# Spatial Based Assessment for Conservation Area Development in Rainwater Catchment Area of Tropical Reservoir, Indonesia

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**Abstract.** Regional food needs increase due to population growth as found in developing countries. Intensification and extensification of agricultural land are solutions to accelerate food production, but often, these activities are not accompanied by adequate conservation practices. This study aims to assess the suitability of land for conservation area development using robusta coffee plants (*Coffea Canephora*). This type of conservation is chosen based on the environmental economics approach consideration. The study used seven indicators (annual rainfall, air temperature, air humidity, soil type, soil acidity, soil organic content, and land slope) to assess land suitability levels for coffee plants. Those indicators were provided in raster format and analyzed in ArcGIS 10.8 and then categorized into four sequential scores, namely highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N). The results indicate 97.50% of the area in the moderately suitable class, while 0.27% of the study site covered a suitable class area, and 2.47% of the area had a marginally suitable class. This finding allows the development of 4.64% of the potential (unused) area in the catchment area to increase vegetation cover by using coffee plants. This research provides important information for watershed management, especially for catchment area conservation planning.

## 1. Introduction

Food needs are known to be increasing due to increasing population growth, especially in developing countries. Food production needs to be increased in line with the fulfillment of population nutrition [1]. On the other hand, land conversion from agricultural land to housing, industrial facilities, and other developments reduces food production areas. Thus, to fulfill food needs, land use management is necessary to ensure appropriate land availability for agricultural crop production. The role of water resources is essential to support food production. Hence, soil and water conservation must be implemented in agricultural practices.

Land development and management optimization is important for food production, especially in tropical climates. Intensification and extensification method on available land is considered the right way to meet the population's food demand. Sustainable intensification and extensification can potentially secure food needs in the long term. This method emphasizes the importance of increasing productivity while reducing environmental adverse impacts [2].

Sustainable intensification and extensification are categorized to be successful if applying a comprehensive assessment of land suitability for food production. Land potential assessment is carried out using land suitability analysis. This method is important for decision-making in sustainable land resource planning and management [3].

Comprehensive land suitability assessment aims to identify the most suitable areas for crop production by using intensification and extensification. Often, land intensification and extensification that cause a reduction in vegetation cover are not accompanied by the application of conservation principles, including what occurs in upstream watersheds. This condition will ultimately damage the land and result in reduced food production due to disruption of the water conservation function in the upstream area and the production function in the downstream area. This study focuses on strengthening the conservation of upstream watershed areas through increasing vegetation to protect the area's function as a water catchment area while solving the socio-economic problems of the local community.

Robusta coffee plants (*Coffea Canephora*) are considered as the vegetation crops in this study. This plant has a good function for conservation and has a good economic value. Hence, using this type of

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vegetation can reduce people's dependence on agricultural crops, which tend to damage the land. Seven indicators, namely temperature, annual rainfall, air humidity, soil type, soil and water acidity, soil organic content, and land slope, were used to determine the land suitability class for coffee plants.

## 2. Methods

### 2.1. Study Area

This study was conducted in the Wadaslintang Reservoir catchment area of 192.53 km$^2$, located in Wonosobo, Central Java Province, Indonesia (Fig. 1). The study location consists of varied topography, including steep slopes to gentle plains. Analysis of data from the climatology station in the study site states that the average annual rainfall is greater than 3000 mm during two seasons in a year, the rainy season (October to March) and the dry season (April to September). The average temperature is around 26°C, with a humidity level of around 81%. The Reservoir has a storage capacity of 443 million m$^3$ sourced from the catchment area above. The function of this reservoir is as a water source of irrigation, power generation, fisheries, and water consumption for the surrounding community.

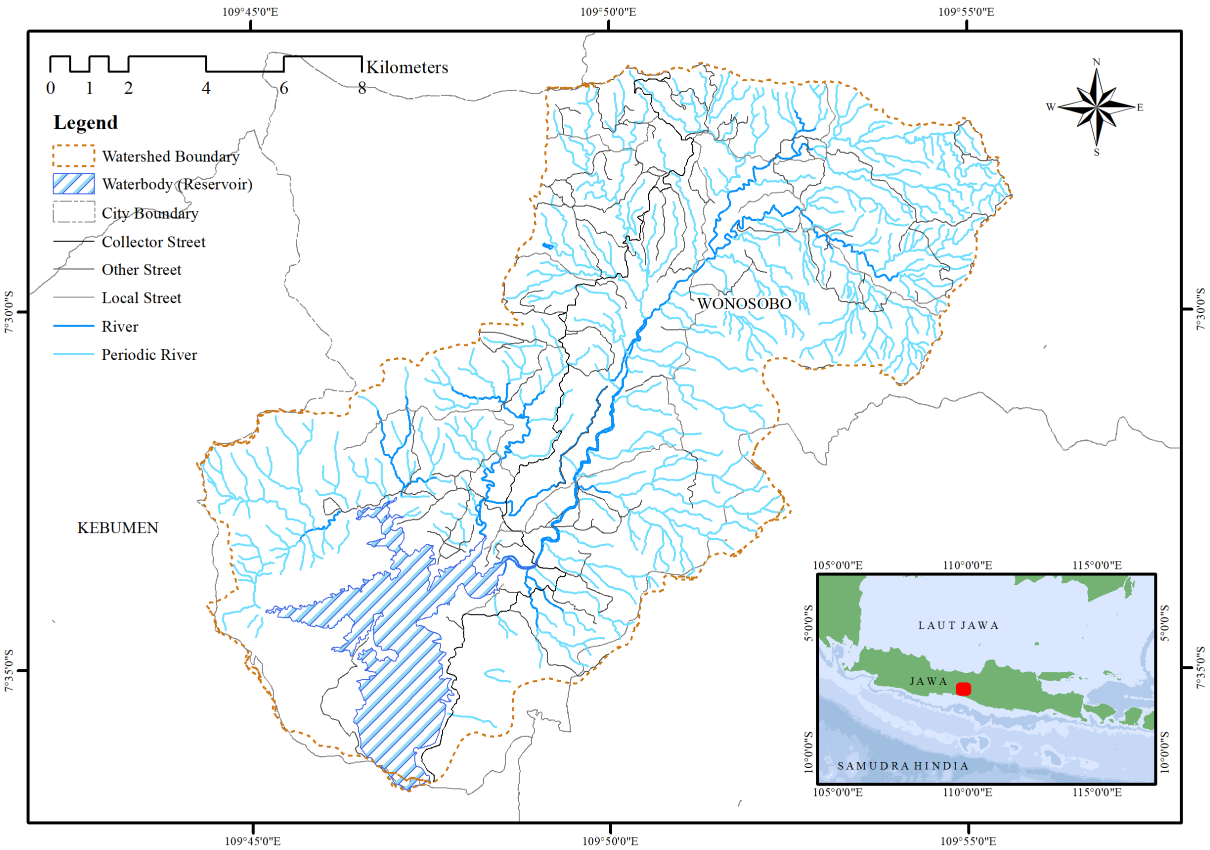


**Fig. 1.** Map of the study area

### 2.2. Land Suitability Analysis

The assessment of land suitability indicators for robusta coffee plant cultivation in this study was collected in the dry and rainy seasons in 2023. Referring to the 1976 FAO and the Ministry of Agriculture Indonesia standard [4] with modifications [5], seven key indicators were used for land suitability analysis, namely temperature, rainfall, air humidity, soil type, water acidity (pH), soil organic content, and land slope and provided in raster map format with 30 meters resolution. Those indicators were then analyzed by using the overlay method in spatial analysis tools of ArcGIS 10.8. Overlay analysis will produce a grid or land unit with the same size as the resolution of the raster map used.

The analysis method is performed by applying score for each indicator assuming that all indicators have an equal influence of weighting factor. Table 1 shows the category of suitability level, namely suitable or S1 (score: 3), moderately suitable or S2 (score: 2), marginally suitable or S3 (score: 1), and unsuitable or N (score: 0). Land suitability class is determined based on the total score of all indicators analyzed using the overlay method. Land suitability level is classified into four classes such as suitable or S1 (total score: 16-21), moderately suitable or S2 (total score: 11-15), marginally suitable or S3 (total score: 6-10), and unsuitable or N (total score: 0-5).

**Table 1**. Land Suitability Classification for Robusta Coffee

| **Indicators** | **Land Suitability Class** | | | |
|---|---|---|---|---|
| | **S1** | **S2** | **S3** | **N** |
| Mean temperature (˚C) | 25 - 28 | 20 - 25 | - | < 20 |
| | | 28 - 32 | 32 - 35 | > 35 |
| Mean annual rainfall (mm year$^{-1}$) | 1,000 - 2,500 | - | 1,250 - 1,500 | < 1,250 |
| | | 2,500 - 3,000 | 3,000 - 4,000 | > 85 |
| Humidity (%) | 40 - 65 | 65 - 75/35-40 | 75 - 85/30 -35 | < 30 |
| Soil Texture | SC, C, SiC, CL, SCL, SiCL | L, SiL, Si | SL | S, LS |
| pH $H_2O$ | 6.0 – 7.0 | 5.5 – 6.0 | < 5.5 | - |
| | | 7.0 – 7.6 | > 7.6 | - |
| Soil organic matter | > 5% (high) | 4% - 5% (moderate) | 3% - 4% (low) | - |
| Slope (%) | < 8 | 8 - 16 | 16 - 30 | > 30 |

## 3. Results and discussion

Each map of indicator needs to be classified according to land suitability class as described in Table 1. Land suitability assessment was performed based on the existing condition of indicators obtained from data analysis and field verification [6].

### 3.1 Temperature

Temperature data was gained from the Climatology Station, the main office of Serayu Opak River, the Ministry of Public Works and Housing Indonesia, at the study site. The average daily temperature value is included in the Suitable or S1 category and received a score of 3, recorded at 26.81°C. High temperatures have a negative impact on the development of the vegetative stage and productivity of coffee plants. The growth of root and shoot tissue will be inhibited [7]. Conversely, temperatures that are too low also reduce the vigor of coffee seedlings, inhibiting growth and causing the leaves to turn yellow [8].

### 3. 2 Rainfall

Rainfall data was obtained from three rain gauge stations of the main office of Serayu Opak River, the Ministry of Public Work and Housing Indonesia (Fig. 2). The average annual rainfall in the first station (south) is 3,263 mm year$^{-1}$, which is categorized in class S3 or in accordance with a score of 1. While, the average at second and third (middle and north), is 3,598 mm year$^{-1}$ and 3,512 mm year$^{-1}$, which is included in class S3 as well. The number of dry and wet months are closely related to the availability of water for cultivation, so the annual rainfall data are used as indicators of land suitability analysis. The intensity of rainfall significantly impacts agricultural activities, as found in the study site.

High rainfall can affect the growth of coffee plants both well and badly. Sufficient rainfall allows root and shoot growth, germination, and general plant development [9]. Some of the adverse effects of high rainfall are excessive waterlogging of agricultural land so that the soil is saturated and lacks oxygen causing plants to die. In addition, the loss of nutrients from the soil may inhibit coffee plant growth. High rainfall causes high levels of water humidity, which can increase the risk of bacterial and fungal infections in coffee plants. Furthermore, heavy rain can cause soil erosion, damaging coffee plant roots and reducing productivity [10].

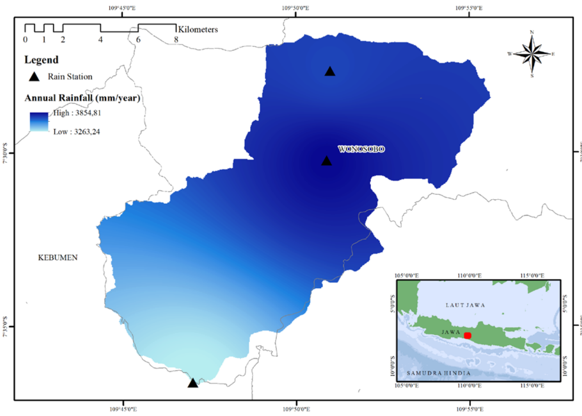


**Fig. 2.** Annual rainfall map of the study site

### 3.3 Air Humidity

The average daily humidity value in the study area was 81.61%. The humidity value in the study site was categorized as marginally suitable or S3 category with score 1 for coffee plants. Air humidity is one of the climatic factors that significantly affects the growth of coffee plants [11]. Air humidity reflect the role of elevation on coffee plants growth. It strongly correlates with elevation, where the humidity decreases with increasing elevation.

### 3.4 Soil Type

The research location is composed of three types of soil, namely red-yellow latosolic, reddish brown latosolic, and red-yellow podzolic [12], as shown in Fig. 3. The research location is mostly dominated by red-yellow latosolic soil covering 88.22% of the total area. Meanwhile, the other areas are covered by 10.49% reddish-brown latosolic soil and 1.29% red-yellow podzolic soil. Regarding soil texture, red yellow latosolic soil and reddish-brown latosol soil are categorized as S1 or highly suitable class with a score of 3. The texture of clay-sandy (SC) is owned by red-yellow latosolic soil, while reddish-brown latosol soil has a clay texture (C). On the other hand, red-yellow podzolic soil, which has a silt clay texture (SiL), is categorized as S2 or a moderately suitable class (score: 2) for coffee growth [13].

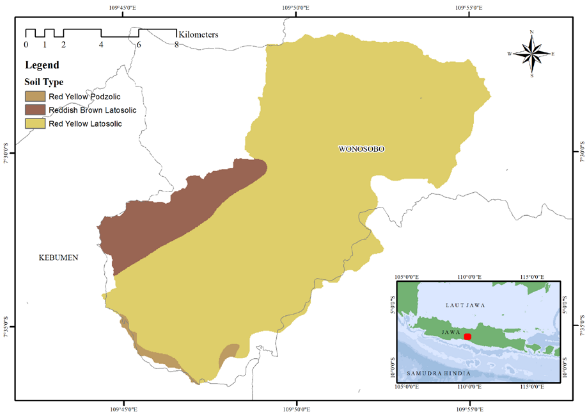


**Fig. 3.** Soil-type map of the study area

### 3.5 Soil acidity (pH)

Soil acidity or pH is the amount of hydrogen ions (H+) in the soil, with a neutral category at a pH value of 7. The pH of the soil and water in the field greatly influences nutrient availability, plant growth, and productivity. The minerals that make up the soil play a major role in determining how the soil responds. Nutrient availability, phytotoxicity, and plant compatibility can all be obtained through pH. The optimal pH range for most plants is in the range of 5.5 to 7.0 [14]. In this study, the pH value was obtained from analyzing water and soil samples in the laboratory. The pH value ranged from 7.15 to 9.01, averaging 7.93. Referring to Table 1, the distribution of pH values at the research location consists of two areas, namely areas with water pH> 7.6, a marginally suitable class or S3 with a score of 1, and other areas, a moderately suitable class or S2 with a score of 2, as shown in Fig. 4.

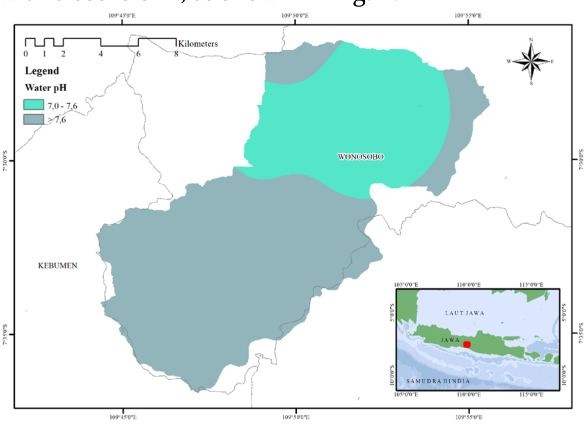


**Fig. 4.** pH value of the study area

### 3.6 Soil Organic Matter

Analysis of soil samples showed that the study site was dominated by medium soil organic matter (4-5%) classified as moderately suitable or class S2, as shown in Fig. 5. The study site also included areas with low soil organic matter content (3-4%) classified as marginally suitable or S3 and high soil organic matter content (more than 5%) classified as highly suitable or S1. Soil organic matter content reflects the percentage of soil consisting of plant or animal tissue. Organic matter content ranges from 3% to 6% in most productive agricultural soils [15].

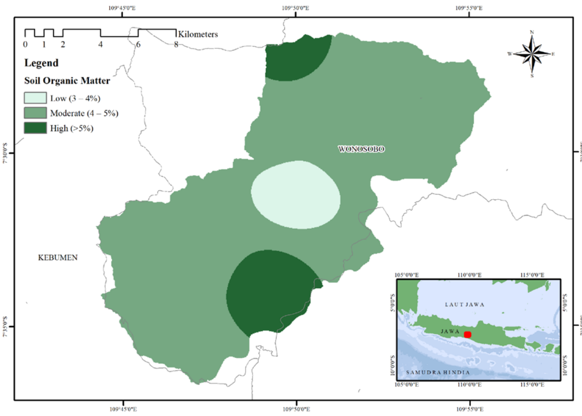


**Fig. 5.** Soil organic content of the study area

### 3.7 Land Slope

A land slope is a natural land surface that shows the difference in elevation between two locations. The length and steepness of the slope affect the rate of soil erosion. The potential for soil erosion increases with a higher percentage of steep slopes and a larger volume of water runoff [16]. In this study, the slopes were classified into four classes: <3%, 3-8%, 8-15%, and >15%. The land slope map was analyzed from DEMNAS issued by the Indonesian Geospatial Information Agency in 2023. The analysis results showed that the study location mostly consisted of slopes of more than 15%, as shown in Fig. 6. This indicates that most areas are included in class N or unsuitable for coffee plant cultivation. In general, areas with relatively flat terrain are conducive to agriculture practices.

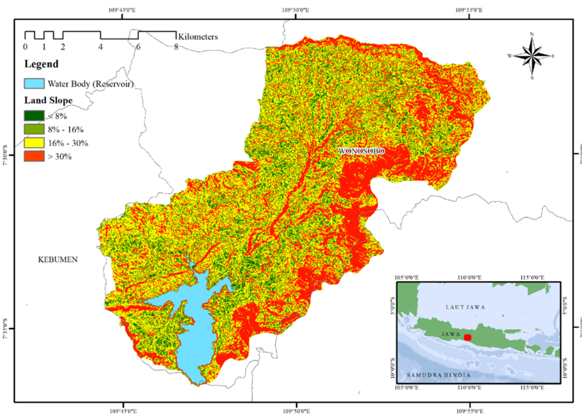


**Fig. 6.** Land slope map of the study area

### 3.8 Land suitability analysis

Land suitability analysis is important for sustainable land resource planning and management. This analysis is used to assess the potential of land in a particular land use. All indicators presented in raster maps in this study resulted in a land suitability map for robusta coffee plants (Fig. 7). Land suitability classification is divided into four classes, namely: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N). A higher land suitability value indicates that more land is suitable for coffee plants. According to the results obtained, it can be observed that almost the entire area of 186,89 km$^2$, or 97.50% of the total study area, falls into the category of moderately suitable or S2 for coffee plants cultivation. Meanwhile, the remaining 2.47% of the study area, or equivalent to 4.73 km$^2$, is classified as marginally suitable, and the area of highly suitable or S1 covers an area of 0.52 km$^2$ or 0.27% of the study area.

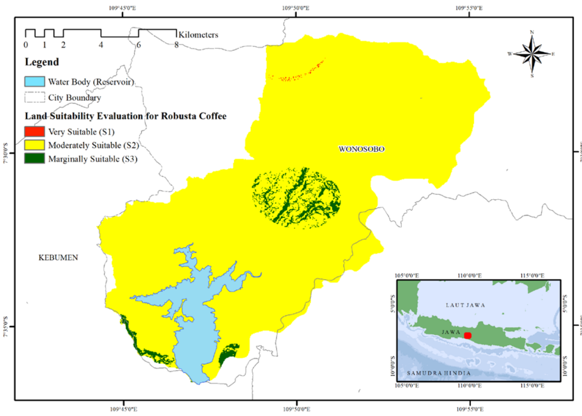


**Fig. 7.** Land suitability analysis map of the study area

According to the land use type, dry agricultural land is the largest area in the research location [12]. 4.64% of the total land area is shrubs that have the potential to be developed for coffee plants land. Shrubs were selected to minimize the socioeconomic effect due to the high dependence of the local inhabitants on land for farming. A direct conversion in a short period of land use type from agricultural mixed crops to coffee plants may trigger socio-economy conflict for the inhabitant. Coffee plants have been proven to function effectively as conservation plants [17]. Coffee plants have also been known by the community around the study site.

The results of the land suitability socio-economy effect due to a high dependence, which generally show a suitability class of S2, strengthen the potential of shrub land to be developed into coffee plants land. Some factors are unfavorable for land suitability and need to be considered, namely land slopes, especially for areas with more than 15% slope. Land development must be accompanied by conservation principles to minimize the negative impacts of land development.

Water catchment areas are not recommended for agriculture, but the facts show that the community's dependence on land is quite high. As a solution, agricultural practices in the research location must be accompanied by cropping planning and massive land and water conservation practices. Massive conservation efforts can reduce land degradation risk caused by excessive agricultural activities [18,19].

## 4 Conclusions

The study results show that most of the study location areas are suitable for development into coffee plant land. Based on the existing land cover conditions, which are reinforced by the study findings, the potential area for coffee plants land is around 4.64% in the form of shrubland. Robusta coffee plants can also be mixed with other agricultural crops in farmland. The land slope is a major factor limiting the suitability of farmland. Development of farmland in the study area requires the implementation of intensive land and water conservation practices.

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