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ANALYSIS OF THE LEVEL EROSION HAZARD ON LAND USE CHANGE IN THE TENGGULUN HULU SUB-WATERSHED, ACEH TAMIANG DISTRICT

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ABSTRACT

The objectives of this paper are 1) to determine the level of erosion hazard in 2003, 2013 and 2023 in the Hulu Watershed of Tenggulun District, Aceh Tamiang Regency, 2) to determine the level of erosion hazard in the future, namely in 2033, 3) and to know the Erosion Disaster Policy Direction in the Hulu Watershed of Tenggulun District, Aceh Tamiang Regency. The method used is a mixed methods, namely survey research and spatial data analysis. Furthermore, in processing the direction of disaster mitigation policies, the Analytical Hierarchy Process method is carried out, which aims to formulate the priority of appropriate directions for erosion disaster mitigation. Based on the study's results, the level of erosion hazard using the USLE method in 10 years has significantly changed in 2003, 2013, and 2023. Severe erosion events are found in Selamat Village and Tenggulun Village. Furthermore, the prediction of the level of erosion hazard using the mollusce plugin method, to be able to see the simulation of future changes, and can see the kappa value index with a value of 6-8 which means the results of the value are very good within the scope of the kappa index assessment. Therefore, it can be used in the future. In addition to a policy analysis of erosion disaster mitigation policy direction, three criteria were obtained: the environment, erosion disaster mitigation, and policy. Subcriteria that are prioritised include the existence of sustainable watershed management.

Keywords: *Disaster Mitigation; AHP; Watersheds; Erosion; Geographic Information System*

INTRODUCTION

Watersheds are divided into three parts, namely upstream, which functions as a protection area, while in the middle, as a distribution of water utilisation, and downstream, as land use for humans (Fei et al., 2024). A watershed is an area of limitation of the ridges of water flow originating from the fall of rainfall to the earth's surface, then the water collects in a river (Kironoto et al., 2020). Suppose the watershed can be managed following applicable regulations. In that case, the quality of the river can be maintained. However, on the contrary, if the watershed is damaged due to changes in land use, increasing population and lack of environmental awareness, the need for water will decrease and can lead to high rates of sedimentation and river erosion (Huda et al., 2020; Wu et al., 2024).

River erosion is a natural event that occurs around the banks of the river. This can be caused by high levels of rainfall intensity, soil types, unsuitable land and hilly topography (Hasan et al., 2024). Erosion that occurs continuously can decrease the capacity of infiltration or absorption of water into the soil and can lead to disasters (Levine et al., 2024).

Aceh Tamiang Regency has a watershed close to local settlements, and the watershed's condition is eroding. This event occurs due to the higher level of rainfall intensity, and the water around the watershed will gradually erode the riverbanks, which causes the river water flow to overflow, which can cause disasters (Jakfar et al., 2020). Tenggulun is one of the sub-districts located in Aceh Tamiang, Aceh Province. Tenggulun is one of the sub-districts located in Aceh Tamiang, Aceh Province. Based on incident information obtained through BPBD, erosion in Tenggulun is getting wider and can even threaten local settlements. There is a residential area that is the most severe because the distance between the backyard of the house and the riverbank reaches 2 meters; if there is no countermeasure, then the residential area can be washed away by the water current (Damanik et al., 2022; Yulius, 2018).

Based on Aceh Tamiang Regional Disaster Management Agency (BPBD) data, erosion events often occur in 4 sub-districts, namely in the upstream part in Tamiang Hulu and Tenggulun Districts. In 2023, in Kampung Selamat, erosion occurred; in that place, there were community settlements whose houses were eroded by erosion and almost collapsed. Meanwhile, in the downstream part, precisely in Seruway and Bendahara Districts, erosion occurs more severely due to the swift flow of water and the embankment that the swift water has damaged. However, the embankment has been built with concrete construction. Based on information obtained through BPBD Aceh Tamiang, residential areas are the most severe because the distance between the backyard of the house and the riverbank can reach 2 meters. Without a countermeasure, the water flow can wash away the residential area. Temporary prevention efforts can be overcome by stacking burlap along the riverbank to temporarily anticipate erosion disasters (Damanik et al., 2022).

Erosion that occurs continuously will cause various problems on land, especially in watersheds (Wilis, 2020). Erosion land changes often occur can be caused by factors of population needs for a land so that it can cause disasters in the surrounding area, if these conditions are allowed to continue or if there is no countermeasure, it will result in a high number of disasters, one of which is the higher erosion rate (Ihwan et al., 2023; Suhairin, 2020). Therefore, it is necessary to have a policy direction for mitigating watershed land changes due to erosion, which aims to prevent environmental damage and maintain the function of watershed areas (Banun et al., 2022).

Disaster mitigation policy direction is one of the efforts to reduce the risk of disaster events, either physically carried out or raising awareness of the surrounding community's threat of disaster. In addition, the direction of disaster mitigation policies can be used as a reference by the government in making disaster management decisions (Febrianto et al., 2020).

Advances in technology that are increasingly sophisticated erosion hazard levels can be analysed using Geographic Information Systems (GIS). A Geographic Information System (GIS) is a system that can analyse an event that occurs on the Earth's surface (Duressa et al., 2024). The USLE (Universal Soil Loss Equation) method generally analyses the erosion hazard level. This method is used to predict the long-term average erosion of surface erosion (sheet erosion) and gully erosion in a particular land situation (Hishamunda et al., 2024; Pham et al., 2018).

Similar research has also been carried out by Anggara et al. (2024). Rendra et al. (2023) found that the method used in analysing erosion uses RUSLE (Revised Universal Soil Loss Equation), while researchers use USLE (Universal Soil Loss Equation) within 10 years and determine the direction of erosion disaster mitigation policies. This research is able to provide an overview of the erosion hazard zone and its relationship with land use change within a certain time span.

Based on the background explanation, this writing aims to determine the level of erosion hazard to watershed land change and the direction of disaster mitigation policy. Hopefully, this research can be used as a reference or a source of knowledge, and the analysis stage can use Geographic Information Systems (GIS). Erosion disaster mitigation policy

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direction efforts are carried out to minimise erosion events by carrying out policy direction actions that are correct and following applicable policies (Ajtai et al., 2023).

MATERIALS AND METHODS

This research was conducted in the Hulu Watershed in Tenggulun District, Aceh Tamiang Regency. Geographically, it is located at 03°53'19.00" - 04°21'50.00" LU and 97°48'34.00" -98°12'42" EAST. The research location can be seen in **Figure 1** below:

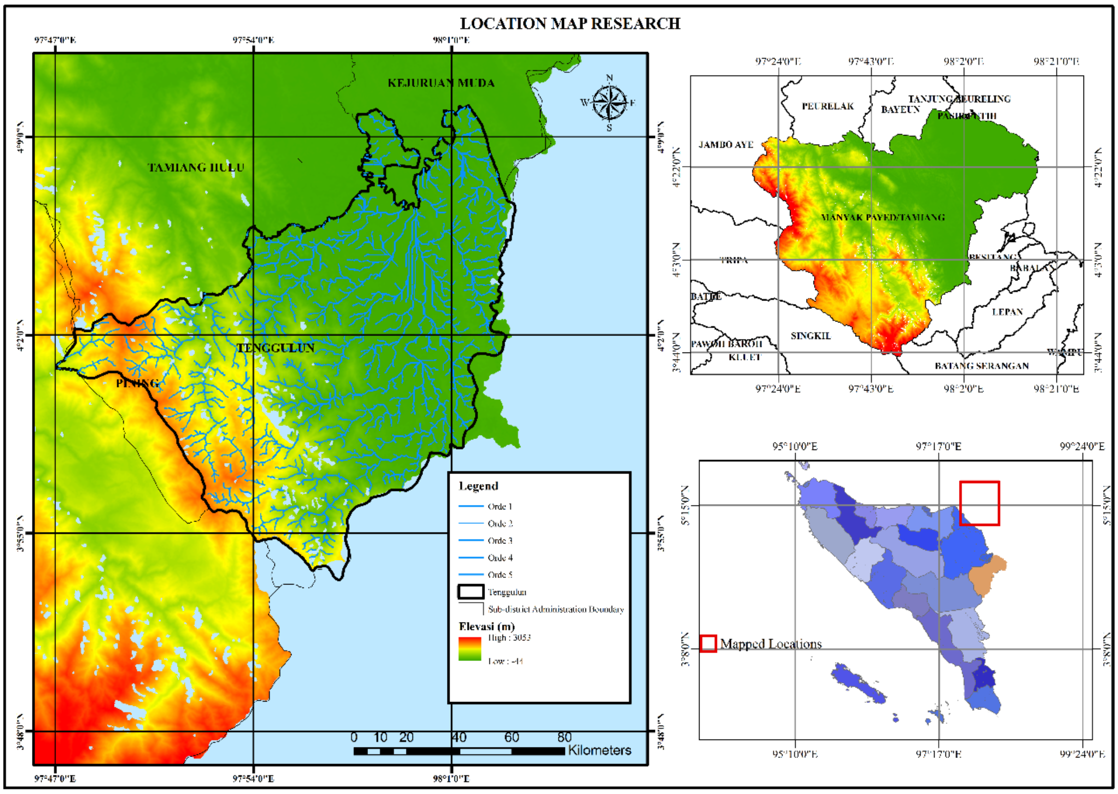

Figure 1. The Proportion of Each Section
Source: Research Results, 2024

This type of research is qualitative and quantitative, or a combination method (Mixed Methods), and survey research and spatial data analysis are conducted. Furthermore, in processing the direction of disaster mitigation policies, the AHP (Analytical Hierarchy Process) method is carried out to formulate priority directions suitable for mitigating erosion disasters. The indicators used in prioritising appropriate directions for erosion disaster mitigation are policies, erosion disaster mitigation and the environment (Febrianto et al., 2020; Pratama et al., 2019; Umar & Dewata, 2018).

The research procedures required during the assessment can be seen in **Table 1** below:

Table 1. Research Instrument

Material Type And Data	Source	Utility
Watershed map	Ministry of environment and forestry	As a determination of the research, Location Boundaries
Rainfall Map	Aceh Tamiang Central Statistics Agency	Indicators in erosion hazard level (TBE) analysis
Soil Type Map	Food and Agriculture Organisation (FAO)	Indicators In Erosion Hazard Level (TBE) Analysis
Slope Map	Digital Elevation Model (DEMNAS)	Indicators In Erosion Hazard Level (TBE) Analysis
Land and plant management map	USGS Imagery And Field Analysis	Indicators in erosion hazard level (TBE) Analysis
Land Change Map 2003, 2013, 2023	Landsat 7 images in 2003, Landsat 8-9 in 2013 and 2023	As a map of land change
Directions For Erosion Disaster Mitigation Policies	Observations, Interviews, AHP (Analytic Hierarchy Process)	To find out appropriate directions for mitigating erosion disasters

Source: (Oktapiani et al., 2020)

Erosion Hazard Level (TBE) Map

The erosion analysis for each map parameter is then carried out in an overlay process in ArcGIS 10.4 layers using the USLE method by entering data on slope, rainfall erosivity, plant management/land use, and soil erodibility or soil type. The processing process is assisted using ArcGIS 10.4 and can be continued by calculating the erosivity index using the Smith & Weischmeier formula. This formula can be stated as follows (Nurkholis et al., 2023):

$$A = R \times K \times LS \times C \times P \quad (1)$$

The Information :

A : soil erosion rate (tons/ha/year)

R : rain erosivity index (Kj/ha)

K : soil erodibility index (tons/Kj)

LS : slope index

C : vegetation cover index

P : land cultivation index/soil conservation measures

After carrying out the map overlay process, the Erosion Hazard Level classification stage is carried out, and there are four classifications, which can be seen in **Table 2** below:

Table 2. Classification of Erosion Hazard Level

Clasification	Land Loss (Ton/Ha/Year)	Explanation
I	< 1,0	Low
II	1,01 - 4,00	Curently
III	4,01 – 10,00	Heavy
IV	>10,00	Very Heavy

Source: (Sumarauw et al., 2024)

Erosion Hazard Level Prediction Map for 2033

The prediction analysis process for the level of erosion hazard in the watershed in 2033 can be carried out using the Cellular Automata Markov (CA-Markov) technique using the QGIS 2.14 application using the MOLUSCE plugin. The level of accuracy that has been achieved can be seen based on the kappa index produced on the prediction results map.

a. Ca-Markov

CA-Markov is a model for predicting changes/use of land cover in an area within a certain time in the future. The Markov model is an approach used to obtain transition probability matrix values (change values) by considering past land changes to predict future land changes. CA-Markov has four methods: artificial neural network, logistic regression, weights of evidence and multi-criteria evaluation. These four methods can predict land cover in an area (Achmadi et al., 2023).

b. Validation

The validation stage compares the temporary simulation map with the analysis result map to determine the kappa value. This index value can determine whether the results of this prediction process are appropriate or not. If the simulation value results are excellent, then there is no need to repeat the accuracy, because it follows the provisions of the kappa value index (Achmadi et al., 2023).

c. Kappa Index

The kappa index is an assessment of the level of accuracy that is important in satellite image processing, because the kappa value can be used to evaluate the error matrix value in the processing process. The kappa index matrix can be seen in **Table 3** below:

Table 3. Kappa Index

No.	Kappa Index	Explanation
1.	< 0.00	Low
2.	< 0 – 0.20	Slight
3.	< 0.21 – 0.40	Enough
4.	< 0.41 – 0.60	Currently
5.	< 0.61 – 0.80	Good
6.	> 0.80	Very Good

Source: (Hapsary et al., 2021)

Analysis of Erosion Disaster Mitigation Policy Direction Processing

Policy direction in determining disaster mitigation policies is carried out using the AHP (Analytical Hierarchy Process) method, where the formulation of priority directions for appropriate erosion disaster mitigation efforts is aimed at minimising the impacts that occur due to disasters. The AHP method is suitable for making decisions and providing clear thoughts or reasons.

For use in determining decision-making. The steps that must be taken are as follows (Safira et al., 2024; Sulistyaningtyas et al., 2024):

a. The first stage carried out is determining the goals or objectives of the problems that occur. This serves to determine the criteria and sub-criteria in decision-making.
b. The second stage is determining the sub-criteria in each criterion section to determine the highest priority decision-making.
c. The third stage is to give a value to each sub-criterion, and then the system will produce the highest priority decision. The provisions for assessing criteria and sub-criteria in the Analytic Hierarchy Process (AHP) method can be seen in **Table 4** below:

Table 4. AHP Criteria

Value	Explanation
1	Both elements are equally important.
3	One element is a little more important.
5	One element is more important than the other elements.
7	One element is clearly more important than the other.
9	One element is absolutely more important than the others.
2,4,6,8	Values between two adjacent consideration values

Source: (Christian et al., 2023)

Determination of priority assessments is carried out in pairs, in order to get the most priority value. After getting the most priority value, you can see the highest matrix; this matrix can be used to determine policy direction.

RESULTS AND DISCUSSION

Erosion Hazard Levels in 2003, 2013 and 2023 in the Tenggulun Aceh Tamiang Sub-district Watershed

The level of erosion hazard that occurred in the upper watershed of tenggulun in 2003 using the USLE method found that in that year it had three classifications, namely the level of light erosion hazard had an area of (13,300 ha), medium had an area of (23,384 ha) and heavy had an area of (6,471 ha). Light erosion hazard is classified in Suka Makmur, Simpang Kiri, Tebing Tinggi, and Rimba Sawang villages. In contrast, the classification of moderate erosion hazard is found in Tenggulun village, and heavy classification is found in part of Selamat village.

Meanwhile, at the level of erosion hazard in 2013, there were three classifications at the level of mild erosion hazard with an area of 15,288 ha found in the villages of Suka Makmur, Simpang Kiri, and Tebing Tinggi, and a moderate classification with an area of 14,755 ha found in the village of Rimba Sawang but also found in Tenggulun and Selamat. At the same time, the heavy classification with an area of 13,112 ha is found in part in the villages of Tenggulun and Selamat.

The classification of the level of erosion hazard in 2023 has three types, with a mild classification (16,140 ha) located in the village of Sempang Kiri, while the moderate classification (12,550 ha) is found in the villages of Suka Makmur, Tebing Tinggi, and Rimba Sawang. The heavy classification (14,465 ha) is found in the villages of Tenggulun and Selamat. For more details, see **Table 5**, **Figure 2**, and **Figure 3**:

Table 5. Change in Erosion Hazard Level

Years	Classification	Extent (ha)	Percentage (%)
Erosion	Heavy	6.471	15%
Hazard Level 2003	Medium	23.384	54%
	Light	13.300	31%
	Totally	43.155	100 %
Years	Classification	Extent (ha)	Percentage (%)
Erosion hazard level	Heavy	13.112	30%
2013	Medium	14.755	34%
	Light	15.288	36%
	Totally	43.155	100 %
Years	Classification	Extent (ha)	Percentage (%)
Erosion hazard level	Heavy	14.465	34%
2023	Medium	12.550	29%
	Light	16.140	37%
	Totally	43.155	100 %

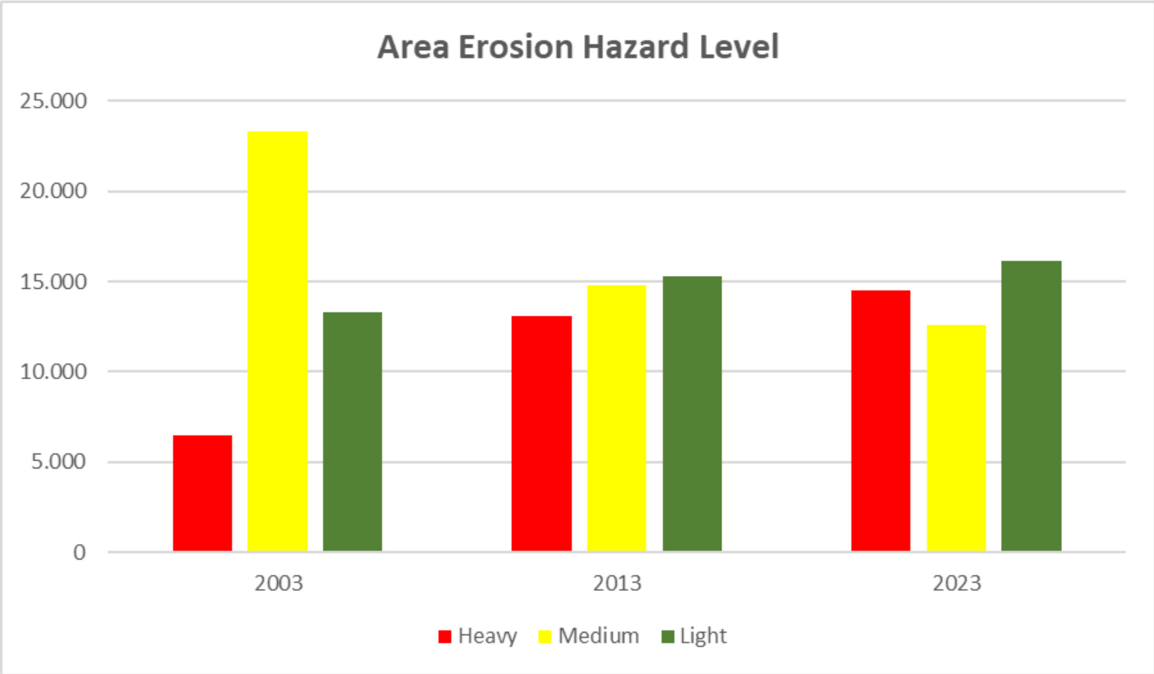

Figure 2. Erosion Hazard Area Diagram

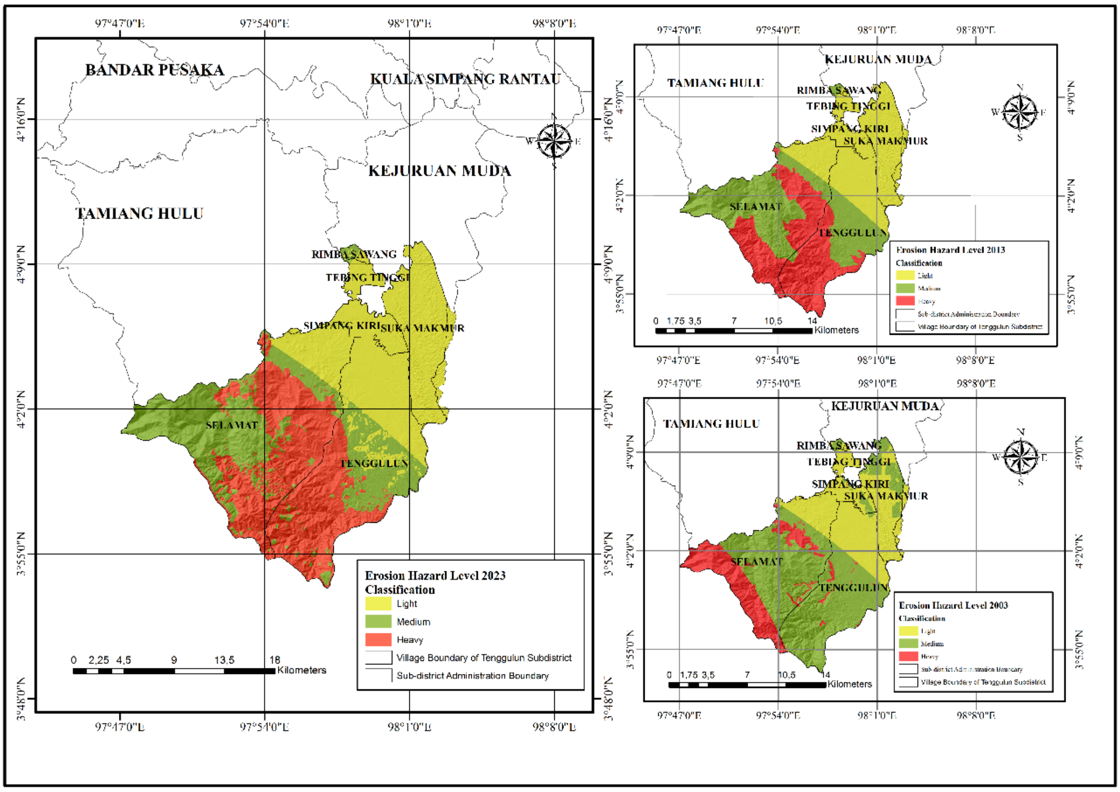

Figure 3. Erosion Hazard Level Map

According to Laudengi et al. (2024), erosivity or high rainfall can affect erosion because high rainfall will cause falling raindrops to destroy the soil condition, so the soil cannot withstand the weight of the rainwater.

Meanwhile, according to Aliffian & Rendra (2024), soil erodibility can also affect erosion because the grains from rainwater can cause soil particles to experience peeling or displacement due to kinetic energy from rainwater. Soil that experiences relatively slow absorption and is continuously exposed to water flow is more likely to experience destruction.

According to Abhipraya et al. (2024), the slope and slope length factors greatly affect the level of erosion hazard. These two factors relate to how water flows on the soil's surface; the steeper the slope, the faster the water flows, so the chance of erosion is higher.

Land cover is also an indicator of erosion (Andriyani et al., 2020). If there is high vegetation, then erosion is less likely to occur. Conversely, if the vegetation in an area is low, the opportunity for erosion will also be higher. Therefore, several factors for erosion according to (Abhipraya et al., 2024; Andriyani et al., 2020; Harjadi & Puspaningrum, 2022; Laudengi et al., 2024) are high rainfall intensity, soil type, slope and also land cover. The method commonly used in erosion processing is the USLE. To get the overall value of each parameter, a raster calculator stage is carried out to get the TBE value for each year.

Future Change in Erosion Hazard Level in 2033

The TBE projection processing process incorporates 2003 and 2013 data, and the need for driving factors to make the prediction results more accurate and get a high kappa value. The driving factors can use elevation, slope, river distance and road data.

The next stage is after the projection stage, which is carried out with the person's correlation method, a variable that measures the relationship between one variable and another.

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The next stage is after the projection stage, which is carried out with the person's correlation method, a variable that can measure the relationship between one variable and another.

Furthermore, at the stage of area change, this stage can be seen in the changes in the area of TBE from 2003 to 2013. In addition, the transition matrix can be seen at this stage, which means that the chances of TBE occurring in the 2003-2013 period can be seen. The value range of 0.01-0.99 means there is a potential for change, while if the matrix value shows a value of 0 or 1, then there is no potential for change in the Erosion Hazard Level.

After the TBE area and transition matrix stages are carried out, the next stage is the transition potential modelling stage, using the Artificial Neural Network (ANN) method, because previous researchers often use this method, and it can also be seen graphically to obtain the level of accuracy of the kappa value. The parameters used in the ANN method are Neighbourhood 1 px, learning rate 0.100, maximum iterations 1000, hidden layers 10 and momentum 0.050. Based on the methods and parameters, the overall accuracy is -0.02268, the minimum validation overall error is 0.15836, and the current validation kappa is 0.82.

The next stage is validation, which aims to determine the level of prediction accuracy achieved. The table below shows that the resulting kappa value is 0.81407. It can be seen that the value is said to be very good and can be used to predict TBE in the future.

After getting the appropriate kappa value, return to the cellular automata tools to make a prediction simulation map. The researcher chooses the number of simulations to be two because the researcher only sees how TBE will be in the next 10 years, namely in 2033.

Based on the prediction results using the Mollusce plugin through the help of the Q-GIS 2.16 application, it can be seen that the prediction of the Erosion Hazard Level in 2033 increased compared to previous years, for more details, can be seen in **Table 6**, **Figure 4** and **Figure 5**:

Table 6 Erosion Hazard Level Prediction Table 2033

Years	Classification	Extent (ha)	Percentage (%)
Erosion hazard level 2033	Heavy	27.615	64%
	Medium	11.165	26%
	Light	4.375	10%
	Totally	43.155	100 %

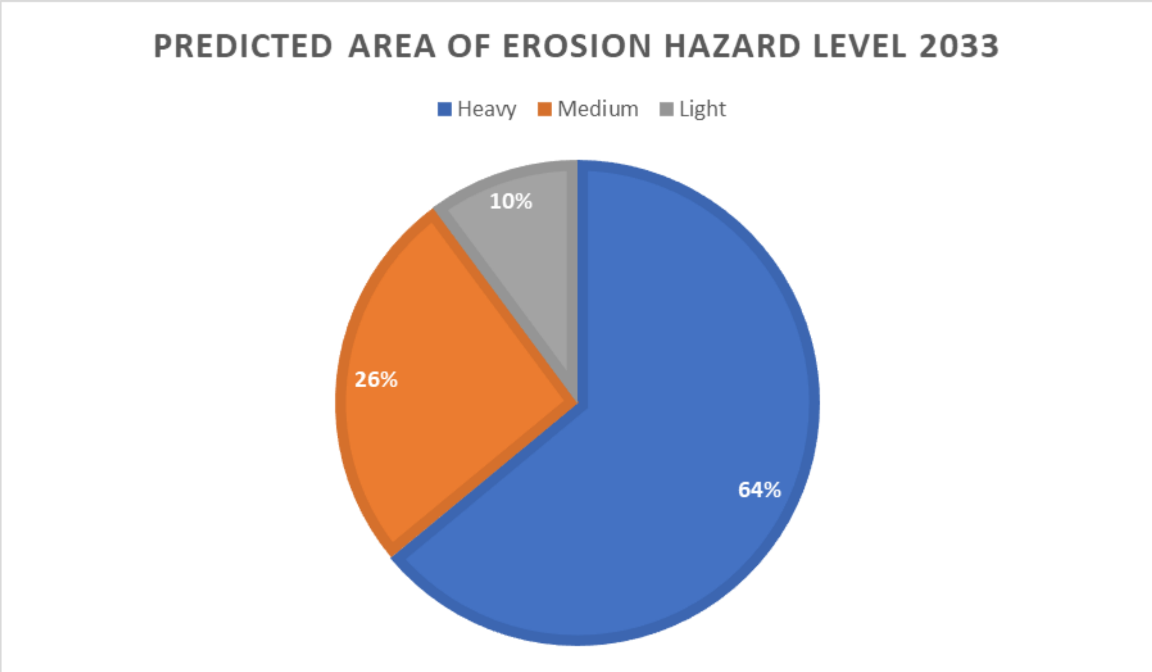

Figure 4. Diagram of Predicted Area of Erosion Hazard Level Map in 2033

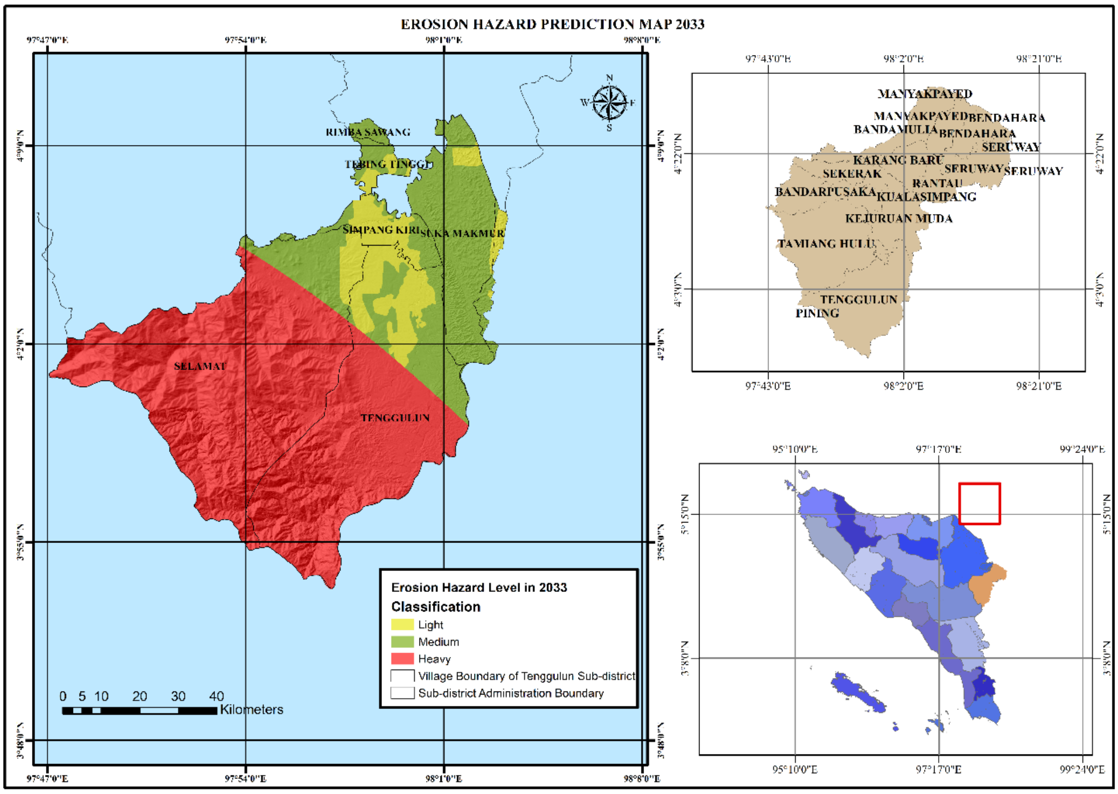

Figure 5. Prediction Map 2033

The future Erosion Hazard (TBE) level is determined by inputting the 2003 and 2013 TBE maps, then entering variables such as rivers, roads, slopes and heights to get future prediction results. Furthermore, the input of the TBE area is carried out in the range of each year, and then a test analysis is carried out, which aims to match the predicted value in the future, so that this prediction can be used later. According to (Bai et al., 2022), to predict the future state of the erosion hazard level, a model called MARCOV cellular automata is used and requires variables such as slope, height, road and river distance. Meanwhile, according to (Hapsary et al., 2021; Mosavi et al., 2020), the kappa value generated in determining predictions can reach a value of 6-8, which means that it can be said to be good and can be used in predicting the level of erosion hazard in the future.

Erosion Disaster Mitigation Policy Direction for the Upper Watershed of Tenggulun Aceh Tamiang Sub-district

Based on the results of the analysis that has been obtained, the direction of erosion disaster mitigation policies in the Upper Watershed of Tenggulun Aceh Tamiang Subdistrict, the researcher takes three criteria to make a description of the policies that will be applied in mitigating erosion disasters in the watershed, these policies can be in the form of the environment, erosion disaster mitigation and also the policy. Furthermore, sub-criteria are determined to select priority comparisons based on other sub-criteria. The criteria and sub-criteria in determining policy direction can be seen in **Figure 6** below:

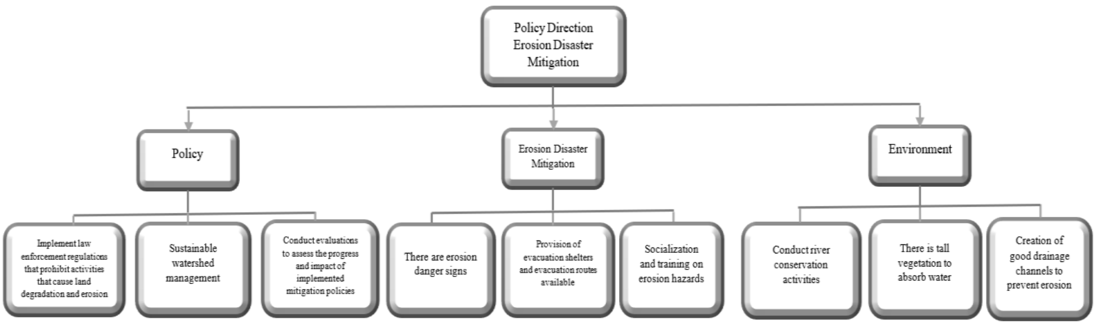

Figure 6. Hierarchy of Erosion Disaster Mitigation Policies for the Upper Watershed of Tenggulun Aceh Tamiang Subdistrict
Source: Analysis Expert Choice 11

The results of determining sub-criteria based on the whole (Combined) can be seen that the criteria that are most prioritised in the direction of erosion disaster mitigation policies are the policy criteria, which have a value of 0.503, while for the second priority, namely the environmental criteria, the results are 0.313. The third priority, namely erosion disaster mitigation, is 0.184. For more details, see **Figure 7** and **Figure 8** below:

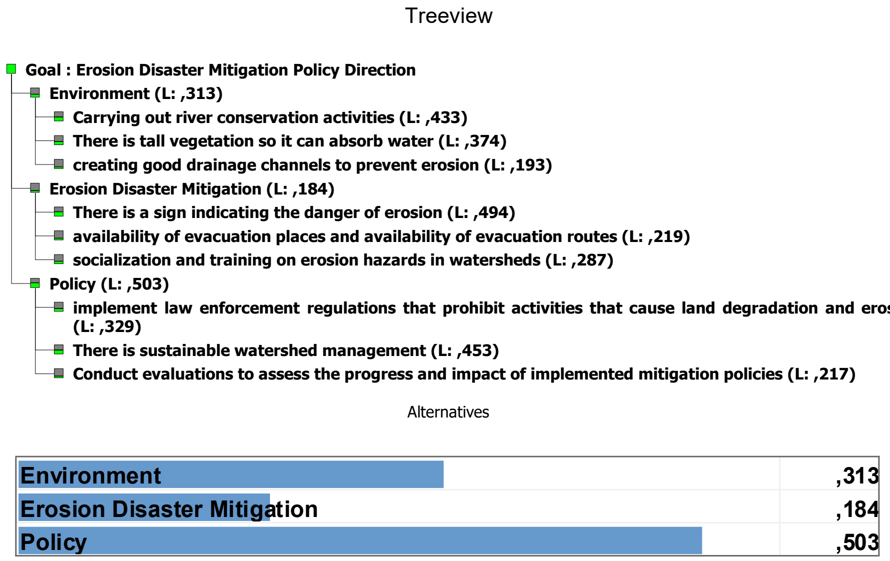

Figure 7. Consistency Score of Erosion Disaster Mitigation Policy Directive Priority
source: Analysis Expert Choice 11

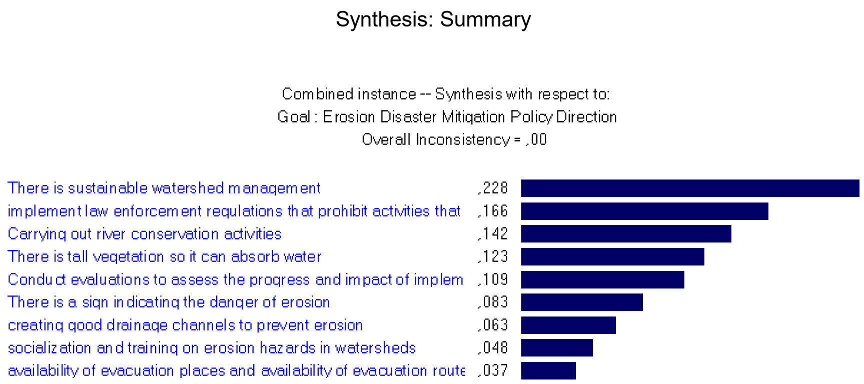

Figure 8. Prioritisation of Alternative Erosion Hazard Mitigation Policy Directions
source: Analysis Expert Choice 11

The direction of erosion disaster mitigation policy obtained three criteria: the environment, erosion disaster mitigation and policy. The environmental criteria are associated with sustainability or environmental protection activities to minimise the risk of erosion disasters. While the erosion disaster mitigation criteria are reviewed based on what can be done before and after the erosion disaster, the policy criteria are reviewed based on the regulations that must be carried out and applied in policies for erosion disaster management. Based on the results of the analysis of policy priorities that have been obtained, based on interviews and discussions according to their fields of expertise, then processed into the Expert Choice software, it was found that there are five main priorities including sustainable watershed management, establishing law enforcement regulations that prohibit activities that cause land degradation and erosion, carrying out river conservation activities, there is high vegetation so that it can absorb water, and conducting evaluations to assess the progress and impact of the mitigation policies implemented. The five priorities are things that have been done by the government and the community, namely, carrying out sustainable watershed management and carrying out river conservation activities, such as planting vertifer grass and carrying out material preparation activities such as piling sacks containing soil along the riverbanks, which aims to minimise erosion. Similar studies have also been conducted by (Febrianto et al., 2020; and Umar & Dewata, 2018), stating that disaster mitigation policy directions can be a solution that can be applied to minimise losses from disasters. The determination of indicators and sub-indicators is adjusted to the problems that occur.

CONCLUSIONS

The level of erosion hazard that occurs in the tenggulun sub-district of Aceh Tamiang district has three types of classification, namely heavy, medium and low, which each year changes the erosion hazard level from 2003 to 2023. This is influenced by high rainfall, soil types that are difficult to absorb water so that the flow of water will gradually erode because it carries the upper soil layer, steep slopes and lack of vegetation around the river, if there is a lack of vegetation then the roots of the plants are not able to absorb water. Currently, the Regional Disaster Management Agency (BPBD) is making disaster mitigation efforts in areas where erosion often occurs, namely by planting vertifer grass and carrying out material preparation activities such as stockpiling burlap filled with soil along riverbanks to anticipate temporary erosion disasters.

Predictions of future erosion hazard levels in 2033 were analysed using the Q-Gis application version 2.16 by applying the Mollusce plugin method, which is a plugin to be able to see simulations of changes that will occur in the future. The plugin has several stages, namely data input accompanied by adding erosion-related variables, the correlation evaluation stage, area changes, modeling of potential transitions, cellular automata simulation, and validation. After all stages are completed, the number of kappa values can be seen; if the value is 6-8, then the prediction map analysis results can be used for the future.

Determining disaster mitigation policy direction includes three criteria: environmental, erosion, disaster mitigation, and policy. The analysis of policy direction was carried out using the Expert Choice 11 application. After the analysis stage was carried out and based on the results of interviews and the results of discussions by the field of expertise of the three policy direction criteria, the priority of policy direction was obtained on three criteria, namely the first determination of policy criteria which had a value of 0.503, while for the second priority, namely environmental criteria, the result was 0.313. The third priority, erosion disaster mitigation, obtained a result of 0.184. Of the three criteria, the first most prioritised sub-criterion is the existence of sustainable watershed management, with a value of 0.228. The second priority is the implementation of law enforcement regulations prohibiting activities that cause land degradation and erosion, with a value of 0.166. The third priority is to carry out river conservation activities with a value of 0.142.

The limitations of this research are limited to the study of sub-dash areas, not the entire dash, the data used uses a 10-year time frame, and uses erosion disaster prediction using Artificial Neural Network (ANN). This research recommends the need for field verification of the research area in the form of erosion and land use classification, using high-resolution image data to be more accurate and to avoid disturbing predictions of other methods.

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