PREDICTIVE MAPPING OF CRITICAL LAND IN BENGAWAN SOLO WATERSHED: AN INTEGRATED APPROACH USING LANDSAT IMAGERY AND TERRAIN ANALYSIS

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Abstract. Inappropriate land use can have negative impacts, increasing the risk of land becoming critical. This research has significant implications for natural resource management and environmental conservation, providing a better understanding of land criticality and the need for intensive area protection. The Bengawan Solo watershed is rich in biodiversity, water resources, and important sources of livelihoods, so a deeper understanding of land criticality is needed to protect ecosystems and support sustainability. This research aims to map critical land by considering land cover, slope, erosion hazard level, and forest area. This research will use satellite image analysis and geographic information system (GIS) data to identify and map critical land in the Bengawan Solo watershed. This research method integrates scoring techniques using remote sensing and GIS methods. The data used in this research include Landsat 9, rainfall data, soil type data, forest area data, and Forest And Buildings removed Copernicus DEM (FABDEM) data. Advanced methods were used in processing each variable, including random forest algorithm for land cover, digital terrain model (DTM) data for slope, universal soil lost equation (USLE) method for erosion hazard level, and forest area data based on MoEF. The study results show land criticality in the Bengawan Solo watershed in 2023, with most areas having a low slope (0-8%), which is considered non-critical, covering 30.50% of the total area. In contrast, the potentially critical category (8-15%) dominates with 45.94% of the area, indicating the potential risk in areas with moderate slopes. Areas with steeper slopes fall into the critical (10.29%) and very critical (2.68%) categories. The critical land mapping accuracy test results showed an accuracy rate of 90.67%, precision of 73.29%, recall of 83.61%, and F-Score of 76.05%. A limitation of this study is the availability of very high-resolution image data for parameter extraction. Future research could include land cover change modeling to predict future land change trends and their impact on erosion risk and environmental sustainability. Furthermore, flood risk mapping and drainage system evaluation can assist in developing flood mitigation strategies and drainage infrastructure improvements.

Keywords: *critical land, random forest, landsat, Bengawan Solo*

1 INTRODUCTION

Based on data from the Central Bureau of Statistics (BPS) in 2023, the population of Bojonegoro Regency reached 1,341,259 people, with a population growth rate of 0.23% per year from 2018 to 2023 (Kabupaten Bojonegoro Dalam Angka, 2022). This growth poses significant challenges related to the increasing demand for land, while land availability is stagnant. The people of Bojonegoro Regency rely heavily on land in their daily lives.

One of the impacts of this population growth has been a decline in the function of the Bengawan Solo watershed, as the watershed is mostly located in Bojonegoro Regency (Arianto &

Nawiyanto, 2022). To improve the quality of life, careful land management is required, considering the physical condition, capability and suitability of the land. Land use without consideration can have a negative impact, increasing the risk of land becoming critical(Abushnaf et al., 2013).

Critical land is a form of land degradation that causes a temporary or permanent decline in productivity (Sutopo Purwo Nugroho, 2008). It is characterized by a decrease in soil physical, chemical, and biological properties, negatively impacting agricultural productivity, the environment, and the availability of natural resources. Holistically, critical land indicates environmental degradation due to unwise land use (Feng et al., 2022). In general, necessary land is a clear indicator of environmental degradation due to various types of unwise land resource utilization (Nugroho and Prayogo, 2008). The main characteristics of critical land are bareness, aridness, and even rocks on the land's surface, generally located in areas with undulating land topography or steep slopes (Prawira et al., 2005).

Monitoring the signs of critical land is needed to implement preventive measures. Early prevention efforts to prevent the occurrence of critical land involve raising public awareness regarding land use by its capacity (Surya Candra, 2013). Thus, people are expected to avoid intensive land resource exploitation without rehabilitation and conservation efforts.

Critical land management and increased human needs are essential to maintain the balance of land and water resources (Mishra et al., 2021). Areas experiencing critical land need rapid and intensive monitoring to prevent natural disasters like landslides. Diverse geographical characteristics require specific land management approaches. In Bojonegoro District, critical land is a problem, with a potential area of 1,143 ha based on the 2013 Regional Spatial Plan (RTRW). Therefore, research and updating of regional data in 2023 is required.

Previous research has also analyzed critical land in protected forest areas using geographic information systems (Surya Candra, 2013) (Ramli et al., 2023). The critical land analysis is also carried out using slope maps, land cover maps, erosion hazard maps, land management maps (Auliana et al., 2018) and productivity. (Widyatmanti et al., 2018). Other research on critical land uses topography, soil, erosion, and vegetation parameters (Amaliyah & Umar, 2020). Land degradation prediction also uses multi-source geospatial data variables consisting of global topographic, bioclimatological, geo-environmental, biophysical, accessibility and human modification data (Yulianto et al., 2023). Based on literature studies that have been conducted from previous research, there are several research gaps, namely, the extraction method for land cover is carried out using the random forest method, the remote sensing data used is Landsat 9 data where this analysis and data have never been used to map critical land in the Bengawan Solo watershed.

This data processing process utilizes spectral transformation, allowing land cover mapping without directly surveying the entire area (Al-Taei et al., 2023) (N. Simarmata et al., 2022). Land cover, especially critical land mapping, is crucial to environmental understanding and management. Critical land mapping refers to identifying and classifying land with particular ecological importance, risk, or impact. In this context, using machine learning methods, such as Random Forest (RF)(Svoboda et al., 2022) (Nguyen et al., 2018), is becoming increasingly important to improve the accuracy and efficiency of such mapping (Rodriguez-Galiano et al., 2012). Besides land cover, other important parameters for critical land mapping are NDVI, slope, erosion hazard level, productivity, and land management (Bashit, 2019).

Regulation P.3/PDASHL/SET/KUM.1/7/2018 by the Director General of Watershed Control and Protected Forests stipulates technical guidelines for preparing critical land spatial data, including land cover parameters, slope, erosion hazard, productivity, and management. Therefore, critical land mapping and analysis activities must be carried out using the latest data. The results of critical land mapping are expected to serve as a reference for stakeholders and policymakers in conducting land rehabilitation to improve the carrying capacity of the watershed. In addition, it is likely to serve as a basis for developing sustainable land protection and management strategies in the Bengawan Solo watershed and assisting in mitigating the risk of natural disasters such as floods and landslides.

This research aims to map critical land by considering land cover, slope, erosion hazard level, and forest area. This research will use satellite image analysis and GIS data to identify and map critical land in the Bengawan Solo watershed.

The scope of the study includes an analysis of various factors affecting critical land conditions, including land cover, slope, erosion hazard level, and forest area. The analytical method involves using medium-resolution satellite imagery with GIS modeling. However, this study has limitations, including the availability of data with high spatial resolution.

The main novelty of this research lies in the holistic approach that includes the use of satellite imagery and GIS analysis to identify and classify critical land. In addition, this research makes an important contribution to the understanding and management of critical land in the Bengawan Solo Watershed.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

Most of the Bengawan Solo river basin is located in Bojonegoro Regency, part of East Java Province, with a length of approximately 100 km and an area of 24,753 hectares (Arianto & Nawiyanto, 2022). The Bengawan Solo River has its headwaters in the south and becomes the natural boundary of the province before flowing eastward to the northern region of Bojonegoro Regency. The north area of the Bengawan Solo watershed is very fertile and has extensive agricultural land. Astronomically, Bengawan Solo is located between 6°59' and 7°37' South latitude and 112°25' and 112°09' East longitude (Figure 2–1).

The total population is 1.450.889 people, with a population density of 62,889 people/km2. Most of the population in the Bengawan Solo watershed has a livelihood in agriculture. (*Kabupaten Bojonegoro Dalam Angka 2024.*).

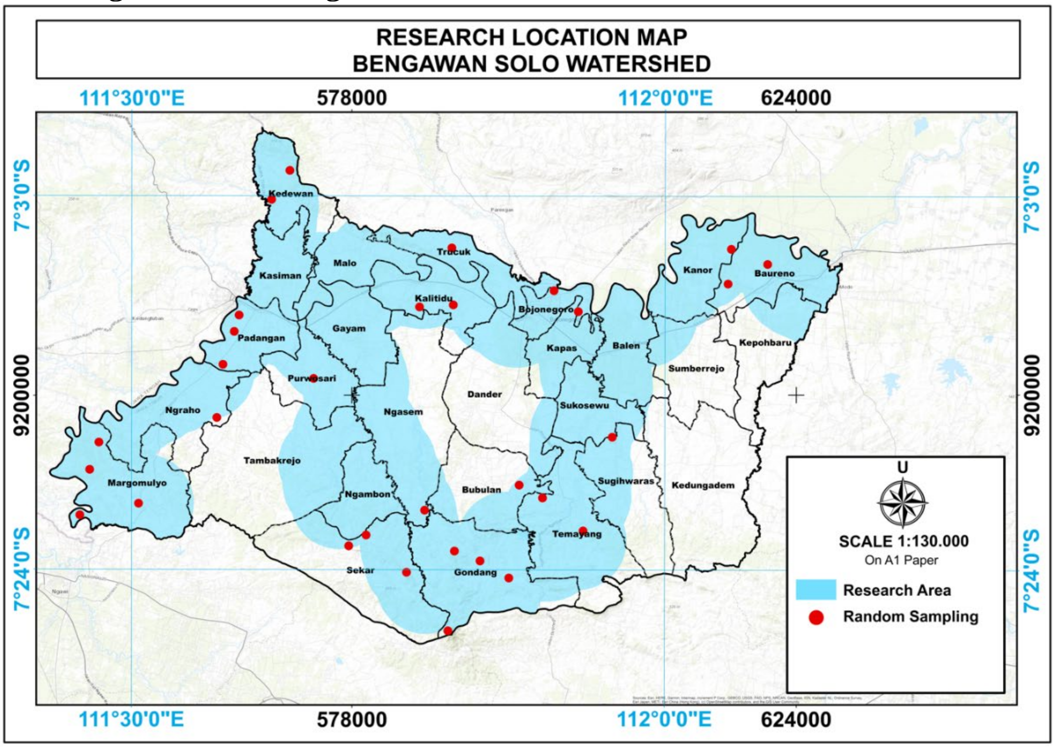

Figure 2-1: Research Location Map of Bengawan Solo Watershed

2.2 Research Data

Image data in this study uses the part of Bengawan Solo Watershed, Landsat 9 image with acquisition time September 9, 2023, digital elevation model (DEM), Erosion Hazard Level Map, and forest area map. The Landsat 9 image, a medium-resolution image, has a spatial resolution of 30 m. The DEM data used is FABDEM data, which is DTM data with the exact spatial resolution, namely 30 m. FABDEM has been processed and improved to enhance elevation accuracy, thus providing a more precise representation of the Earth's surface topography. The erosion hazard level data is obtained through processing using the USLE method, which involves several datasets, including rainfall data, soil type data, slope data, and land cover data. The forest area data based on the KLHK, where the district's territory in determining critical land analysis is divided into two areas: inside and outside. Inside refers to forest areas, while outside refers to areas outside forest functions or APL.

2.3 Research Methods

The initial research stage involved comprehensive data collection, including Landsat 9 satellite imagery, topographic data, and other parameters relevant to land conditions, such as slope and erosion hazard. The image is downloaded via Google earth engine, the image used is already in the form of surface reflectance pixels. However, spectral transformation is still carried out to restore the true value because previously the image was still factorized. Furthermore, a GIS integrated spatial data, including satellite images, with other information such as administrative boundaries and river networks. Essential variables and parameters were determined, covering aspects such as land cover, slope, and erosion hazard level. More details are presented in figure 2-2.

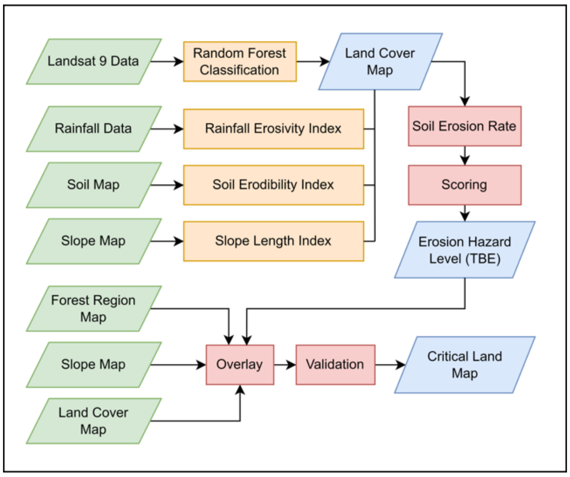

Figure 2-2: Research Flowchart

Spatial Analysis of Critical Land Mapping in Bengawan Solo Watershed refers to the latest critical land mapping guidelines based on (Decree of the Minister of Environment and Forestry Number SK.306/MENLHK/PDASHL/DAS.0/7/2018) concerning Critical Land Determination. The determination in preparing critical land data and maps is based on GIS and Remote Sensing—critical land analysis in the Director General of Watershed Control and Protected Forests Regulation No. P.3/PDASHL/SET/KUM.1/7/2018 includes land cover, slope, erosion hazard level, and forest area/area variables.

Selecting land cover, slope, erosion hazard level, and forest area parameters is essential in evaluating land criticality in the Bengawan Solo watershed. Land covers such as built-up land, water bodies, mixed vegetation, open land, and forests have different impacts on soil erosion; forests can act as a natural erosion barrier, while open land is more susceptible to erosion. The slope is crucial, with steeper slopes having higher erosion rates. Erosion hazard parameters describe erosion risk based on rainfall, soil type, and vegetation cover, guiding where erosion is most likely. Forest areas are essential in erosion mitigation by reducing stormwater runoff through their natural erosion buffering function.

The utilization of remote sensing imagery such as Landsat 9 OLI/TIRS imagery was chosen because of the easy access to data provided and good cloud cover data. DEM is critical data for erosion problems. One of the biggest causes of erosion is altitude. Therefore, FABDEM data was chosen as the best approach as it is accurate for forests and areas with low slopes (Saberi et al., 2023) (Meadows et al., 2024). The soil type data refers to data from the International Soil Reference and Information Center, a global organization that provides open-source information and has a resolution of 250m.

2.3.1 Image Pre-Processing

The data used is atmospherically corrected surface reflectance derived from data generated by the Landsat 9 OLI/TIRS sensor. The image used was downloaded through Google Earth Engine, so it has been corrected using the Land Surface Reflectance Code (LaSRC). However, in the process, the image must be multiplied by the required factorization value. In the optical band, the surface reflectance value must be multiplied by 0.0000275 and added by -0.2. The thermal band has a multiplier value of 0.00341802 and is increased by 149. This research uses optical bands, so it is the first option in the process.

2.3.2 Land Cover Parameter

The land cover reflects physical materials on the Earth's surface that visualize the relationship between natural and social processes. This information is crucial for modeling and understanding natural phenomena. Land cover data also supports the study of climate change and the relationship between human activities and global change. The quality of land cover information is a significant factor in improving the performance of ecosystem, hydrological, and atmospheric Top of Form models (Cahyono et al., 2019)

The land cover classification in this study was carried out using the random forest (RF) method. The selection of the RF method for land cover mapping in the Bengawan Solo watershed is based on several advantages that strengthen its validity. RF can handle multispectral data well, has resistance to overfitting, and can handle complex variable interactions. In addition, RF can accurately perform multiclass classification based on the region's complexity of land cover (Aldiansyah & Saputra, 2023).

Many trees are produced by this RF method, and these trees serve as the foundation for the majority vote (bagging ensemble method). This majority vote determines the label class in the output (Danoedoro & Murti, 2021). RF is a technique in machine learning that belongs to the ensemble learning category. Ensemble learning refers to an approach that combines multiple models or algorithms to improve prediction performance and accuracy. By combining the results of various models, the variation and error of each tree can be balanced. So, the advantage of RF is that it is very effective in dealing with overfitting problems; this is because the tree or classification generated by RF is done randomly so that it will not be affected by overfitting (Breiman, 2001).

In the research using Google Earth Engine, the first step was to select a study area and a relevant dataset, namely Landsat imagery. Next, training data is formed by determining the regions where suitable attributes can be obtained. Features such as image bands became model inputs, while category labels were determined for classification (Simarmata et al., 2023). Form and train a random forest model with appropriate parameters. The results are applied to the entire image, resulting in a visualized classification map for evaluation. Validation methods, such as error matrices, are used to measure the accuracy and performance of the model against data not involved in training.

2.3.3 Erosion Hazard Level (TBE) Parameter

The level of erosion hazard (TBE) is determined by comparing actual erosion (A) with tolerable erosion (T) in the research area. In the study of critical land determination in Bengawan Solo

Watershed using the USLE method. The USLE method is a long-term prediction using rainfall data, soil type, topography, vegetation cover, and land processing (Pham et al., 2018). This method was chosen because it has become a proven standard in evaluating soil erosion by considering several relevant environmental factors such as rainfall, soil type, slope, and land use. In addition, its ability to provide quantitative results allows for a more accurate assessment of the erosion hazard level in the study area.

Every map type undergoes data processing to provide the five index values required to determine the degree of erosion hazard. These are divided into five categories: extremely light, light, medium, heavy, and very heavy. These are the parameters that were applied.

$A = R \, x \, K \, x \, L \, x \, S \, x \, C \, x \, P$......................(1)

where:
A = Soil erosion rate (tons/ha/year)
R = Rainfall erosivity index
K = Soil erodibility index
L = Slope length index
S = Slope index
C = Vegetation cover index
P = Index of tillage or soil conservation measures

TBE must be calculated using four maps: rainfall, soil type, slope, and land cover maps, according to the formula. Table 2-1 shows the relationship between the different types of maps and the elements used to calculate soil erosion rates.

Table 2-1: Factors used in TBE calculation

TBE Calculation Parameters	Symbol	Map Type
Erosivity index	R	Rainfall map
Soil erodibility index	K	Soil map
Index value of slope length and slope	LS	Slope map
Vegetation cover and tillage index	CP	Landcover map

The process of calculating the index value of each map data is done with various formulations, namely:

1. Erosivity Index (R)

This erosivity factor considers the physical properties of the soil, such as texture, structure, and permeability, as well as other factors that affect how susceptible the soil is to erosion by rainwater. Intense or prolonged rainfall can significantly impact erosion more than lighter rainfall. Historical rainfall data for a particular area is often used to calculate the R-Factor value. This data measures how much rain in the region contributes to soil erosion.

The annual rainfall erosivity, or R, is defined by the USLE equation. The product of maximum 30-minute rainfall intensity (I30) and total rainfall energy (E) yields rainfall erosivity. The Bols equation can express the two elements, E and I30.

$EI30 = -8.79 + (7.01 \, x \, R)$...........(2)

where EI30 = rainfall erosivity and R = monthly average rainfall.

2. Erodibility Index (K)

The soil erodibility factor (K) is a parameter that measures the susceptibility of a soil type to erosion caused by rainfall. This factor is calculated by considering the soil's various physical and chemical properties, including texture, structure, density, saturation level, water infiltration ability, and erosion rate (Rahmat Hanif Anasiru, 2015). Soil texture refers to the soil's relative ratio of sand, dust, and clay. Soils with high clay content tend to be less erodible than soils with high sand content. Clay particles form more robust aggregates, which are more challenging to erode by rainfall. Soil structure refers to how soil particles are organized and connected (Arifandi & Ikhsan, 2019). Soils with good structure tend to have solid aggregates and are resistant to erosion.

This factor considers slope length (L) and land slope (S) to predict the level of erosion that may occur. The slope factor (LS) index value is obtained from primary data on map units that have undergone soil conservation measures, especially mechanical soil conservation measures covering most of the study area, and secondary data (Yuningsih et al., 2012). There are two parts to the slope and length factor (LS): the slope factor and the slope length factor. The slope length factor is the horizontal distance from the top of the downward-flowing surface where the slope gradient decreases to the starting point or when the runoff becomes focused on a particular channel (Tuti Herawati, 2010). The slope length and slope index in this study were obtained using a derivative of the land slope percentage map (S) generated by DEM data based on the equation.

$$LS = 0.2\ s\ 1.33 + 0.1 \qquad (3)$$

where s is the slope length.

3. Vegetation cover and tillage index (CP)

The land cover factor (C) in USLE measures how susceptible an area is to erosion based on the type of land use and vegetation cover. Each land cover type has a different C-Factor value, which describes how well the vegetation and land cover can resist erosion. C-Factor values are decimal numbers between 0 and 1, where 0 means the land cover is very effective at reducing erosion, while one means it is very susceptible to erosion. Land cover analysis also considers land use and vegetation cover changes over time.

In addition to the C-Factor, the erosion control practice factor (P) is also essential in USLE. It reflects soil conservation measures implemented within the area, such as cover crops, terraces, or other measures to reduce erosion (9). Analysis: The value of the CP factor is determined based on the land use type and land management on each land unit. In this study, the data used to determine the value of the land use and soil management (CP) factor is the land use map in the relevant Bengawan Solo Watershed.

2.3.4 Slope Parameters

The ratio of the horizontal distance to the height difference (vertical distance) of the land is called the slope. Other ways indicate the slope's quantity, such as percent and degree. The topographic shape of an area can be seen based on the slope. Slope plays a crucial role in various geological and geomorphological processes such as erosion, sedimentation, landslides, and landform development.

This slope factor influences the rate of erosion and deposition in an area where steep slopes are prone to erosion, while flat slopes tend to be prone to deposition. Changes in slope can alter erosion and deposition patterns. Spatial data on slope can be generated by processing elevation data, such as contour lines on topographic maps or DEM. Slope gives an idea of the physical condition of the land, assuming that steeper slopes will increase the speed of water flow and its transport energy. Steep slopes also tend to increase the potential for erosion due to the impact of more rain grains. Compiling spatial data on slope makes this parameter important in critical land analysis (Bashit, 2019).

2.3.5 Land Productivity and Management Parameters

For analysis purposes, the district area in determining critical land analysis is divided into two areas: inside and outside. Inside is the forest area, while outside is the area outside the forest function or APL. The management of forest area map variables will be related to the area management system of a region. One of the factors used to evaluate crucial land in protected forest areas is management. This is determined by how well management components are implemented, such as having area limits, security, supervision, and whether or not counseling is done. In cultivated and protected areas outside cultivation, the management aspect includes applying soil conservation technology, whether complete, incomplete, or absent. By its character, the data is attribute data that contains information about management aspects based on the Directorate General of Watershed Control and Protected Forests in 2018.

2.3.6. Validation and Ground Checking

This step is carried out to validate the results of critical land analysis using GIS technology. Validation of mapping results is carried out by comparing mapping results with field surveys. Field parameters are measured by testing samples in the laboratory to obtain soil fertility results at the research site.

The confusion matrix accuracy test is essential for evaluating how well a critical land class map is produced from data analysis. This method compares the classification performed by the algorithm with the actual classification from field data or valid reference sources. This process creates a matrix that shows the number of pixels or areas that were correctly classified into the appropriate class (true positives), the number of pixels or regions that were misclassified (false positives), as well as the number of pixels or areas that were not detected (false negatives) (El Baroudy, 2016)(Arifin & Fitrianah, 2018). True positive is positive data predicted to be accurate, while true negative is harmful data predicted to be true. While true negative is harmful data, it is predicted as positive data. Precision is the level of accuracy between the information requested by the user and the answer given by the system. Recall is the system's success rate in retrieving information, and accuracy is defined as the level of closeness between the predicted value and the actual value (Nurnaningsih et al., 2021) :

$$Presisi = \frac{\text{TP}}{\text{TP+FP}} \quad \text{......................................(4)}$$

$$Recall = \frac{\text{TP}}{\text{TP+FN}} \quad \text{......................................(5)}$$

$$Akurasi = \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}} \quad \text{..........................(6)}$$

$$F - score = 2 \text{ X } \frac{\text{Precision x recall}}{\text{Precision+recall}} \text{..............(7)}$$

3 RESULTS AND DISCUSSION

3.1 Land Cover Classification

The results of the analysis of land cover classification in Bengawan Solo Watershed in 2023 using Landsat 9 imagery in processing are 5 (five) classes. The following table of land cover classification in 2023 is presented in Table 3-1.

Table 3-1: Land Cover Classification in 2023

No	Description	Area (Ha)	Percentages
1	Built-up Area	45.010,22	28,38%
2	Water Body	2.210,06	1,39%
3	Mixed Vegetation	86.828,27	54,74%
4	Open Land	9.722,22	6,13%
5	Forest	14.843,91	9,36%

Source: Analysis Results, 2023

Based on Table 3-1, the largest percentage result of land cover classification in 2023 is in the mixed vegetation class with a result of 54,74%, while the smallest percentage result is in the land cover of water bodies with a value of 1,39%. The results of the land cover classification in 2023 are shown in Figure 3-1.

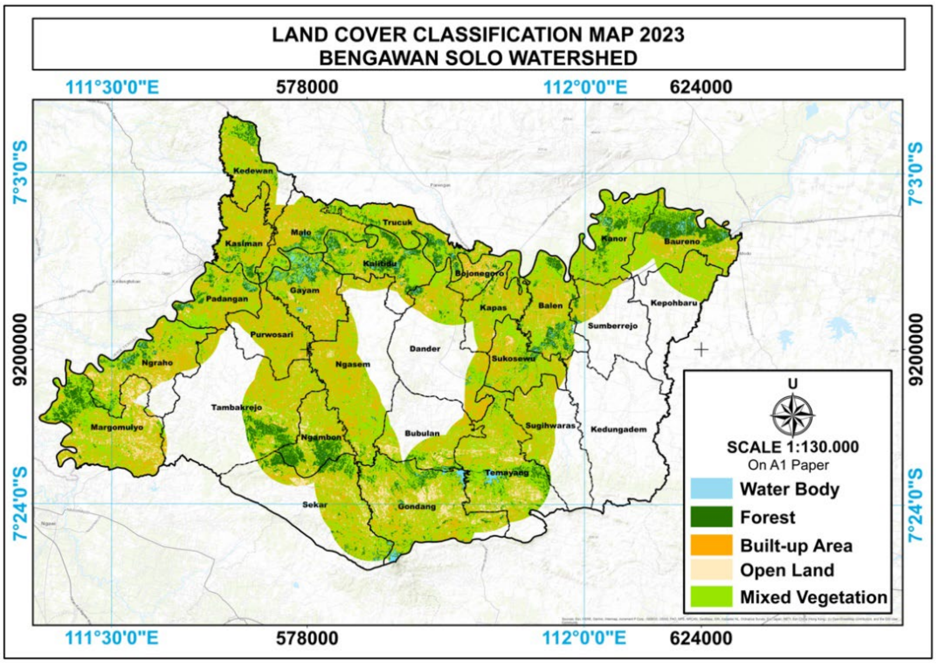

Figure 3-1: Land Cover Classification Map of Bengawan Solo Watershed

In Figure 3-1, the land cover classification results in Bengawan Solo Watershed reflect a diverse composition. Built-up land cover reaches 45.010,22 Ha, or about 28,38% of the total area, signifying significant urban growth in the last five years. This percentage indicates continued progress in the area of urban development and infrastructure. Furthermore, water body areas cover 2.210,06 Ha or about 1,39%. of the total area. This reflects the presence of various water bodies, such as rivers, lakes, or irrigation canals that remain essential to the region's ecosystem and economy.

Mixed vegetation covers a vast area of 86.828,27 Ha or about 54,74% of the total area. This shows that the region still has a lot of land surrounded by different vegetation types, such as plantations, fields, or agricultural land. Land cover in the form of vegetation plays a vital role in maintaining biodiversity and environmental sustainability (Juniyanti et al., 2020). Open land has an area of about 9.722,22 Ha, or about 6,13% of the total area, indicating more open land use, such as agricultural land or available land not covered by vegetation. Forest covers an area of about 14.843,91 Ha or about 9,36% of the total area. Although the area is relatively small compared to other classes, forest conservation and management remain significant concerns in maintaining the sustainability of the environment and natural resources. These changes illustrate the dynamics in land use and the environment over time.

Based on the sub-district analysis, the most significant area for the land cover class in 2023 is built-up land, water bodies, and mixed vegetation, namely Tambakrejo Sub-district, where the results of the respective regions of the sub-district are 10,073.52 Ha, 6,226.38 Ha, and 1,869.57 Ha. Next, the most significant area for the open land class is in Gayam Sub-district, which is 411.93 Ha. In addition, the largest area of the forest class is found in Gondang, with an area of 1,528.11 Ha.

3.2 Erosion Hazard Level

The results of the erosion hazard level are obtained based on five parts, namely the erosivity index (R), the erodibility index (K), the length and slope index (LS), the vegetation cover and land management index (CP), and the erosion hazard level class. The Erosion Hazard Level (TBE) can be calculated by comparing the erosion rate in a land unit and the adequate soil depth. The erosion process can lead to decreased soil productivity and fertility, reducing the carrying capacity of the soil for agricultural production. TBE is determined by comparing actual erosion (A) with tolerable erosion (T) in an area with the USLE equation.

Table 3-2: Analysis of the Level of Erosion Hazard (TBE) in Bengawan Solo Watershed

No	KBE	A Value	TBE	Area (Ha)	Percentages
1	I	<15	Very Low	19.761,51	12,52%
2	II	(>15-60)	Low	67.699,68	42,90%
3	III	(>60-180)	Moderate	52.294,79	33,14%
4	IV	(>180-480)	Severe	11.162,27	7,07%
5	V	(>480)	Very Severe	6.871,55	4,35%

Source: Analysis Result, 2023

Based on the percentage results in Table 3-2, the A value ranges from 0 to 2863.33 for 2023. The deficient class category or value (A < 15) has an area of 19.761,51 Ha, with a percentage value reaching 12,52%. Erosion Hazard Class (KBE) II for the low category or value of A (>15-60) has the most significant area with a percentage of 42,90% of the total area or 67.699,68 Ha. Next, KBE Level III with a medium category or A value (>60-180) has an area of 52.294,79 Ha or a percentage of 33,14%. KBE level IV with high category has an area of 11.162,27 Ha or 7,07%, and for a very high category with actual erosion value >480 has a percentage of 4,35% or 6.871,55 Ha.

The largest area of shallow erosion class with the classification of erosion values (0-15) is in Tambakrejo Subdistrict with an area of 7,860.33 Ha. Furthermore, the highest area in the low-class category or erosion value (>15-60) is in Tambakrejo Subdistrict, which is 6,912.18 Ha. Third, the highest area in the moderate erosion class category with erosion values (>60-180) is in the Beureno District, with an area of 2,198.79 Ha. The analysis results in Figure 5 visualize the erosion hazard level in Bengawan Solo Watershed (Figure 3-2)

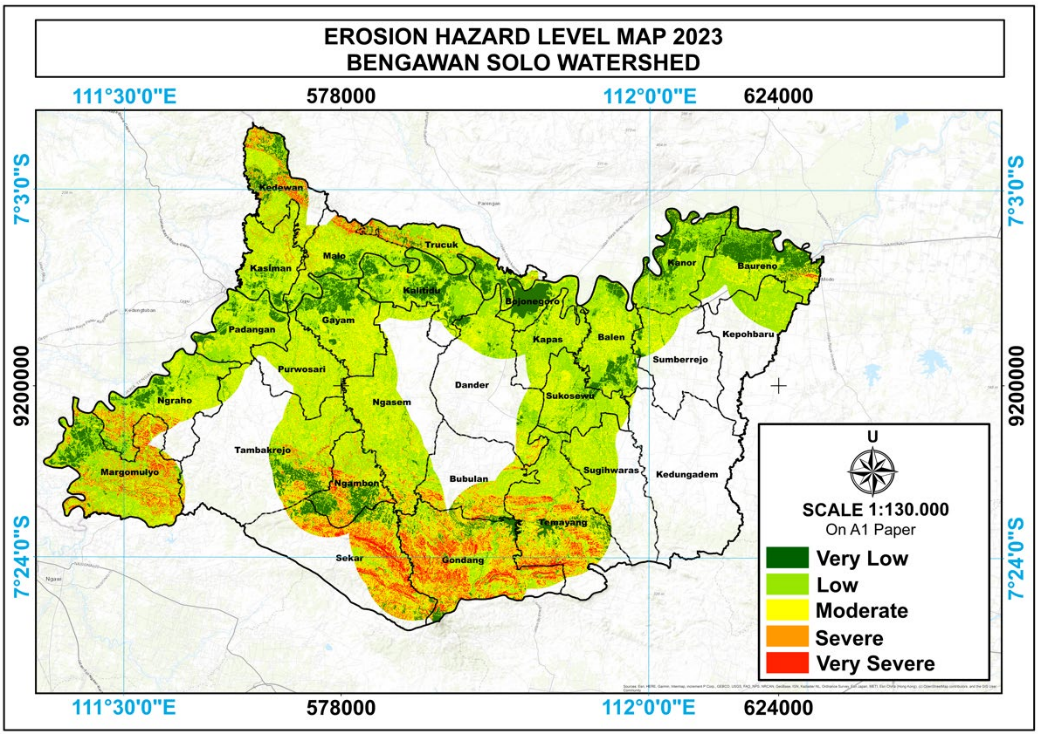

Figure 3-2: Map of Erosion Hazard Level of Bengawan Solo Watershed

The finding that upstream areas have high erosion rates and low vegetation density highlights the importance of better management and monitoring. This could include revegetation and land rehabilitation by replanting native vegetation or introducing cover crops in deforestation or land degradation areas.

3.3. Slope Map

The slope map for critical land analysis purposes in Bengawan Solo

Watershed is classified into 5 (five) classes. This slope class division refers to the Director General of Watershed Control and Protected Forests 2018 (Table 3-3)

Tabel 3-3: Slope Class in Bengawan Solo Watershed

No	Slope	Class	Area (Ha)	Percentages
1	0-8%	Flat	115.807,58	73,32%
2	>8-15%	Ramps	22.369,14	14,16%
3	>15-25%	Somewhat Steep	13.541,73	8,57%
4	>25-40%	Steep	4.852,61	3,07%
5	>40%	Very Steep	1.377,49	0,87%

Source: Analysis Result, 2023

The slope classification results in Table 3-3 are dominated by flat slopes (0-8%) with a percentage of 73,32% of the total or an area of 115.807,58 Ha. The lowest slope area is in the very steep slope class (>40%) with a percentage of 0,87% or an area of 1.377,49Ha. The sloping category class (>8-15%) has an area of 22.369,14 Ha or a percent value of 14,16%. Next, for the analysis of the moderately steep class (>15-25%), it has a percentage value of 8,57% or an area of 13.541,73 Ha. The steep slope class with the category (25-40%) has an area of 4.852,61 Ha or a percentage area of 3,07% of the total area of Bengawan Solo Watershed.

The largest area of the 0-8% classification slope class or flat class category is in Ngasem District, with an area of 12,583.35 Ha. Furthermore, the highest area in the slope class category (>8%-15%) is found in Tambakrejo District, which is 4,935.96 Ha. Third, the highest area in the category of a rather steep class with a topographic slope (>15%-25%) is found in the Sekar Subdistrict, with an area of 3,680.19 Ha. Then, the topographic area with steep and very steep categories is located in the Gondang Subdistrict with an area of 1,628.55 Ha and 694.98 Ha, respectively.

The classification of slope levels is closely related to identifying critical land or areas highly vulnerable to erosion and environmental damage. Flat slopes risk shallow erosion (Pasaribu, 2022). However, in these areas, critical land may be associated with other problems, such as waterlogging or poor drainage. Furthermore, gentle slopes have a lower level of erosion risk than steeper slopes. However, they can still have critical lands, especially if the soil type is erodible or other factors increase erosion risk (Figure 3-3)

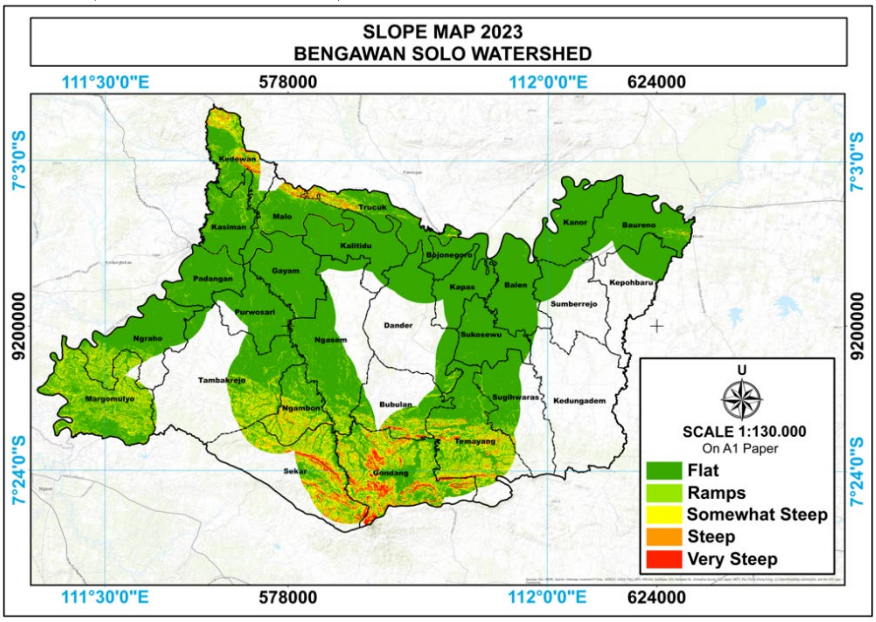

Figure 3-3: Slope Map of Bengawan Solo Watershed

The moderately steep slope class in Figures 3-3 and 3 has a higher erosion potential. These areas are more likely to have critical lands prone to erosion, and conservation measures may be needed to protect these lands. The Steep slope class has a significant risk of erosion. Areas with steep slopes often fall into the critical land category, and serious conservation measures may be needed to reduce erosion and maintain soil fertility. Very steep slopes can be categorized as essential areas regarding erosion. Erosion can be damaging, and critical lands on steep slopes often require extra protection and strong conservation measures.

3.4 Productivity and Land

Management Results

Management data is attribute data, so the data needs to be spatialized so that analysis can be carried out for spatially-based critical land determination. The extent and classification of Forest Areas in Bengawan Solo Watershed are listed in Table 3-4.

Table 3-4: Forest Area in Bengawan Solo Watershed

No	Region		Area (Ha)	Percentage
1	Inside	Protection Forest	1.137,56	0,72%
		Production Forest	60.132,59	37,91%
2	Outside	APL	97.344,93	61,37%

Source: KLHK,2022

Forest area map in Bengawan Solo Watershed based on Table 3-4 The protected forest area is 1.137,56 Ha or has a percentage of 0.72%, and the Production Forest has an area of 60.132,59 Ha (37.91%). The area of APL (area outside the forest) is approximately 97.344,93 Ha (61.37%). The map of forest areas in Bengawan Solo Watershed is shown in Figure 3-4.

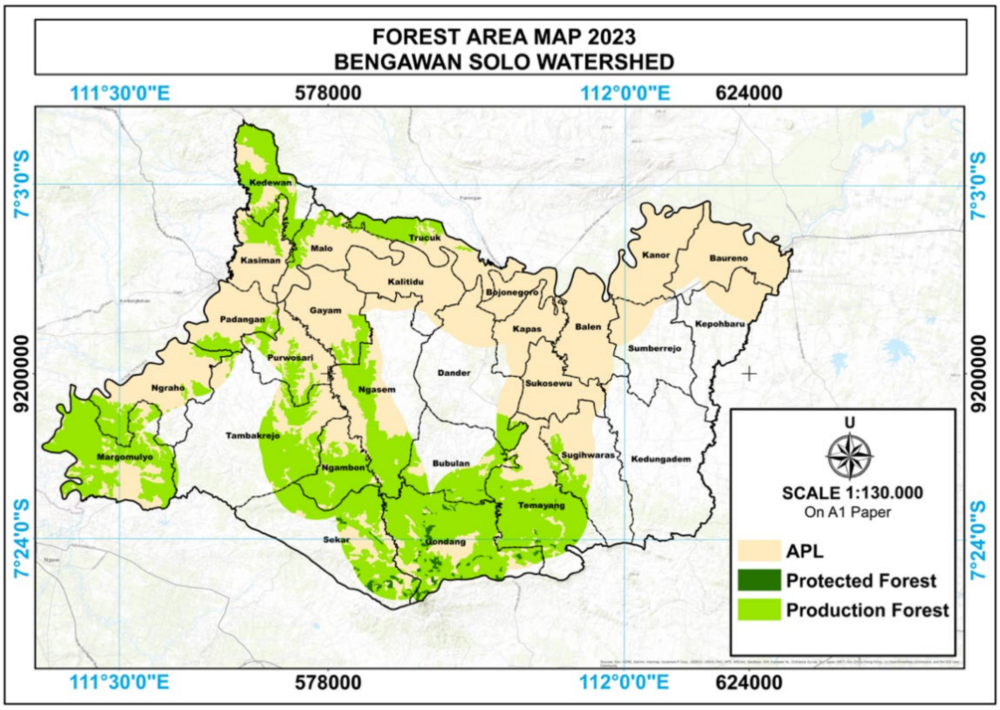

Figure 3-4: Forest Area in Bengawan Solo Watershed

The data in Figure 3-4, categorized as inside or outside the forest area, is a classification made of the type of area function based on the authority of the Government, especially the Ministry of Environment and Forestry, related to its duties and functions in managing forest areas.

3.5 Accuracy Assesment

Field measurements were taken at several sample points to see the soil fertility level and compare it with the results of critical land mapping. The accuracy test was conducted using sampling points using the random sampling method. A total of 30 sample points were randomly distributed in the study area. Most of the sampling was done in agricultural areas, forests, and open land (Figure 3-5). The soil parameters measured in such analyses are grouped into classes based on specific value ranges. These classes include ranges from "very low, low, medium-high, and very high" for parameters such as organic matter content, total nitrogen, and exchangeable cations, and classes such as somewhat alkaline for soil pH.

Figure 3-5: Sampling of soil fertility

Table 3-5: Accuracy Test of Critical Land

	TP	FP	FN	TN	Precision	Recall	Accuracy	F-Score
Non-Critical	7	3	2	18	70,00%	77,78%	83,33%	73,68%
Potential Critical	5	2	3	20	71,43%	62,50%	83,33%	66,67%
Moderately Critical	1	1	0	28	50,00%	100,00%	96,67%	66,67%
Critical	3	1	0	26	75,00%	100,00%	96,67%	85,71%
Very Critical	7	0	2	21	100,00%	77,78%	93,33%	87,50%
Total					**73,29%**	**83,61%**	**90,67%**	**76,05%**

Based on Table 3-5, the critical land classification performance evaluation results show an accuracy rate of 90.67%, precision of 73.29%, recall of 83.61%, and F-Score of 76.05%. This shows that the model has a relatively high accuracy and ability to classify data, with an F-Score value that reflects the balance between precision and recall in classifying critical land.

3.6 Map of Land Criticality Level

The criticality status map of an area is determined by following the technical guidelines for preparing critical land spatial data of the Directorate General of Watershed Control and Protected Forests in 2018 by overlaying the administrative area map, land use map, and erosion map. At the same time, the critical land status map in an administrative area is obtained by overlaying the criticality status map of the administrative area with the land slope map outside the forest area. The results of the largest area in 2023 in the Forest Area in the non-critical and potentially critical classes are in Tambakrejo District, with an area of 3,221.55 Ha and 4,439.16 Ha. The second analysis for the moderately crucial class, the most significant area, is in the Ngasem Sub-district, which is 2,999.43 Ha. The study's most important area of the somewhat critical class is in the Margomulyo Sub-district, which is 2,127.60 Ha. Then, for the area in the required class, the most significant area is found in the Sekar Sub-district, which is 4,249.44 Ha, and very critical in the Margomulyo Sub-district, which is 826.20 Ha.

The results of the most significant area 2023 outside the Forest Area in the not critical, potentially critical, and somewhat necessary classes are found in Kedungadem District with an area of 3,358.98 Ha, 5,994.00 Ha, and 1,075.86 Ha. Analysis for essential and very critical classes has the largest region in Purwosari Subdistrict, which is 554.94 Ha and 53.28 Ha. So, when accumulated for categories within and outside the forest area in 2018 at the Regency level, it can be found in Table 3-5.

Table 3-5: Analysis of the Level of Land Criticism in Bengawan Solo Watershed in 2023

Critical Land Level	Slope					Area (Ha)	Percentages
	0-8% (Ha)	8-15% (Ha)	15-25% (Ha)	25-40% (Ha)	>40% (Ha)		
Not Critical	45.870,10	2.422,89	-	-	-	48.292,99	30,50%
Critical Potential	64.848,72	5.937,20	1.964,37	-	-	72.750,29	45,94%
Moderately Critical	3.807,66	7.055,56	3.206,97	1.935,46	750,99	16.756,64	10,58%
Critical	1.280,85	5.075,53	6.837,93	2.500,59	601,48	16.296,37	10,29%
Very Critical	-	1.877,93	1.532,46	416,56	419,24	4.246,20	2,68%

Source: Analysis Result, 2023

Based on Table 3-5, in 2023, the percentage of critical and very critical land area increased by 10,29% (16.296,37 Ha) and 2,68% (4.246,20 Ha). Meanwhile, the most dominating area is in the crucial potential class, with an area of 72.750,29 Ha, which is 45,94% of the total area of Bengawan Solo Watershed.

One of the main findings is the dominance of the area classified in the critical potential category, reaching an area of 72,750.29 Ha or 45.94% of the total area of the Bengawan Solo Watershed in 2023. This shows that the potential vulnerability to erosion is the region's main focus of land management. This aligns with previous research, which found that factors that can affect critical land in Bengawan Solo are unsustainable land use patterns, such as changes in land use for settlements (Ica Elismetika Komra & Suprapto Dibyosaputro, 2016). In 2023, the percentage of land area classified as critical increased 10,29% equivalent to 16.296,37 Ha, while the crucial area also increased to 10,58%, reaching 16.756,64 Ha. This increase indicates a change in the level of erosion risk in Bengawan Solo Watershed (Figure 3 – 6). However, what is interesting is the dominance of the potentially critical class, which reached 72.750,29 Ha. This area covers about 45,94%of the total area of Bengawan Solo Watershed. This change indicates a shift in risk focus, with critical potential being the region's primary concern in land management.

A visualization of the critical land area results in 2023 can be found in Figures 3-5, which provides an up-to-date visual view of the distribution and essential proportion of land area in Bengawan Solo Watershed. These findings provide more detailed and relevant information regarding the actual condition of the Bengawan Solo Watershed area in 2023 and a solid basis for decision-making in formulating future land management and erosion mitigation policies.

Potentially critical areas, especially along watersheds and areas with steep slopes, need serious attention because these areas have sand land cover, which is a potential area for sand mining by the community. Uncontrolled mining will increase the status of the land to critical land. The upstream area of the Bengawan Solo watershed functions as a rain catchment area, but most of the area has agricultural land use (rice fields and rain-fed rice fields). Engineering is needed to maintain its infiltration function by making biopores, infiltration wells, etc.

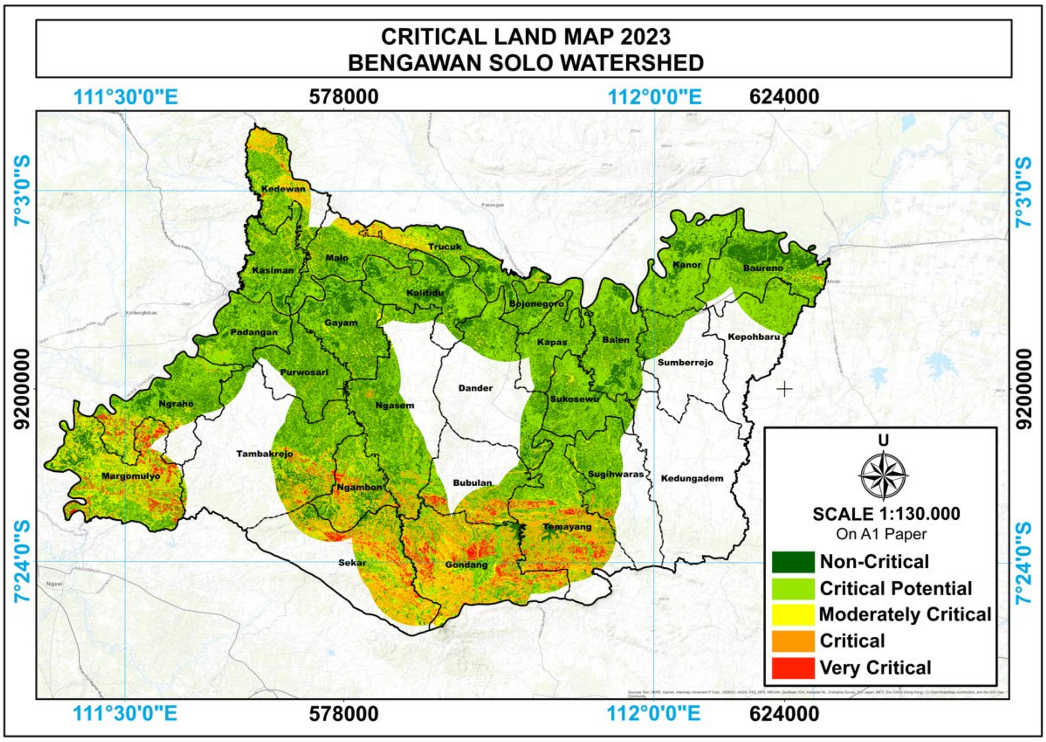

Figure 3-6: Map of Critical Land in Bengawan Solo Watershed in 2023

Watersheds are always associated with upstream and downstream. The headwaters are the most important place and the first place where erosion occurs (Naufal et al., 2023). The research results show that the upstream of the river has a high erosion rate; besides that, the plants on the plain are not dense. This exacerbates the erosion that causes critical land. This shows that the management and use of the area still need improvement. Therefore, it is necessary to regulate land management and monitoring.

Future research will be better if aerial photo mapping, Lidar, or very high-resolution imagery is carried out for higher data accuracy because erosion that causes critical land is closely related to vegetation density and altitude. This research would also benefit from temporal monitoring to identify changes in land cover patterns, erosion rates, and vegetation dynamics over time.

4. CONCLUSION

The Bengawan Solo watershed in 2023 was analyzed for critical land mapping using remote sensing technology and geographic information systems. This study analyzed land cover, erosion hazard, slope, productivity, and land management in the Bengawan Solo watershed in 2023. The main findings show that the area has a varied land cover composition, predominating mixed vegetation, and significant urban growth. Erosion hazard levels are high in upstream areas with low vegetation density. Furthermore, slope analysis revealed that most areas have flat to gentle slopes, but areas with steep slopes require special attention in land management. Land criticality classes are divided into five classes: Not Critical, Potential Critical, Moderately Critical, Critical, and Very Critical. The critical land mapping accuracy test results showed an accuracy rate of 90.67%, precision of 73.29%, recall of 83.61%, and F-Score of 76.05%. The potential critical class dominates, comprising 45.94% of the total area, indicating the need to focus on erosion risk and land management strategies.

For future research to estimate future land change trends and their impact on erosion risk and environmental sustainability, future studies could involve land cover change modeling. In addition, the development of flood mitigation plans and drainage infrastructure improvements can be aided by flood risk mapping and drainage system assessments.

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REFERENCES

Abushnaf, F. F., Spence, K. J., & Rotherham, I. D. (2013). Developing a Land Evaluation Model for the Benghazi Region in Northeast Libya using a Geographic Information System and Multi-criteria Analysis. *4th International Conference on Environmental Science and Development- ICESD 2013*, *5*, 69–75. https://doi.org/10.1016/j.apcbee.2013.05.013

Aldiansyah, S., & Saputra, R. A. (2023). Comparison Of Machine Learning Algorithms For Land Use And Land Cover Analysis Using Google Earth Engine (Case Study: Wanggu Watershed). *International Journal of Remote Sensing and Earth Sciences (IJReSES)*, *19*(2), 197. https://doi.org/10.30536/j.ijreses.2022.v19.a3803

Al-Taei, A. I., Alesheikh, A. A., & Darvishi Boloorani, A. (2023). Land Use/Land Cover Change Analysis Using Multi-Temporal Remote Sensing Data: A Case Study of Tigris and Euphrates Rivers Basin. *Land*, *12*(5), 1101. https://doi.org/10.3390/land12051101

Amaliyah, R., & Umar, R. (2020). Identifikasi Dan Pemetaan Lahan Kritis Dengan Menggunakan Teknologi Sistem Informasi Geografis (Studi Kasus Das Jenerakikang Sub Das Jeneberang Kabupaten Gowa Sulawesi Selatan.

Arianto, D. E., & Nawiyanto, Prof. (2022). Banjir Bengawan Solo dan Pengaruhnya Bagi Kehidupan Masyarakat di Kabupaten Bojonegoro Tahun 2007–2008. *Historia*, *4*(2), 180. https://doi.org/10.19184/jhist.v4i2.25344

Arifandi, F., & Ikhsan, C. (2019). Pengaruh Sedimen Terhadap Umur Layanan Pada Tampungan Mati (Dead Storage) Waduk Krisak Di Wonogiri Dengan Metode Usle (Universal Soil Losses Equation). *Matriks Teknik Sipil*, *7*(4). https://doi.org/10.20961/mateksi.v7i4.38482

Arifin, M. F., & Fitrianah, D. (2018). Penerapan Algoritma Klasifikasi C4.5 dalam Rekomendasi Penerimaan Mitra Penjualan Studi Kasus: PT Atria Artha Persada. *Jurnal Telekomunikasi dan Komputer*.

Auliana, A., Ridwan, I., & Nurlina, N. (2018). Analisis Tingkat Kekritisan Lahan di DAS Tabunio Kabupaten Tanah Laut. *POSITRON*, *7*(2), 54. https://doi.org/10.26418/positron.v7i2.18671

Bashit, N. (2019). Analisis Lahan Kritis Berdasarkan Kerapatan Tajuk Pohon Menggunakan Citra Sentinel 2. *Elipsoida : Jurnal Geodesi dan Geomatika*, *2*(01), 71–79. https://doi.org/10.14710/elipsoida.2019.5019

Breiman, L. (2001). Random Forests. *Machine Learning*, *45*(1), 5–32. https://doi.org/10.1023/A:1010933404324

Cahyono, B. E., Febriawan, E. B., & Nugroho, A. T. (2019). Analisis Tutupan Lahan Menggunakan Metode Klasifikasi Tidak Terbimbing Citra Landsat di Sawahlunto, Sumatera Barat. *Jurnal Teknotan*, *13*(1), 8. https://doi.org/10.24198/jt.vol13n1.2

Danoedoro, P., & Murti, S. H. (2021). Klasifikasi Tutupan Lahan Data

Landsat-8 Oli Menggunakan Metode Random Forest. *03*(01).

El Baroudy, A. A. (2016). Mapping and evaluating land suitability using a GIS-based model. *CATENA*, *140*, 96–104. https://doi.org/10.1016/j.catena.2015.12.010

Feng, S., Zhao, W., Zhan, T., Yan, Y., & Pereira, P. (2022). Land degradation neutrality: A review of progress and perspectives. *Ecological Indicators*, *144*, 109530. https://doi.org/10.1016/j.ecolind.2022.109530

Ica Elismetika Komra & Suprapto Dibyosaputro. (2016). Pengaruh Perubahan Penggunaan Lahan Sempadan Sungai Terhadap Perkembangan Meander Bengawan Solo Provinsi Jawa Timur Tahun 1997—2014. *Jurnal Bumi Indonesia*, *5*(1).

Juniyanti, L., Prasetyo, L. B., Aprianto, D. P., Purnomo, H., & Kartodihardjo, H. (2020). Perubahan Penggunaan dan Tutupan Lahan, Serta Faktor Penyebabnya di Pulau Bengkalis, Provinsi Riau (periode 1990-2019). *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan (Journal of Natural Resources and Environmental Management)*, *10*(3), 419–435. https://doi.org/10.29244/jpsl.10.3.419-435

Kabupaten Bojonegoro Dalam Angka 2022.pdf. (n.d.).

Kabupaten Bojonegoro Dalam Angka 2024.pdf. (n.d.).

Meadows, M., Jones, S., & Reinke, K. (2024). Vertical accuracy assessment of freely available global DEMs (FABDEM, Copernicus DEM, NASADEM, AW3D30 and SRTM) in flood-prone environments. *International Journal of Digital Earth*, *17*(1), 2308734. https://doi.org/10.1080/17538947.2024.2308734

Mishra, B., Kumar, P., Saraswat, C., Chakraborty, S., & Gautam, A. (2021). Water Security in a Changing Environment: Concept, Challenges and Solutions. *Water*, *13*(4), 490. https://doi.org/10.3390/w13040490

N. Simarmata, K. Wikantika, S. Darmawan, A. B. Harto, & A. A. Santo. (2022). Evaluation of Multispectral Image for Mangrove Health Assessment Using Sentinel 2A and Field Spectrometer Data. *2022 IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES)*, 1–7. https://doi.org/10.1109/ICARES56907.2022.9993534

Naufal, N., Mappiasse, M. F., & Nasir, M. I. (2023). Adaptation From Maladaptation: A Case study of Community-Based Initiatives of the Saddang Watershed. *Forest and Society*, *7*(1), 167–183. https://doi.org/10.24259/fs.v7i1.19453

Nguyen, H. T. T., Doan, T. M., & Radeloff, V. (2018). Applying Random Forest Classification To Map Land Use/Land Cover Using Landsat 8 OLI. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-3/W4*, 363–367. https://doi.org/10.5194/isprs-archives-XLII-3-W4-363-2018

Nurnaningsih, D., Alamsyah, D., Herdiansah, A., Aristo, A., & Sinlae, J. (2021). *Identifikasi Citra Tanaman Obat Jenis Rimpang dengan Euclidean Distance Berdasarkan Ciri Bentuk dan Tekstur*. *3*(3), 171–178. https://doi.org/10.47065/bits.v3i3.1019

Pasaribu, P. H. P. (2022). Relationship of slope, soil type,and land use on erosion hazards. *Inovasi*, *19*(2), 147–158. https://doi.org/10.33626/inovasi.v19i2.552

Pham, T. G., Degener, J., & Kappas, M. (2018). Integrated universal soil loss equation (USLE) and Geographical Information System (GIS) for soil erosion estimation in A Sap basin: Central Vietnam. *International Soil and Water Conservation Research*, *6*(2), 99–110.

https://doi.org/10.1016/j.iswcr.2018.01.001

Prawira, A. Y., Wikantika, K., & Hadi, F. (2005). Analisis Lahan Kritis di Kota Bandung Utara Menggunakan Open Source GRASS. *Prosiding PIT MAPIN XIV*.

Rahmat Hanif Anasiru. (2015). Perhitungan Laju Erosi Metode Usle untuk Pengukuran Nilai Ekonomi Ekologi di Sub DAS Langge, Gorontalo. *Jurnal Pengkajian Dan Pengembangan Teknologi Pertanian*, *18*(3), 273–289. https://doi.org/10.21082/jpptp.v18n3.2015.p%p

Ramli, I., Nabila, F., Satriyo, P., & Jayanti, D. S. (2023). Model Pengelolaan Lahan Kritis Pada Daerah Aliran Sungai Krueng Peusangan Menggunakan Sistem Dinamik. *Jurnal Ilmiah Rekayasa Pertanian dan Biosistem*, *11*(1), 44–55. https://doi.org/10.29303/jrpb.v11i1.469

Rodriguez-Galiano, V. F., Ghimire, B., Rogan, J., Chica-Olmo, M., & Rigol-Sanchez, J. P. (2012). An assessment of the effectiveness of a random forest classifier for land-cover classification. *ISPRS Journal of Photogrammetry and Remote Sensing*, *67*, 93–104. https://doi.org/10.1016/j.isprsjprs.2011.11.002

Saberi, A., Kabolizadeh, M., Rangzan, K., & Abrehdary, M. (2023). *Accuracy assessment and improvement of SRTM, ASTER, FABDEM, and MERIT DEMs by polynomial and optimization algorithm: A case study (Khuzestan Province, Iran)*. *15*(1). https://doi.org/10.1515/geo-2022-0455

Simarmata, N., Nadzir, Z. A., & Sari, D. N. (n.d.). *(Shoreline Change Analysis with Sentinel-1 Dual-Polarized Water Index (SDWI) Method based on Multitemporal Data using Google Earth Engine)*. *29*.

Surya Candra, D. (2013). Analysis Of Critical Land In The Musi Watershed Using Geographic Information Systems. *International Journal of Remote Sensing and Earth Sciences (IJReSES)*, *8*(1). https://doi.org/10.30536/j.ijreses.2011.v8.a1735

Sutopo Purwo Nugroho. (2008). Penerapan Sig Untuk Penyusunan Dan Analisis Lahan Kritis Pada Satuan Wilayah Pengelolaan DAS Agam Kuantan, Provinsi Sumatera Barat. *Jurnal Teknologi Lingkungan BPPT*, *9*(2). https://doi.org/10.29122/jtl.v9i2.453

Svoboda, J., Štych, P., Laštovička, J., Paluba, D., & Kobliuk, N. (2022). Random Forest Classification of Land Use, Land-Use Change and Forestry (LULUCF) Using Sentinel-2 Data—A Case Study of Czechia. *Remote Sensing*, *14*(5), 1189. https://doi.org/10.3390/rs14051189

Tuti Herawati. (2010). Analisis Spasial Tingkat Bahaya Erosi di Wilayah DAS Cisadanekabupaten Bogor. *Jurnal Penelitian Sosial Dan Ekonomi Kehutanan*, *7*(4), 413–424. https://doi.org/10.20886/jphka.2010.7.4.413-424

Widyatmanti, W., Murti, S. H., & Syam, P. D. (2018). Pemetaan Lahan Kritis Untuk Analisis Kesesuaian Pemanfaatan Lahan di Kabupaten Kulon Progo. *Jurnal Pengabdian dan Pengembangan Masyarakat*, *1*(1). https://doi.org/10.22146/jp2m.41024

Yulianto, F., Raharjo, P. D., Pramono, I. B., Setiawan, M. A., Chulafak, G. A., Nugroho, G., Sakti, A. D., Nugroho, S., & Budhiman, S. (2023). Prediction and mapping of land degradation in the Batanghari watershed, Sumatra, Indonesia: Utilizing multi-source geospatial data and machine learning modeling techniques. *Modeling Earth Systems and Environment*, *9*(4), 4383–4404. https://doi.org/10.1007/s40808-023-01761-y

Yuningsih, S. M., Raharja, B., & Sudono, I. (2012). Estimasi Laju Erosi Pada Beberapa Daerah Tangkapan Air

Waduk Di Daerah Aliran Sungai Bengawan Solo Dengan Sistem Informasi Geografi. *8*(1).