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GIS Application for Modelling Erosion Hazard in Batam Island

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Abstract

Soil erosion disaster is a disaster that occurs simultaneously with landslide events that occur due to the destruction of the soil layer which then causes erosion followed by landslides. The phenomenon of land erosion occurs due to high rainfall, the influence of slopes and slope length, as well as due to development resources according to Mamarodia (2014). Erosion can also occur due to land degradation, namely the loss of organic matter and nutrients from the root area, this study aims to determine the erosion hazard model in Batam Island which can be displayed in the form of a RUSLE model by utilizing a geographic information system (GIS). The data used in the form of slope maps, land use maps, maps of soil types and rainfall maps on Batam Island using the data processing method used is the RUSLE method to provide information in the form of erosion hazard categories and produce a two-dimensional erosion hazard model map. The result is a map of the erosion hazard model in a two-dimensional form with categories obtained from the combination of the four maps that have been classified. The results of this research are information on the area of soil erosion with very light categories (24,200.42 Ha), light (5,488, 20 Ha), medium (5,100.42 Ha), heavy (3,029.43 Ha), and very heavy (2,929.64 ha) spread over Batam Island. The slope with the highest slope height is class 129,284 ft to 148,627 ft, and the lowest height elevation is in class -6,11 ft to 13,232 ft. the Batam area tends to have an area with an elevation of 13,232 ft to an altitude of 32,574 ft.

Keywords: Erosion Hazard Model, GIS, RUSLE Method, Batam Island.

1. Introduction

According to Mamarodia (2014), the land is a development resource that has the characteristics of an available fixed area. Changes due to natural processes turn down the strength of the rock beyond the shear stress if combined with rising water pressure of excessive wetting and lead to a landslide. The extreme weather that occurred in Batam City, Riau Islands often caused floods and landslides in some areas. On 2nd January 2021, a landslide occurred in Tiban Kampung, Sekupang. One house was reported to have suffered severe damage. While in Bengkong District, there was a slanted rock in front of Government Elementary School 008 Bengkong that caused a landslide and hit a church (Batamnews, 2021). On the other hand, the landslide also occurred during the bad weather on the construction site of the mall, causing 2 deaths which occurred on January 9th, 2021 (Medcom.id, 2021).

Disasters that occur concurrently with landslides are soil erosion that appear due to the destruction of the soil layer caused erosion followed by landslides. Erosion is prone to be found on land with steep slope angles (over 15%) and can occur due to land degradation, accumulation of salt or toxic compounds for plants, also soil damage by water (waterlogging). The cause of soil erosion is very dependent on soil conditions, rainfall, and land-use factors. This situation is the basis for making an erosion hazard model that aims to provide information on erosion hazard levels in Batam Island using RUSLE method. RUSLE or Revised Universal Soil Loss Equation is used to calculate long-term erosion from sheet erosion and groove erosion under certain conditions.

Geographic information systems are powerful to develop a spatial model of erosion hazard in Batam Island which is prone to landslides that accompany erosion. Using the information on thematic maps such as rainfall maps, slope maps, soil type maps, and land use maps to be overlaid and classified to construct an erosion hazard model in Batam Island. Based on the general conditions in the field and the slope class map of Batam Island as a whole, the conditions are relatively flat with hilly variations with a maximum height of 160 m above sea level with slopes ranging from 0-3%. Based on the description in the background section, a problem formulation on

the research is How to model the results of the erosion hazard distribution obtained to develop a better spatial understanding to minimize the damaging impact on the environment and human life? Whereas the purpose of this study is to model the distribution of erosion hazards in the form of a map obtained by combining information of rainfall data, slope data, soil type data, and land use data that have been processed using the RUSLE method into a map of the erosion hazard model in the Batam Island.

2. Methodology

This Research starts with a literature study by conducting research journals or reports that have to do with the problem to be solved. The RUSLE method is then carried out by weighting the data and classifying areas to identify potency of erosion in research area. When overlaying data in a GIS operation, several data sets representing different themes are layered together to identify the data relationships. Weighting as a quantitative data analysis technique used to assign a value to each parameter characteristic using the RUSLE formula. RUSLE (Revised Universal Soil Loss Equation) method for evaluating soil erosion introduced by Wischmeier and Smith (1978), The formula for RUSLE was developed from the USLE equation by replacing the rain erosion index factor (R) replaced by the Erosivity of rain index (R).

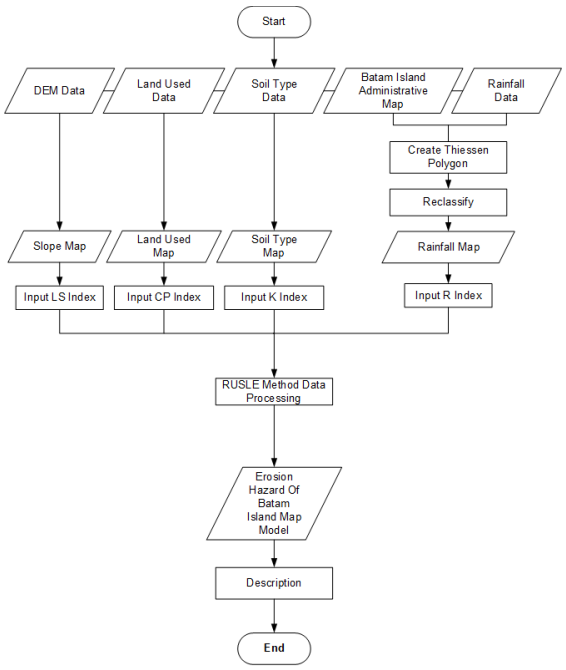


Figure 1. Flowchart Research

Four types of data are needed as the basis for processing based on the formula used, namely rainfall maps, soil types maps, slope maps, and land used maps. In the data classification method in GIS operations, the classes are divided based on the scoring results that have been generated. The result of this research is a model map of the potential for erosion in Batam Island. The research flowchart is presented in Figure 1.

2.1. Research Time and Location

Research area covers Batam Island, Riau Islands Province with research time run from May to October 2021. Geographically, Batam Island has a very strategic geographical location and is in international transportation routes. Located between 0º25'29" North Latitude to 1º15'00" North Latitude and 103º34'35" East Longitude to 104º26'04" East Longitude, Batam Island has an area of 403.88 Km^2 or the equivalent of 40,388 hectares with nine sub-districts such as Nongsa, Batam City, Bengkong, Lubuk Baja, Batu Ampar, Sekupang, Sei Beduk, Batu Aji, and Sagulung.

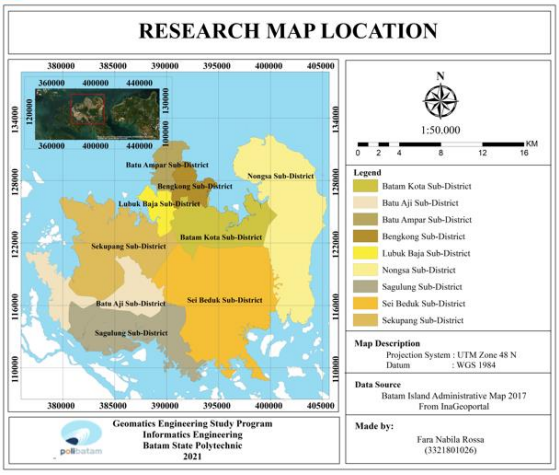


Figure 2. Research Map Location

2.2 RUSLE Method

As a versatile calculation method to evaluate location and planning purposes and support the decision to choose erosion control measures, RUSLE can provide an estimate of the severity of erosion. This includes a number to indicate the benefits of a planned promotion, including the added benefit of a detour or mulch (Hadiharyanto, 2003). The RUSLE model retains the USLE structure. Variables R (rain erosion/ runoff), K (erosion) Soil use), LS (length and slope), C (plant management), P (Conservation measures) Only to calculate the erosion rate. The difference between the USLE method and the coefficient of rain erosion index (R). The index used in the calculation of eroded soil is presented in Table 1 below.

Table 1. Index used in the calculation of eroded soil (Herawati, 2010)

Calculation Index	Map Type	Symbol
Rain Erosivity Index	Rainfall Map	R
Soil Erodibility Index	Soil Type Map	K
Slope length and slope index	Slope Map	LS
Vegetation cover index and land cultivation	Land Used Map	CP

In the processing stage, the erosion hazard map is constructed by overlaying RUSLE data attributes including rainfall (R), slopes (LS), soil type (K), and land use (CP) to produce a classification based on

calculated erosion value. Classification of erosion values is calculated based on the index referring to Table 1 and the following formula:
Eroded Soil (A)

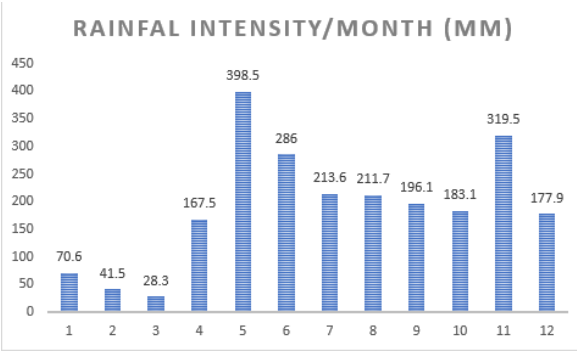
A = R x K x LS x CP ……..(2.2)
Which is
A = Amount of eroded soil (in tons/ha/year)
R = Rain erosivity index
K = Soil erodibility index
LS = Slope index
CP = Land cover index

2.3 R index factor in Batam Island

Rainfall map developed based on monthly rainfall data captured by BMKG Batam data acquisition station in 2020 and calculated with the result displayed in Table 2 and Graph 1.

Table 2. Rainfall Data in Batam Island.

Month	Rainfall	Days	Max Rainfall
January	70.6	9	37.1
February	41.5	9	15.5
March	28.3	5	10
April	167.5	11	62.3
May	398.5	18	115.2
June	286	21	40
July	213.6	17	47.3
August	211.7	16	80.5
September	196.1	15	60.1
October	183.1	14	31
November	319.5	23	48.1
December	177.9	20	37.5



Graph 1. Chart Rainfall Intensity/Month

Rainfall calculation implemented based on the Thiessen polygon method on the rainfall data. Thiessen Polygon method calculates the weight at each data station to represent the surrounding area and formed in Figure 3 below and trimmed based on research area displayed in Figure 4. The area within the basin assumed that the rainfall has the same as the nearest station because the rainfall recorded by a station represents that station.

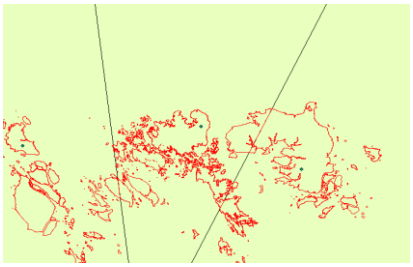


Figure 3. Thiessen Polygon

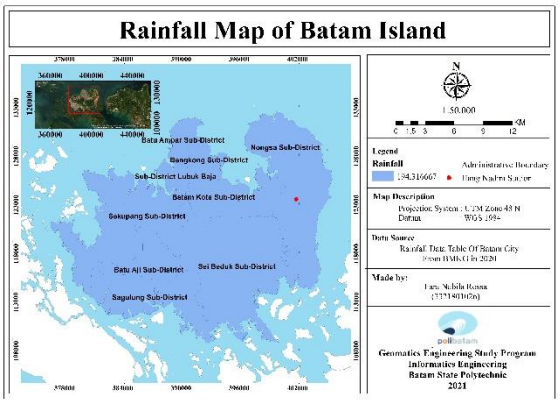


Figure 4. Rainfall Map

The R factor is the result of the calculation of the intensity of the rain. After calculating, the data is converted into a layer that is used to determine the R factor with the Thiessen polygon method, then the next process uses calculations with the formula Rain Erosivity (R),

$EI_{30} = 6.119\ Rain^{1,21} \times Days^{-0,47} \times MaxP^{0,53}$.....(2.3)

Which is:

EI30 = R= Monthly rainfall erosivity Index
Rain = Monthly rainfall (cm)
Days = Monthly Days rainfall total (cm)
Max P = Monthly maximum rainfall for 24 hours in that month (cm)

2.4 K index factor in Batam Island

Shows the degree of vulnerability of the soil to erosion, namely soil erosion by particles and the replacement of the kinetic energy of rain. Fine soil textures are easier to clean than coarse soil textures. High organic content will produce high erodibility values. The following is the soil erosion index value used in this study.

Table 3. Soil Erodibility Index (K)

No	Type of soil	Index (K)
1.	Alluvial	0,156
2.	Andosol	0,278
3.	Yellowish-brown Andosol	0,298
4.	Andosol and Regosol	0,271
5.	Grumusol	0,271
6.	Latosol	0,075
7.	Latosol brown	0,175

No	Type of soil	Index (K)
8.	Brown Latosol and Yellowish-brown Latosol	0,091
9.	Brown Latosol and Regosol	0,186
10.	Sorrel Latosol	0,062
11.	Sorrel Latosol and Brown Latosol	0,067
12	Sorrel Latosol and Red Latosol	0,061
13	Sorrel Latosol, Yellowish-Red Latosol and Litosol	0,046
14.	Podzolic	0,107
15.	Yellow Podzolic and Gray Hydromorphic	0,249
16.	Red Podzolik	0,046
17.	Yellowish Red Podzolik	0,166
18.	Regosol	0,301
19.	Litosol and Organosol	0,290

(Source: Bappenas, 2012)

At this stage of processing soil type data based on the area research, it can be seen that the types of soil found in Batam Island are Grumosol, Litosol, Organosol, Podzol, and Podzolic as can be seen in Figure 5. The K factor was obtained based on the soil type data obtained. After the soil type in the research area is known, the K value used in the research area is assumed to have a K value similar to the results of the erodibility calculation from Bappenas contained in Table 3. This value will be input into the data that has been processed by creating a new field with a double data type. Podsolic has red to yellow colour soil, its organic and mineral content are easily leached by rainwater. Podzolic is soil that can experience erosion due to surface runoff, gravel sandy texture (Jaya, 2017). Based on this statement, it shows that the type of soil that can cause the landslides is the type of podzolic soil due to disasters that accompany landslides is erosion disasters.

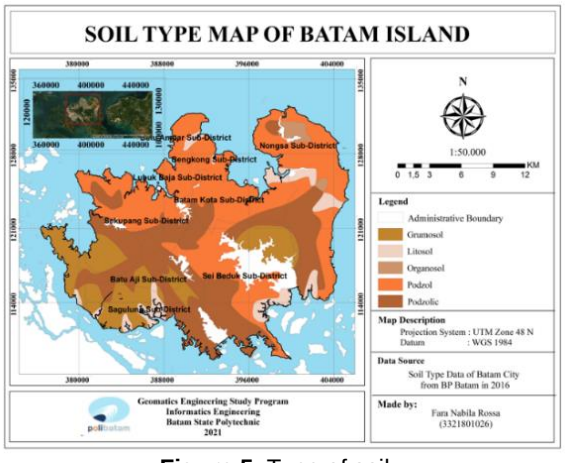


Figure 5. Type of soil

2.5 LS index factor in Batam Island

Batam City DEM data was extracted from DEMNAS website and derived to get the length and tilt of the slope. By using the DEM data, the appearance of slopes and elevations is obtained. To get an accurate slope, then do contour processing first by making contours from DEM data. Then select a clipping to cut the contour, using the Batam area administrative boundary. Then convert the contours and boundaries to UTM and process the contour into a slope by using the slope function. To further reclassify the slope value into 5 (five classes) based on the USLE method in Table 4. The result LS Indes in Batam Island is presented in Figure 6.

Table 4. Index of Slope Length and Slope (LS)

No	Class	tilt (%)	Value LS
1	Flat	0% - 8%	0,4
2	Sloping	8% - 15%	1,4
3	Slightly Steep	15% - 25%	3,1
4	Steep	25% - 45%	6,8
5	Very Steep	>45%	9,5

(Source: RKLT (Land Rehabilitation & Soil Conservation), Book II 1986)

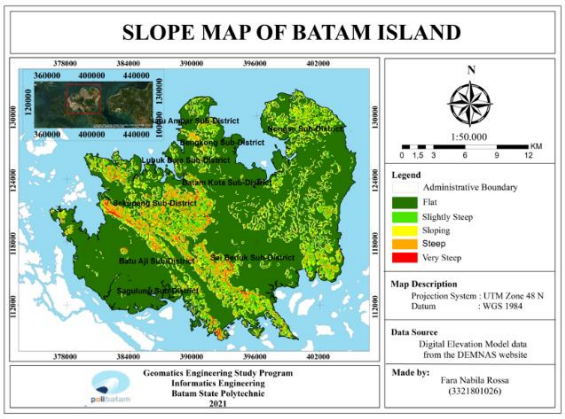


Figure 6. Slope map

2.6. CP index factor in Batam Island

Land use is one of the determining factors that affect and lead the value and amount of eroded land. Land use value is determined based on the type of land in each land unit on Batam Island with CP factor index value as shown in Table 5.

Table 5. Land Use Index (CP)

No	Land Use	Value CP
1	Settlement	1,00
2	Swamp/swamp forest	0,001
3	pond	0,001
4	Factory/building	1,00
5	Airport/Port	1,00
6	Salting	1,00
7	River	0,001
8	Sand	1,00
9	Lake/dam	0,001
10	Vacant land/grassland	0,02
11	Shrubs	0,1
12	Irrigated rice field	0,02
13	Rainfed rice field	0,05
14	forest	0,001
15	garden	0,3
16	Field	0,28

(Source: Bappenas, 2012)

2.7 Erosion Hazard Mapping

Erosion hazards map construction based of computation on R, LS, CP and K parameters

contained in the overlay process of each RUSLE data attribute. Classification is a process of grouping data based on certain types and levels, in which data from erosion that has certain characters have been grouped into certain classes. The classification of erosion values is input by referring to the provisions of the erosion class contained in Table 6.

Table 6. Classification of Erosion Hazard Levels

Erosion Value (A) (ton/ha/year)	Erosion Hazard Level	
	class	Category
< 15	I	Very Light
15-60	II	Light
60-180	III	Currently
180 – 400	IV	Heavy
> 400	V	Very heavy

(Source: Ministerial Regulation No. 32 of 2009 Procedures for Compiling RTk RHL-DAS)

3. Results and Discussion

3.1 Rainfall Index (R)

Rain Erosivity of Rainfall is one of the determining factors that lead to soil erosion. The higher the intensity of the rain, the more the land will receive a lot of rain falling so that the erosion that occurs is also getting bigger (Sucipto, 2007). Rainfall plays an important role in determining the area of erosion. The value of the rain erosivity index (R) uses the following formula:

$$EI_{30} = 6.119\ Rain^{1,21} \times Days^{-0,47} \times MaxP^{0,53} \quad ....(3.1)$$

Which is:

EI30 = R= Monthly rainfall erosivity Index
Rain = Monthly rainfall (cm)
Days = Monthly Days rainfall total (cm)
Max P = Monthly maximum rainfall for 24 hours in that month (cm)

Table 7. Index R and Rainfall

Rain Station	Mean of Rainfall (cm/year)	Area (Ha)
BMKG Station	1836.8	40.747,00

The P value or monthly rainfall (in cm) is a calculation of the average rainfall from January to December during 2020 for each rain station on Batam Island. The average monthly rainfall in Table 7 calculated using the formula (3.1) generate the mean value of rainfall in Batam Island is 1836.8 cm/year in 2020 with an area 40.747,99 Ha that is displayed in Figure 7.

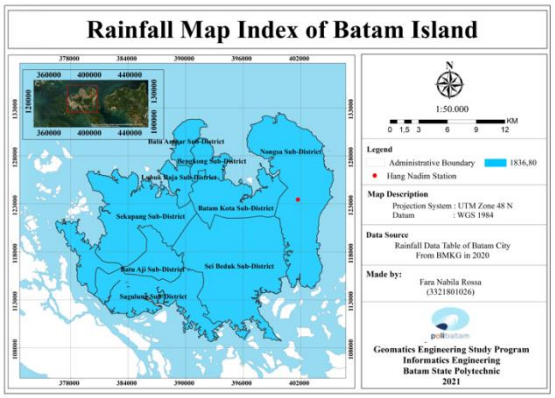


Figure 7. Rainfall Map Index

3.2 Slope Index (LS)

The slope is one of the determining factors that lead to soil erosion. If the research area has a very steep slope, it will affect the value or amount of eroded soil. The slope has an index value as shown in Table 8. The research area has a variety of slopes, the slope class is divided into flat, sloping, slightly steep, steep, and very steep. The slope map was obtained from the DEMNAS data processing. The following is a slope map shown in Figure 10. The area and percentage of the slope map of Batam Island can be seen in Table 8. Based on the area and percentage of the slope map of Batam Island, it can be seen that the research area has a majority flat slope condition.

Table 8. Slope Index

Slope	Index (LS)	Area (Ha)	Percentage (%)
Flat	0,4	28.151,27	70.86%
Sloping	1,4	4.424,40	11.14%
Slightly Steep	3,1	4.085,97	10.28%
Steep	6,8	2.917,86	7.34%
Very Steep	9,5	150,34	0.38%

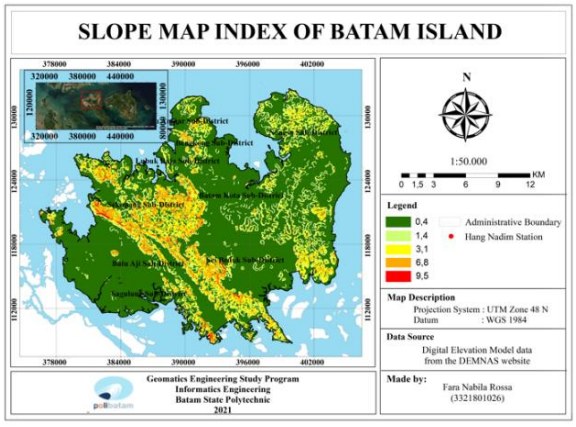


Figure 8. Slope Map Index

3.3 Soil Erodibility Index (K)

Soil erodibility or soil type is one of the determining factors that lead to soil erosion since the type of soil is affecting the value or amount of eroded soil. Soil erodibility has an index value as shown in Table 9. Then adjustments are made to the sub-districts that have soil erodibility and index values. More details can be seen in Table 9.

Table 9. Soil type index

Soil Type	Index (K)	Area (Ha)	Percentage (%)
Podzol, Podzolic	0,107	28.038,56	73.70%
Grumosol	0,271	6.036,56	15.87%
Litosol, Organosol	0,290	2.868,37	10.43%

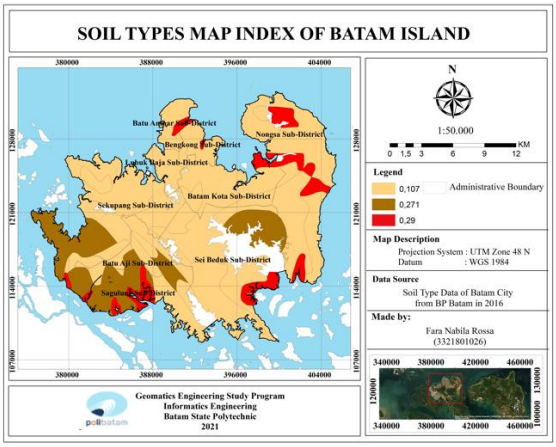


Figure 9. Soil Types Map Index

Based on classification in the form of an index table above, a Soil Type Index Map of Batam Island is produced which is divided into three categories. Which is Soil types podzol and podzolic soil type with index 0.107 has a percentage of 73,70% and 28.038,56 Ha area that spread in the sub-districts of Batam City, Batu Aji, Batu Ampar, Bengkong, Nongsa, Galang, Sei Beduk, Sagulung and Sekupang. Grumosol soil type, with index 0,271 and has a percentage of 15,87% and 6.036,56 Ha, is distributed in Batu Aji, Nongsa Sagulung and Sekupang sub-districts. Litosol and Organosol with index 0.29 has a percentage of 10.43% and 2.868,37 Ha that spread in Batam City, Batu Aji, Nongsa, Sagulung, Sei Beduk, Bengkong, Galang and Batu Ampar sub-districts. Which is distinguished into different colours at the map index below.

3.4 Land Use Map Index (CP)

As one of the determining factors that lead to soil erosion, the type of land use will affect the value or amount of eroded land. Then details of soil erodibility and index values can be seen in Table 10.

Table 10. Land Used Index

Land Use	value CP	Area (Ha)
River	0,001	238,26
Swamp/swamp	0,001	199,95
forest	0,001	8466,88
pond	0,001	62,47
Land	0,02	13949,51
Shrubs	0,1	4246,49
Field	0,28	1822,39
Garden	0,3	1509,08
Settlement	1,00	5550,34
Factory/building	1,00	171,66
Airport/Port	1,00	55,05
Lake	0,01	2861,38

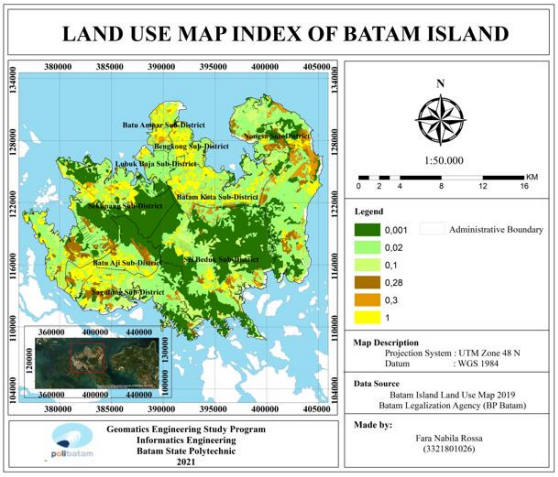


Figure 10. Land Use Map Index

Land Use with an Index of 0.01 includes Lake with an area of 2861.38 Ha, Pond with an area of 62.47 Ha, Forest with an area of 8466.881 Ha, Swamp with an area of 199.95 Ha, and River with an area of 238.26 Ha. which are located in Batu Ampar, Batam City, Batu Aji, Bengkong, Bulang, Galang, Lubuk Baja, Nongsa, Sagulung, Sei Beduk, and Sekupang. Land use with an index of 0.02 is land with an area of 13949.51 Ha in Batu Ampar, Batam City, Batu Aji, Bengkong, Bulang, Lubuk Baja, Nongsa, Sagulung, Sei Beduk and Sekupang sub-districts. Land Use with an index of 0.1 is Shrubs with an area of 4246.49 ha located in Batu Ampar, Batam City, Batu Aji, Bengkong, Bulang, Lubuk Baja, Nongsa, Sagulung, Sei Beduk, and Sekupang. Land Use with an Index of 0.28 is Field with an area of 1822.39 Ha located in Batu Ampar, Batam City, Batu Aji, Bengkong, Lubuk Baja, Nongsa, Sagulung, Sei Beduk, and Sekupang sub-districts. Land use with an index of 0.3 is Gardens with 1509,08 Ha area located in Batu Ampar District, Batam City, Batu Aji, Bengkong, Lubuk Baja, Nongsa, Sagulung, Sei Beduk, and Sekupang. Land Use with an index of 1.00, namely Building with an area of 171.66 Ha, Airport with an area of 55.05 Ha, Settlement with an area of 5550.34 Ha and Sand with an area of 17.229442 ha located in Batu Ampar, Batam Kota, Batu Aji, Bengkong, Lubuk Baja, Nongsa, Sagulung, Sei Beduk, and Sekupang. Which is distinguished into different colors. The map

of the Batam Island and Cover Index is shown in Figure 10.

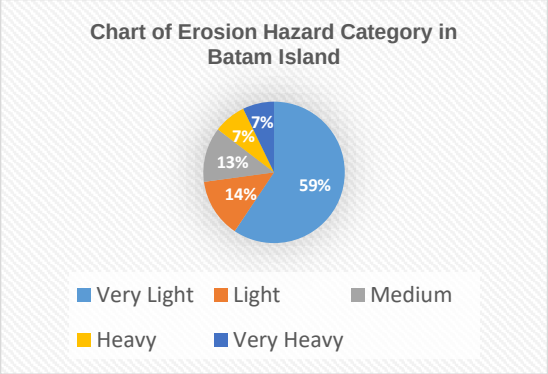
3.5 Distribution of Soil Erosion Areas

Based RUSLE above formula on 2.2 the results of distribution of soil erosion parameters, Batam Island is dominated by areas with very light erosion categories, which are 24.200,42 Ha or about 59.39% of the Batam Island area, light is 5.488,20 Ha or about 13.47% of the total area. Batam Island, with an area of 5.100,42 Ha or about 12.52% of the area of Batam Island, and a heavy area of 3.029,43 Ha or about 7.43% of the area of Batam Island. Very heavy with 2.929,65 Ha area or about 7.19% of the area of Batam Island. For more details can be seen Table 11 Tables of Soil Erosion Categories on Batam Island.

Table 11. Category Soil Erosion in Batam Island

Erosion Value (A)	Category	Area (Ha)	Percentage (%)
< 15	Very Light	24.200,42	59.39%
15-60	Light	5.488, 20	13.47%
60-180	Medium	5.100,42	12.52%
180 – 400	Heavy	3.029,43	7.43%
> 400	Very Heavy	2.929,64	7.19%

Based on the classification in the form of the table above, the Distribution of Soil Erosion in Batam Island is divided into four categories. Very light category with 24.200,42 Ha or 59.39% spread in Batam City with 2.217,76 Ha, Batu Aji with 2.080,30 Ha, Batu Ampar with 9,46 Ha, Bengkong 421,77 Ha, Nongsa 1.511,12 Ha, Lubuk Baja with a 791,47 Ha, Sagulung with 2.459,04 Ha, Sei Beduk with 8.756,17 Ha, and Sekupang with 5.051,56 Ha. Light category with 5.488,20 Ha or 13,47% distributed in Batu Ampar with 373,84 Ha, Batam City 269,08 Ha, Batu Aji with 20,09 Ha, Bengkong with 11,94 Ha, Lubuk Baja with 20,70 Ha, Nongsa with with 3.260,65 Ha, Sagulung with 290,95 Ha, Sei Beduk with 661,94 Ha, and Sekupang with 578,97 Ha. Medium category with 12,52% or 5.100,42 Ha located in Batu Ampar with 98,82 Ha , Batam Kota with 1.157,66 Ha, Batu Aji with 400,27 Ha, Bengkong District with 137,13 Ha, Lubuk Baja with 29,26 Ha, Nongsa with 1289, 07 Ha, Sagulung with 815,49 Ha, Sei Beduk with 477,64 Ha, and Sekupang 694,94 Ha. Heavy category coverage only 7,43% or with 3.029,43 Ha scattered in Batu Ampar 76,74 Ha, Batam City with 0.0562 Ha, Batu Aji with 490,53 Ha, Bengkong with 2,67 Ha, Lubuk Baja with 115,22 Ha, Nongsa with 1.617,18 Ha, Sagulung with 573,70 Ha, Sei Beduk with 20,03 Ha, and Sekupang 32,51 Ha. And the lasy category wich is ery heavy category covers 2.929,64 Ha or 7,19% of the research area in Batu Ampar with 526,94 Ha, Batu Aji with 576.28 Ha, Bengkong with 551,13 Ha, Nongsa with 754,74 Ha, Sagulung with 620,313 Ha. In visualisation, graph 2 displayed coverage percentage of each category and spatially delivered information in Figure 11.



Graph 2. Chart of Erosion Hazard Category in Batam Island

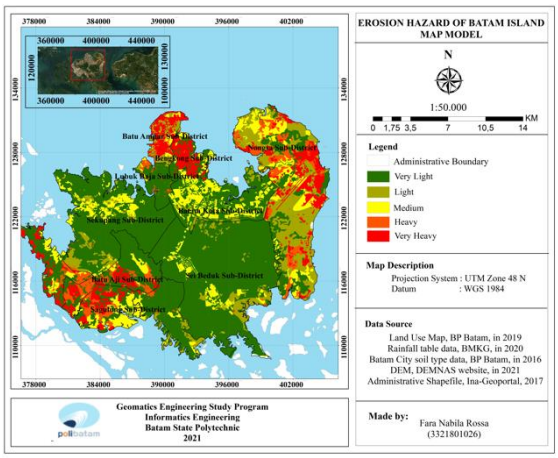


Figure 11. Erosion Hazard of Batam Island Map Model

4. Conclusion

Modelling the distribution area of soil erosion hazard by knowing the level of erosion rate information obtained by processing the slope data, soil type, land use, and rainfall in Batam Island can be done using the method Revised Universal Soil Loss Equation (RUSLE). The distribution area on four categories of soil erosion spread over nine sub-districts in Batam Island, such as Batam City, Batu Aji, Batu Ampar, Bengkong, Lubuk Baja, Nongsa, Sagulung, Sei Beduk, and Sekupang. Based on the information obtained from the erosion hazard model, it can be seen that the highest risk of being affected by erosion in the Batu Ampar cover 526.94 Ha, Batu Aji 576.28 Ha, Bengkong 551.13 Ha, Nongsa 754.74 Ha, and Sagulung with 620,313 Ha.

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