	Low slope, slow river flow, high sedimentation.	Large-scale agricultural areas, settlements, and urban development.	Downstream
Buffer Zone	Transition area with characteristics between cultivation and conservation zones.	Plantations, perennials, production forests.	Middle Stream
Conservation Zone	High slope, fast river flow, high erosion.	Protected forest, primary forest, national park.	Upstream

#### 4. Conclusion

In this study, the Langsa watershed conservation zoning map was divided into three areas. First, the conservation area located in the Langsa watershed upstream is characterized by 15-25% steep slope with high rainfall of 339 mm/month, high vegetation density ( $0.45 < \text{NDVI} < 0.58$ ), an area of 3.55 km<sup>2</sup>, and 12 m width. The area has been prioritized as a protected forest or national park. Second, the buffer zone is directly adjacent to the second main area, namely upstream and downstream. In addition, it is a transition zone for two regions and is characterized by 8-15% moderate slopes, high rainfall of 339 mm/month, with  $0.33 < \text{NDVI} < 0.45$  moderate vegetation density, as well as 17 m width, and an area of 4.84 km<sup>2</sup>. This area is useful as a production forest or perennials for the benefit of the community. Third, the cultivation area is the downstream zone in the watershed ecosystem that functions as a land-use area for agriculture, aquaculture, and services. The cultivated area has 0-8% relative flat slope, low rainfall of 113 mm/month, a low vegetation density ( $\text{NDVI} < 0.33$ ), and an area of 63.75 km<sup>2</sup>. Therefore, the place is safe as urban development areas or large-scale agricultural land for food products.

#### Conflicts of Interest

The authors declare no conflict of interest.

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