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Erosion Prediction and Soil and Water Conservation Scenario Using The SWAT Model

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ABSTRACT

Increasing population and development has resulted in inappropriate land use within watersheds that increase soil erosion. One of the hydrologic models that can be used to predict erosion and soil and water conservation in a watershed is SWAT. This research was conducted to predict erosion and the guidance of soil and water conservation in the Yeh Empas Watershed. This research was carried out in several stages, including data collection, data analysis and map validation using the ROC (receiver operating characteristic) and AUC (area under curve) methods. Results revealed that Yeh Empas Watershed had a very light EHL (erosion hazard level) category was found in the downstream area with an annual erosion value of 0 – 14.68 t/ha. In the middle area, the EHL was categorized as light with an erosion value of 15.44 – 57.22 t.ha^{-1}.y^{-1}. The upstream area has moderate EHL with a value of 65.20 – 178.64 t.ha^{-1}.y^{-1}. The validation of the EHL map using the ROC method showed a result of 0.83. This value was classified as very good. It can be concluded that SWAT predictions can be used in estimating erosion and soil and water conservation scenario to reduce 85% erosion.

1. INTRODUCTION

Watershed or DAS (Daerah Aliran Sungai) is an ecosystem unit consisting of main elements comprising natural resources such as soil, water, and vegetation, along with human resources as users of these natural resources (Upadani, 2017). A watershed (DAS) is a land area that accommodates, stores, and drains rainwater to a lake or sea naturally (Harliando *et al*., 2023). Factors that cause and affect the amount of erosion are climate, soil, topography, vegetation cover crops, and human activities (Septiyanti *et al*., 2023). Utilization of resources in a watershed exerts pressure on land conditions, leading to land degradation. Degraded land not only signifies unproductiveness but also contributes to the expansion of critical land due to insufficient conservation efforts, thus posing erosion potential (Wahyunto & Dariah, 2014). Soil erosion assessment is an important step to determine the magnitude of the rate of soil erosion and the level of its danger (Faisol & Mashudi, 2023).

Erosion prediction and soil and water conservation guidance in the Yeh Empas Watershed using the Universal Soil Loss Equation (USLE) method and 2015 data indicate that the erosion rates range from slight to very severe, with significant differences in figures, and no validation was conducted in this study (Widyantara *et al*., 2015). Use of the USLE method it can be used as a basis for land use selection and soil conservation measures aimed at reducing on-site effects of soil erosion (Lestari & Simanjuntak, 2022). The USLE method have a weakness, even though it offers rapid processing but often overestimates on small land units and imbalanced data scales. Errors in selecting erosion prediction formulas can lead to significant discrepancies, failing to adequately represent actual occurrences over large-scale areas (Hanafi & Pamungkas, 2021). USLE is also useful for land for buildings and non-agricultural uses, however, cannot be predicted deposition (Yanti *et al*., 2020). With the advancement of erosion prediction science, this can be further developed using hydrological models. A model represents a depiction of a state, object, or event. This representation needs to be expressed in a simple form, by eliminating or minimizing complex and indirectly related variables. A hydrological model is a simple representation of a complex hydrological system (Harsoyo, 2010).

One of the hydrological models suitable for erosion prediction in a watershed scope is the Soil and Water Assessment Tool (SWAT). SWAT is a model developed to predict land and water management practices in large complex watersheds under various soil conditions, land uses, and management scenarios over long time periods (Neitsch *et al*., 2011). This model can be applied to the Yeh Empas Watershed because SWAT is effective and efficient in evaluating the impacts of alternative resource management practices within a watershed (Utomo *et al*., 2020). The SWAT model can predict erosion values for each Hydrology Response Unit (HRU). HRU is a unit of land formed based on the characteristics of HRU-forming parameters, including slope, soil condition, land use, and climatic conditions (Habib, 2020). Based on the above description, this research aims to predict erosion in the Yeh Empas Watershed. Information on erosion hazard levels can be used to determine appropriate soil and water conservation planning in the watershed.

2. MATERIALS AND METHODS

Research was conducted in the Yeh Empas Watershed located within the administrative region of Tabanan Regency, with the upstream situated in the Penebel District and the downstream in the Tabanan District. The Yeh Empas Watershed covers an area of approximately 11,565.87 hectares with a width of about 3.44 kilometers and a main river length of approximately 33.55 kilometers flowing across the regency. The Yeh Empas Watershed plays a crucial role in irrigating agricultural land owned by residents within the basin to support the local economy. The increase in population, development pressure, and rapid socioeconomic pressures within the basin tend to lead to inappropriate land use due to insufficient attention to land conservation efforts.

2.1. Tools and Materials

The tools used in this research include an ASUS laptop with AMD Ryzen 3 specifications and 4.00 GB RAM, ArcGIS 10.3 application, ArcSWAT 2012, GPS Maps Camera, Microsoft Office Access 2019, Microsoft Office Excel 2019, and Microsoft Office Word 2019. The materials involved in this study comprise Digital Elevation Model (DEM) data with an 8x8 m resolution, administrative maps of Tabanan Regency obtained from the Geospatial Information Agency (BIG), river network maps, soil type maps, land use maps for the year 2017, and climate data from 2012 to 2021 from 2 stations, namely Bongan and Buruan stations in Tabanan Regency sourced from the Watershed Management Agency of Unda Anyar. The research stages are explained in Figure 1.

2.2. Research Implementation

2.2.1. Watershed Delineation

Watershed delineation is the process of determining an area that contributes to surface runoff at an outlet point (Yudha *et al*., 2022). The stages of watershed, sub-watershed, and physical aspects of the watershed boundary formation. Several stages involved in this process include stream definition, inlet and outlet determination, watershed outlet selection and definition, and calculation of sub-watershed parameters.

2.2.2. HRU Analysis

In this stage, soil maps, land use maps, and slope maps were used as inputs. These inputs are overlaid to generate land unit units with specific characteristics. The benefit of establishing an HRU is for the accuracy of load predictions (runoff with sediment, nutrients, etc. transported by runoff) from sub-watersheds (Saputri *et al*., 2022).

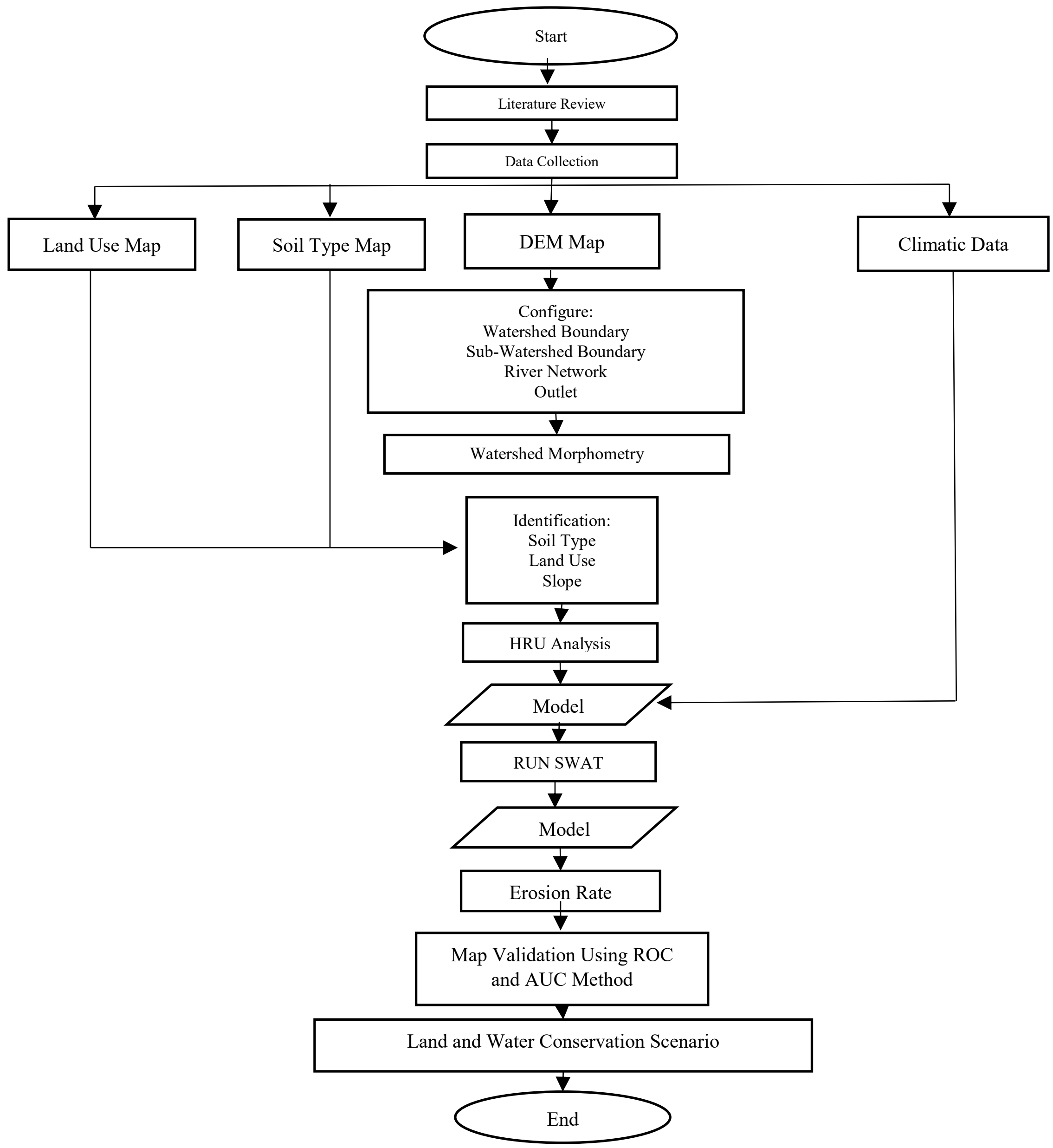

Figure 1. Research flow diagram

2.2.3. Climate Data Input

The climate data included rainfall, minimum temperature, maximum temperature, humidity, sunlight intensity, and wind speed. SWAT database processing involves tabulating rainfall data and other climate data. Climate data entry carried out to obtain output in the form of daily discharge from simulation results (Rau *et al*., 2015).

2.2.4. SWAT Model Run

The SWAT model was executed by entering simulation period, namely 10 years. The simulation results from the SWAT model included separate output files for Sub-Watershed (output.sub file), and HRU (output.hru file). The SWAT simulation results were in the form of a SWAT output table.mdb, which can be opened in Microsoft Access.

2.3. Data Analysis

2.3.1. Erosion Rate Prediction

Erosion prediction in the SWAT model uses the MUSLE method, where MUSLE utilizes runoff factors to predict erosion and sediment. The following equation is used to calculate erosion magnitude using the MUSLE method (Neitsch, 2009).

$$S_{ed} = 11.8\ (Q_{surf}.Q_{peak}.A_{hru})^{0.56}\ K_{USLE}.C_{USLE}.P_{USLE}.L_{SUSLE} \quad (1)$$

where: S_{ed} is sediment yield (ton/ha), Q_{surf} is surface runoff (mm/ha), Q_{peak} is peak runoff discharge (m^3/s), A_{hru} is the Hydrologic Response Unit (HRU) area (ha), K_{USLE} is USLE soil erodibility factor, C_{USLE} is USLE land cover management factor, P_{USLE} is USLE support practice factor, and LS_{USLE} is USLE topographic factor. In the SWAT model, the values of the MUSLE equation factors are available in the database or are results of SWAT simulations. The SWAT model predicts the amount of soil erosion (ton.ha^{-1}.y^{-1}) in each HRU.

2.3.2. Conservation Guidance

Conservation guidance is conducted after obtaining the TBE (Threshold-Based Erosion) class values. The selection of conservation guidance refers to the modification by Putra *et al*. (2017) depicted in Table 1.

Table 1. Soil and water conservation action guidance

Land Characteristic		Conservation Guidance
Slope (%)	**Erosion**	
0 – 3	Very light	Fertilization/liming, use of cover crops and green manure, crop rotation
3 – 8	Light	Contour management, fertilization, crop rotation, mulching, terrace based on width
8 – 15	Moderate	Crop rotation, mulch utilization, terrace based on width
15 – 30	Moderately heavy	Bench terraces with grass reinforcement, grass soil cover crops, crop rotation, mulch utilization, organic/inorganic fertilizer application
30 – 45	Heavy	Bench terraces, manual cultivation
45 – 65	Very heavy	Permanent soil cover crops
> 65	Very heavy	Left in natural condition

Source: Kumajas (1992) in (Putra *et al*., 2017)

In addition to referring to Table 1 for soil and water conservation guidance, simulation using SWAT is also employed to evaluate the effectiveness of the recommended conservation measures in the Yeh Empas Watershed. The simulation results of soil and water conservation guidance display changes in erosion outcomes resulting from the implemented conservation measures. Subsequently, these erosion outcomes are analyzed and compared with erosion outcomes without the simulation of soil and water conservation. The vegetative treatment carried out is by planting hardy plants such as pine, teak and mahogany trees at moderate, heavy and very heavy erosion hazard levels. In this case, the land use that can be changed or reforested is plantation/moorland/shrub land (Dianasari *et al*., 2018).

2.3.3. Map Validation Using ROC Analysis Method

ROC (Receiver Operating Characteristic) analysis is a method used to describe, organize, and classify several predefined categories in a statistical model based on its performance. The application of ROC analysis has expanded to describe and analyze the behavior of diagnostic systems (Nugroho & Nugroho, 2020). A probability table, also known as a confusion matrix, is the initial step in determining a condition by creating a classification model and instances. The classification model and instances used in this research are actual erosion occurrences and predicted erosion occurrences. The relationship between actual erosion occurrences and predicted erosion occurrences is determined in each column of the occurrence. The ROC curve is a graphical representation that shows the classification model's performance at all classification thresholds. This curve maps two parameters:

1. True Positive Rate (TPR), synonymous with sensitivity, is defined as follows:

$$\textbf{TPR} = \frac{TP(True\ Positif)}{TP+FN\ (False\ Negatif)} \quad \ldots\ldots(2)$$

2. False Positive Rate (FPR) is defined as follows:

$$\textbf{FPR} = \frac{FP\ (False\ Positif)}{FP+TN\ (True\ Negatif)} \quad \ldots\ldots(3)$$

When all classification data includes TPR and FPR, the data can be plotted into an ROC graph, and each point representing data from the classification can be connected to form an ROC curve. The ROC curve is the result of plotting true signal (sensitivity) and false signal (1-specificity) across the entire range of possible cutoff points. The range of the area under the ROC curve is from zero to one (Nur & Oktora, 2020). This curve demonstrates the probability or accuracy level of the model. Several important points to note in the ROC graph are if the graph shows the bottom left point (0.0), it represents the probability value never indicating a positive condition, meaning the sorting did not produce false positive and true positive conditions. On the other hand, the graph shows the top right point (1.1), representing the probability value.

2.3.4. Area Under Curve (AUC)

AUC is an area under the ROC curve. The AUC value provides an overview of the overall measurement of the adequacy of the model used. AUC is calculated from the lower boundary of the ROC graph according to the generated graph (Janssens & Martens, 2020). When the AUC is calculated for an exogenously administered drug that is not endogenously produced, it is known that the initial concentration is zero, and, eventually, the drug will be eliminated and the concentration will return to zero. However, if there is some nonzero baseline value for the response of interest, it becomes less clear how to accurately calculate the AUC (Scheff *et al*., 2011). The larger the AUC, the better the variable studied in predicting events. Based on this, the AUC assessment categories from the calculation of the area under the graph to determine the results of predictions using the ROC method can be seen in Table 2 (Maskoen & Purnama, 2018).

Table 2. AUC Value Classification

No	AUC	Value Description
1.	>0,9 – 1	Outstanding
2.	>0,8 – 0,9	Very Good
3.	>0,7 – 0,8	Good
4.	>0,6 – 0,7	Fairly Good
5.	0,5 – 0,6	Not Good

3. RESULTS AND DISCUSSION

3.1. Erosion Prediction with SWAT Model

The erosion results from the SWAT model simulation provide information on erosion across 160 HRUs. Factors influencing erosion hazard levels consist of HRU-forming parameters, including land use, soil type, slope steepness, and climatic conditions. The distribution of erosion in the Yeh Empas Watershed can be seen in Figure 2 and Table 3. According to the SWAT model, areas in the Yeh Empas Watershed categorized as very light erosion hazard are found in the downstream region with values ranging from 0 to 14.68 t.ha^{-1}.y^{-1}, covering an area of 2670.22 ha or 35.79% of the study area. In the mid-region, erosion values range from 15.44 to 57.22 t.ha^{-1}.y^{-1}. These values fall under the light erosion hazard category, covering an area of 4066.85 ha or 54.15% of the study area. The mid-region has slopes <8%, resulting in low surface runoff and erosive energy insufficient for soil detachment and transport processes. In the upstream region, erosion values range from 65.20 to 178.64 t.ha^{-1}.y^{-1}, categorizing it under the moderate erosion hazard with an area of 722.94 ha or 9.69% of the study area. Areas with moderate erosion hazard have steep to very steep slopes. Soil erosion events are greatly influenced by slope steepness; on steep slopes, infiltration rates decrease, leading

Table 3. Erosion hazard levels (EHL) in the Yeh Empas Watershed based on the Directorate General of Watershed Management and Social Forestry Regulation 2013

Erosion Hazard Level (EHL)	Erosion Value ($t.ha^{-1}.y^{-1}$)	Area (ha)	Area (%)
Very Light	0-15	2670.22	35.79
Light	15-60	4066.85	54.15
Moderate	60-180	722.947	9.69

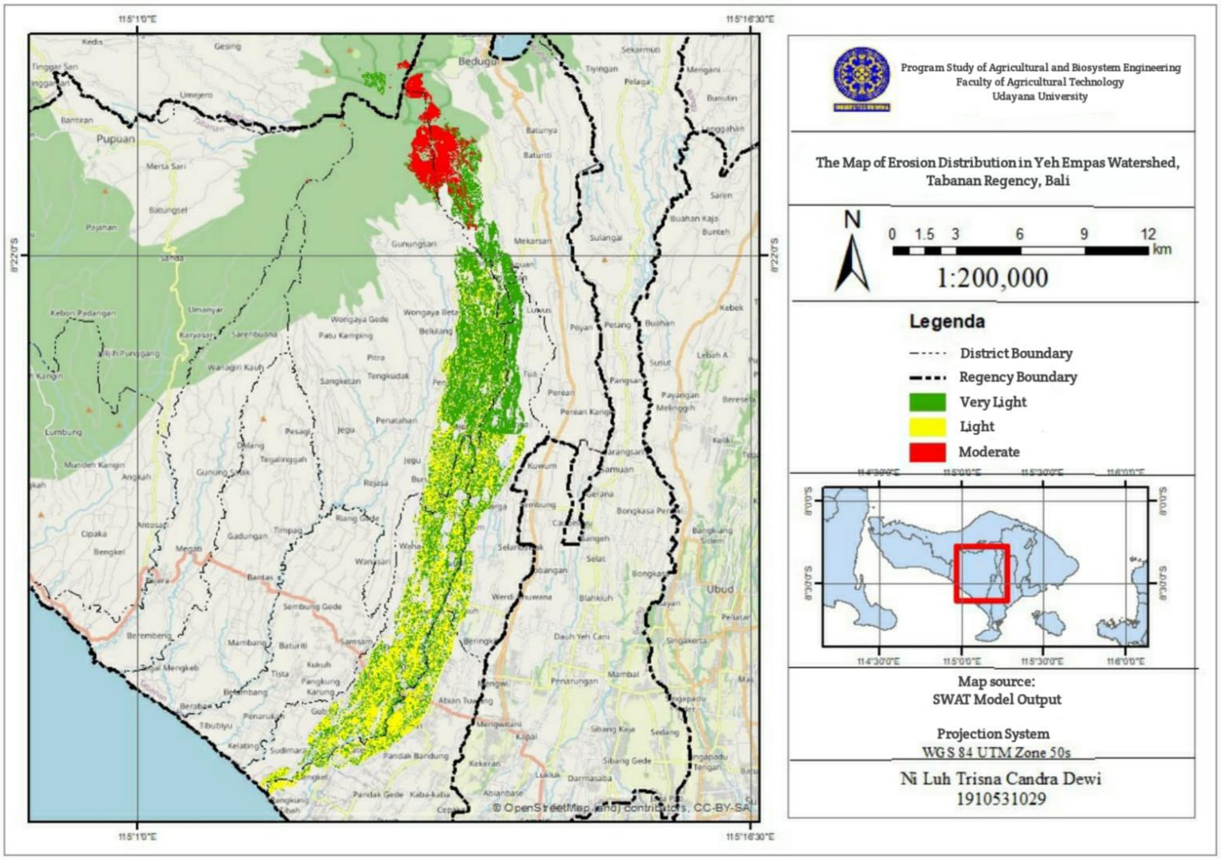

Figure 2. Erosion distribution in the Yeh Empas Watershed

Regarding soil type, the mollic andosol soil type contains 6% organic matter in the top layer and has a mollic A horizon. Despite containing organic matter that can reduce surface runoff and erosion rates, mollic andosol soil has a smooth texture (smeary) (Gunawan *et al*., 2020). In terms of land use, the upstream region consists of primary and secondary dryland forests. While primary dryland forests can mitigate erosion due to their ability to reduce surface runoff, the same sub-basin and HRU also contain secondary dryland forests exploited by humans for various purposes. This exploitation results in deforestation and increased surface runoff. In the mid-region, erosion ranges from 15.44 to 57.22 tons/ha/yr, falling under the category of light erosion hazard. The downstream area exhibits very light erosion with values ranging from 0 to 14.68 tons/ha/yr. HRUs with very low erosion rates have specifications such as slopes of 0-8%, okric andosol soil type, and land use for paddy fields and fallow lands. If it's fast erosion in an area can be determined, then a usage policy can be determined land and appropriate conservation measures for minimize erosion(Novitasari et al., 2019).

3.2. Erosion Map Validation

Based on field validation results using SWAT model outputs in each sub-basin and HRU, 32 prediction points and 50 actual points were obtained. Accuracy testing of the erosion hazard map in this study employs the ROC method. This analytical method yields results in the form of ROC curves and AUC values. The actual erosion occurrences and predicted erosion occurrences are divided into three regional parts: upstream, midstream, and downstream. The probability index values obtained are shown in Table 4.

Table 4. Number of TP, FN, FP, TN occurrences

Region	Occurrence	Number of Occurrences
Headwaters	TP	3
	FN	1
	FP	7
	TN	1
Middle	TP	11
	FN	14
	FP	3
	TN	9
Downstream	TP	9
	FN	7
	FP	5
	TN	11

Table 5. ROC Analysis Statistic Index

TPR	FPR
0.44	0.25
0.53	0.31
0.75	0.68

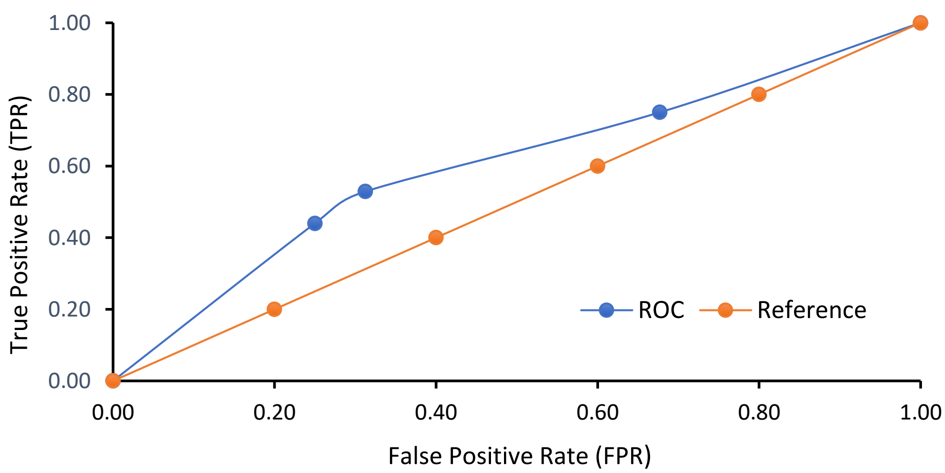

Figure 3. ROC Curve

The values of statistical analysis ROC index are described in Table 5. Based on the table, it is found that the TPR value yields high values in the erosion map validation, resulting in a low FPR value. The validation of erosion prediction maps using the ROC method resulted in an AUC value of 0.83, indicating excellent performance. This AUC value was obtained from calculating the lower limit of the curve according to its shape. In the AUC classification, it falls into the "excellent" category. This is because the AUC area exceeds the Random Performance value, as shown in Figure 3. The figure includes a reference line determined by the boundaries of erosion predictions and actual erosion.

3.3. Guidance to Soil and Water Conservation

The objective of soil and water conservation guidance is to prevent soil damage from erosion and to restore damaged soil. Specifically, soil and water conservations are performed through conservation actions (P) to reduce the amount of erosion produced (Arsyad, 2010). The results of soil and water conservation (SWC) simulations are obtained by applying several guidance to each sub-watershed. The SWC techniques proposed in this study, as listed in Table 1, are as follows:

1. Guidance 1: SWC with terracing. Terracing is a conservation method aimed at reducing slope length, retaining water to reduce the speed and quantity of surface runoff.
2. Guidance 2: SWC with contouring. Land management according to contour involves the formation of flow barriers that can increase water absorption by the soil.

The simulation results of soil and water conservation guidance using terracing showed a decrease in erosion of 4.7% in the middle and downstream regions. In the upstream regions, which is dominated by moderate erosion hazard levels, there was no change in the erosion value or the area of erosion occurrence. This is because terracing conservation is aimed at reducing slope length, where the slope steepness in the upstream area falls into the steep and very steep categories with the use of secondary and primary forest lands. In the Yeh Empas sub-watershed, conservation through contouring in the area of moderate erosion hazard can reduce erosion by 85%, namely from 722.94 ha (25.03%) before the simulation to 49.41 ha (0.66%). The area of light erosion hazard decreased to 254.02 ha (3.40%), while the area of very light erosion hazard decreased to 7156.58 ha (95.93%). This is because land preparation according to contouring involves plowing following the contour to cut the slope, forming beds of soil piles and parallel channels along the contour lines. Contouring will be more effective if followed by planting along the contour as well.

4. CONCLUSIONS

Based on the results of prediction, validation, and soil and water conservation guidance in this study using the SWAT model, the following conclusions can be drawn:

1. The downstream area of the Yeh Empas sub-watershed is classified as very light erosion hazard with an erosion value ranging from 0 to 14.68 tons/ha/year and an area of 2670.22 ha or 35.79% of the Yeh Empas sub-watershed area. The middle area is classified as light erosion hazard with an erosion value ranging from 15.44 to 57.22 tons/ha/year and an area of 4066.85 ha or 54.15% of the Yeh Empas sub-watershed area. The headwaters area has an erosion value ranging from 65.20 to 178.64 tons/ha/year and is classified as moderate erosion hazard, covering an area of 722.94 ha or 9.69% of the Yeh Empas sub-watershed area. The validation of erosion prediction maps for the Yeh Empas sub-watershed using the ROC method shows an accuracy rate of 83%. In the AUC classification, it falls into the "excellent" category.

2. Soil and water conservation guidance in the Yeh Empas sub-watershed involve contouring conservation, which can reduce erosion by 85%.

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