Assessment of The Potential Land Erosion and Actual Accumulated Sedimentation for Carrying Capacity in Bone River, Gorontalo Province

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Abstract. In 2020, there were 7 floods in Gorontalo City and Bone Bolango Regency due to the overflow of the Bone River which resulted in the breaking of several bridges, damaged embankments, and water-logging in residential areas and community plantations around the river. One of the causes of this flood is a decrease in river capacity due to high sedimentation caused by mechanical sand mining activities in Bone River. Therefore, it is necessary to know the carrying capacity of sedimentation in Bone River so that there is a stable dynamic equilibrium. The use of carrying capacity is a method of measuring sedimentation limits in the river. The carrying capacity is calculated by dividing the net of river capacity using topography in the year of 2007 to 2021 and the potential land erosion using USLE method. The results show the ratio of sedimentation rate in Bone River caused by erosion is 12.67%. This study resides in its simplicity to provide a solid basis strategy for regional policies to address the real causes of problems and risks. It certainly provides adequate information to improve the management of water regulation or sediment control structures in order to control flooding in the Bone River.

1. Introduction

Natural disasters include earthquakes, tsunamis, volcanic eruptions, floods, droughts, storms, and landslides, all of which are caused by natural occurrences or a series of natural events. Flooding is one of the natural disasters that can devastate the land around it. The flow of water over a natural run-off channel is referred to as a flood [1]. In Indonesia, based on reports of natural disasters 2020 by Indonesian National Board for Disaster Management there were 1,518 flood events during 2020 which was 32.64% and was the main of all-natural disasters in Indonesia. Gorontalo Province is one of the areas affected by the flood disaster in Indonesia.

In June 2020, the flood event in Bone River on 11th June 2020 due to heavy rain with high intensity for 11 hours, then affected 2,204 families and 2,174 housing units in Gorontalo City and Bone Bolango Regency area, this event is one of the 7 flood events in the area in the period from June to August 2020 (River Basin Association of Sulawesi II Gorontalo, 2020). Recently, there was a study on the flood index in the Bone River, which resulted in a high level of flood hazard index in housing units at Gorontalo City and Bone Bolango Regency [2]. Due to this, it is important to analyse the causes of flooding in the Bone River.

One of the causes of flooding in the Bone River is high sedimentation. The fundamental driver of channel morphology and landscape evolution is sediment movement, which has ramifications for chemical and biological river processes as well as human activities [3] and it can lead to reduced river capacity. Therefore, when the flood comes, the Bone River cannot accommodate the flood. The main cause is mechanical sand mining activities in the river. Mining sites are located on each bank along the river and also in the river delta, this causes an imbalance in sediment transport which affects changes in river morphology and narrowing river channels. Sedimentation is a process of deposition of material carried by water media. The adverse impact as a result of sedimentation is the disruption of river flow in the form of increased surface flow and decreased groundwater levels and the expansion of impermeable land, which is characterized by symptoms when it rains it will easily flood, and during the dry season drought and river, siltation occurs, causing flooding [4]. Sedimentation can be estimated by calculating the erosion rate in the watershed, erosion rate or soil loss rate can be calculated using the formula approach by Universal Soil Loss Equation (USLE), it is very common in Indonesia using USLE to estimate the soil erosion [5], the result can be used to calculate the carrying capacity, as a divisor to the river capacity. The carrying capacity of sediment needs to be conducted for Bone River to be considered in the sand mining regulation to make a flood mitigation plan in Gorontalo City and Bone Bolango Regency.

2. Methodology

The methodology of the study shown in the following flow chart in Figure below.

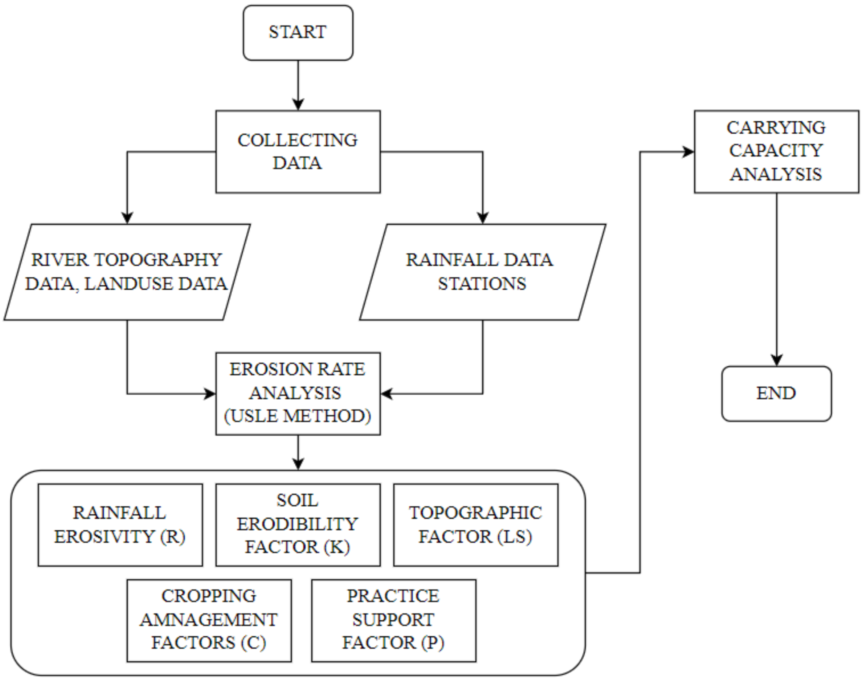

Figure 1. Methodology of the Study

Data collection is the first stage of this study approach. Data collecting included rainfall data from rainfall gauge stations that are located in the basin, river topography data, and land use data. Data were obtained from the River Basin Association of Sulawesi II Gorontalo. From the data, the USLE method was chosen to analyse the erosion rate. Rainfall data is used to find Rainfall erosivity (R) / EI30. USLE value comes from the times of rainfall erosivity (R), soil erodibility factor (K), topographic factor (LS), cropping management factor (C), practice support factor (P). After the USLE value was calculated, then the next step is to find the changes of volume of the Bone River generated from the contour 2021 and contour 2007. The result of carrying capacity analysis is obtained by dividing the USLE value in 14 years with the changed volume of the Bone River.

3. Location of Study

The Bone River is located in Gorontalo Province and North Sulawesi Province, which is the primary river of the Limboto-Bolango-Bone Basin in the Bone River Basin. The Bone River further runs toward the west on the south of Gorontalo city and joins the Tamalate River and the Bolango River on the right, in the downstream of the confluence with the Bolango River, the Bone River changes its direction towards the south, and finally discharges into the Tomini Bay. Figure 2 shows the map of the location study.

Figure 2. Methodology of the Study

4. Results and Discussion

4.1. Catchment Analysis

Catchment analysis is carried out with the outlet at the estuary of the Bone River, the watershed area of 2,702.3 km2 with Bone River has a length of around 76.7 km with an average slope of the river 0.4%. The following Figure 3 indicates the river system and terrain of the Bone Watershed.

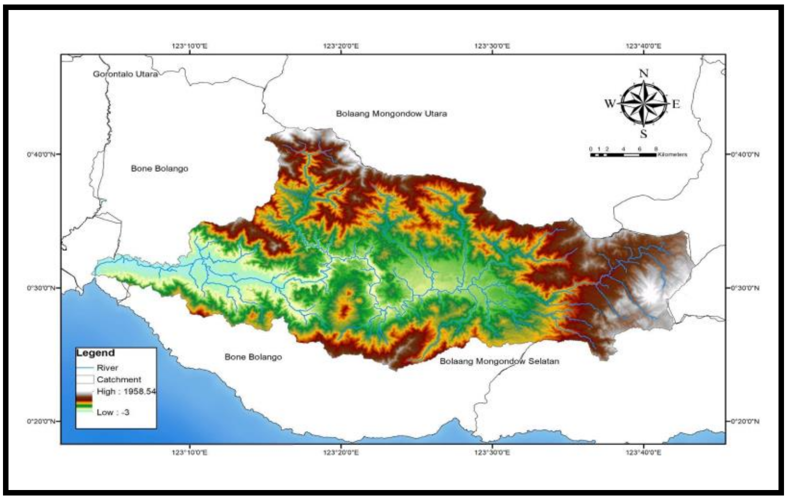

Figure 3. River System and Terrain of The Bone Watershed

Based on the picture above, the bone catchment has the highest elevation of 1,958.54 with a complex river system that has 22 tributaries of the order 2 based on the data from the Geospatial Information Agency in Indonesia. Then, it shows the land use distribution watershed in Figure 4.

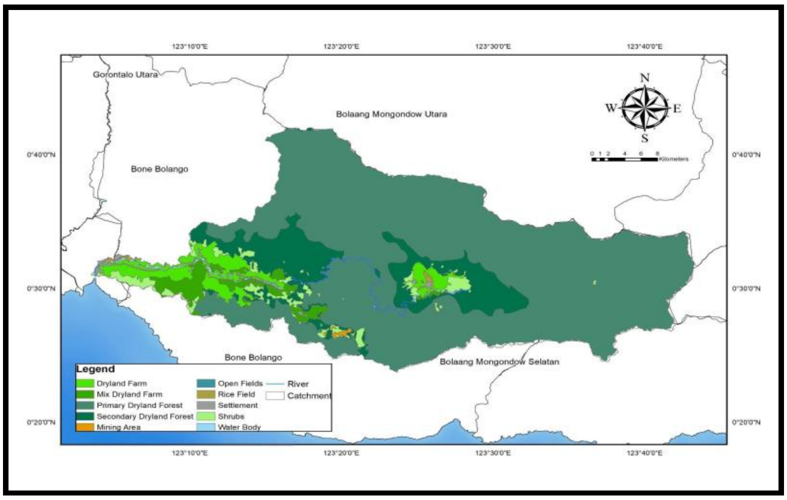

Figure 4. Land Use of The Bone Watershed

The slope of the Bone catchment area is relatively small, with an average slope of about 2.37% in the basin. In the upper reaches, there is a very slight gradient with an average of 1.7%. The area is covered with crops and plants rather than settlements. In the middle of the stream, the slope has increased to 2.77% and there are small settlement areas along the river. Downstream of the 3.77% gradient is a well-developed settlement located in the city of Gorontalo. Land use in the Bone basin is dominated by Dryland Forest (55%), Dryland Farm (31%), Rice Field (5%), and the rest are shrubs, settlements, mining, and open fields.

4.2. Erosion Rate

The Erosion rate will be calculated using USLE [6]. USLE equation is as follows:

$$A = R \, x \, K \, x \, LS \, x \, C \, x \, P \tag{1}$$

which

A = Average annual soil loss (tons/ha/year)
R = Rainfall erosivity (MJmm/ha/hr/year)
K = Soil erodibility factor (tons/MJ/mm)
LS = Topographic factor (dimensionless)
C = Cropping management factor (dimensionless)
P = Practice support factor (dimensionless)

4.2.1. Rainfall Intensity (R)

The erosivity factor of rain is the product of the kinetic energy (E) of a single rain event with a maximum rain intensity of 30 minutes (I_{30}) [7]. The erosivity factor of rain (R) which is the destructive power of rain is defined as the number of units of rain erosion index in a year [8]. The rain erosivity index was calculated using the Bols formula (1978) [7][8][9].

$$EI_{30} = 6.119 \, R^{1.21} \, D^{-0.47} \, M^{0.53} \tag{2}$$

which

EI_{30} = Monthly Rain Erosivity Index
R = Monthly Rainfall (cm)
D = Monthly number of rainy days (days)
M = Maximum rainfall for 24 hours in that month (cm)

In this study, there are 4 available rainfall stations to be analysed to get EI_{30} values in each station. The following table shows the calculation of rainfall erosivity, respectively.

Table 1. EI_{30} Calculation in Rainfall Station of Sukamakmur

Month	1	2	3	4	5	6	7	8	9	10	11	12
R	16.98	16.03	21.04	22.8	29.71	23.89	26.9	14.72	16.71	19.62	26.03	22.23
D	17	15	16	20	23	17	20	12	10	15	18	18
M	6.1	5.2	7.6	8.3	7.2	10.8	6.3	7.3	8.8	11.7	6.3	6.8
EI30	130	117.7	193.4	200.1	241.8	263.2	214.8	142.4	195.6	231.4	216.1	187.7

Table 2. EI_{30} Calculation in Rainfall Station of Alale

Month	1	2	3	4	5	6	7	8	9	10	11	12
R	15.51	12.99	13.4	17.38	16.32	15.88	16.1	10.98	10.68	15.55	17.3	17.65
D	14	12	11	17	14	12	13	8	8	11	14	14
M	8.1	6.7	13.1	9.7	8	9	10.6	10	8.1	24	6.9	10.6
EI30	146.9	114.3	180.6	171.4	155.9	175.5	182.2	142.8	126.6	295.5	154.3	198.2

Table 3. EI_{30} Calculation in Rainfall Station of Pinogu

Month	1	2	3	4	5	6	7	8	9	10	11	12
R	16.5	14.88	21.27	26.31	26.36	23.78	27.88	15.82	14.23	16.57	25.23	21.42
D	12	12	14	21	18	17	17	11	10	13	16	16
M	6.4	10	7.2	10.8	8.3	12.1	15.6	10	14.9	6.5	9.8	7
EI30	149.2	172.8	201.4	272.4	252.5	281	384	186.5	217.4	147.1	274.2	190.2

Table 4. EI_{30} Calculation in Rainfall Station of Pangi

Month	1	2	3	4	5	6	7	8	9	10	11	12
R	13.99	16.57	14.63	23.02	20.19	18.64	19.9	11.55	10.98	13.61	19.29	19.04
D	13	13	14	19	17	15	17	10	10	14	16	16
M	7.7	10.5	6.3	7.5	6.5	9.6	13.4	7.3	5.1	9.1	8.4	8.9
EI30	130.3	192.5	120.5	197	164.3	193.4	239.1	113.4	88.3	135.3	183.8	185.6

From the table of analysis above, the total EI_{30} in each station are Sukamakmur has a total of 2334.2, Alale has 2044.2, Pinogu has 2728.7, and Pangi has 1943.7. After that, interpolation is carried out using Inverse Distance Weighting (IDW) to get the *R* Factor for the Bone Watershed region. The detailed distribution in the map can be shown in the figure below.

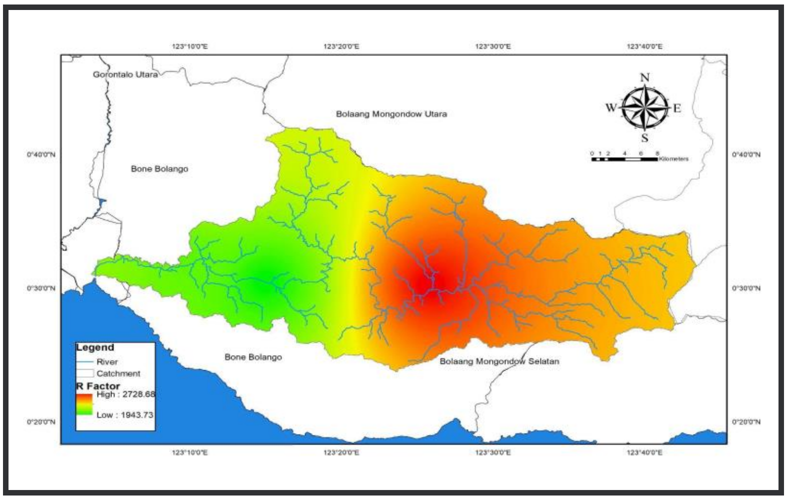

Figure 5. R Factor Map of The Bone Watershed

4.2.2. Soil Erodibility Factor (K)

The soil erodibility factor is the ability of soil particles to peel and remove soil due to the kinetic energy of rain. The value of soil erodibility depends on the influence of soil texture, aggregate stability, infiltration capacity, organic and inorganic matter content of the soil. Soil types using data from Food and Agriculture Organization (FAO) and United Nations Educational, Scientific and Cultural Organization (UNESCO) at 1:5,000,000 scale which will be converted into the value of K factor according to the research results [10]. The type of soil in the Bone watershed is described in Table 5 and the distribution is shown in Figure 6.

Table 5. K value based on type of soil

No	Type of Soil	K Values
1	Fluvisols	0.295
2	Acrisols	0.255

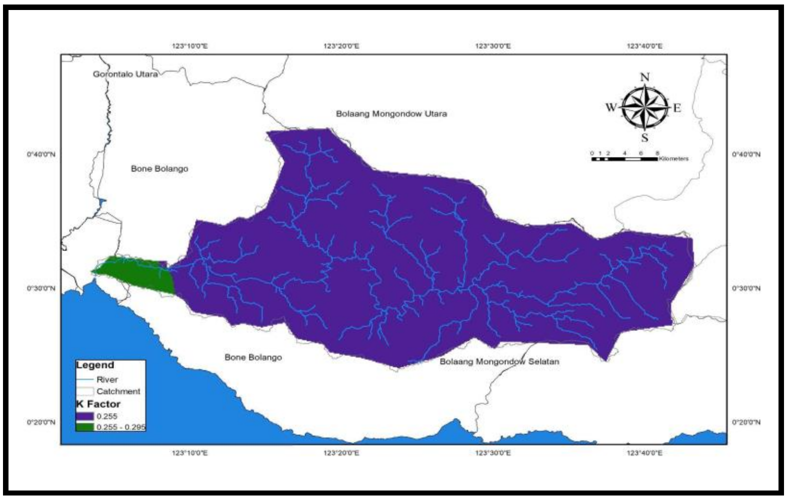

Figure 6. K Factor Map of The Bone Watershed

From the picture above the Bone Watershed is dominated by acrisol soil type and the rest is fluvisol which has values of *K* factor 0.255 and 0.295.

4.2.3. Topographic Factor (LS)

In the prediction of soil loss, the topographic component is the most sensitive parameter of USLE/Revised USLE [11] the slope length gradient factors *L*, slope length, and *S*, slope steepness, make up the topographic factor (*LS*) [12]. This study uses National Digital Elevation Model which has 8m resolution. In Geographic Information System (GIS) software the equation that input in a raster calculator to produce LS map will be as follows [13]:

$$\text{LS}=\text{Power}\left\{(\text{Flow Accumulation})\times\frac{\text{Resolution}}{22.13},0.6\right\} \times\text{Power}\,\{\sin\{(\text{Slope of DEM})0.01745/0.0896,\,1.3) \qquad (3)$$

The result of the topographic factor calculation is shown in Figure 7.

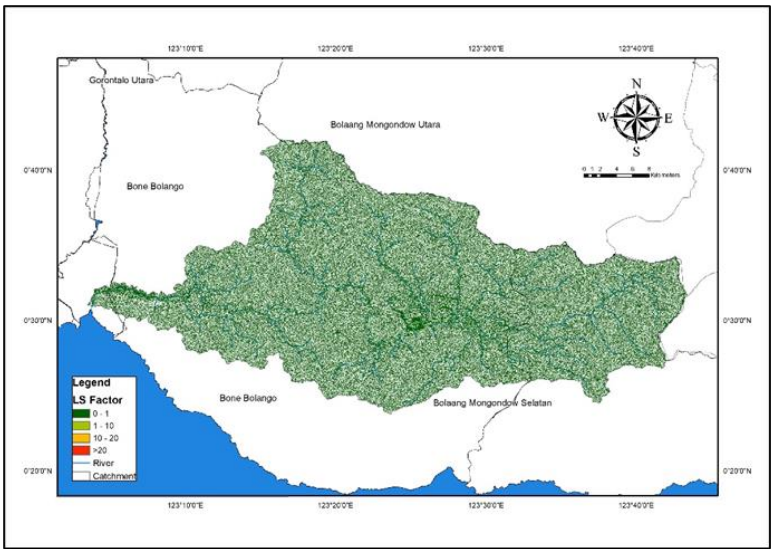

Figure 7. K Factor Map of The Bone Watershed

DEM data from the GIS process shows that the terrain of The Bone Watershed is variant. The result shows that the *LS* factor of The Bone Watershed has a range of 0 - 10 with an average of 0.6. Most of the Bone Watershed terrain has an *LS* factor between 1 - 10 meaning that the slope is not steep and the slope lengths are long.

4.2.4. Cropping Management Factor (C) and Practice Support Factor (P)

The value of the *CP* factor is determined based on the type of land use and land management. The value of the soil management factor/conservation action (*P*) in this study is P = 1 because at the time the research was carried out there was no soil conservation action in all aspects of land use. The value of the Vegetation Factor of Ground Cover and Plant Management (*CP*) contained in the book ”Hidrologi dan Pengelolaan Daerah Aliran Sungai” [7]. Furthermore, the *C* and *P* values are factors of soil conservation and vegetation management practices, which strongly influence surface/basin erosion rates. Factor *C* shows the overall influence of vegetation, foliage, soil surface conditions, and soil management on the degree of soil loss (erosion). Therefore, the magnitude of the number *C* is not always the same in a year [7]. The following Table 6 describes the *CP* value regarding the land use type and Figure 8 represents *CP* factor map of the Bone watershed.

Table 6. *CP* value based on Land Use

No	Land Use	CP Value
1	Primary Dryland Forest	0.001
2	Secondary Dryland Forest	0.005
3	Shrub	0.3
4	Settlement	1
5	Open Field	1
6	Wet Space	0
7	Dryland farming	0.5
8	Mixed Dryland Farming	0.5
9	Rice Field	0.1
10	Mining	1

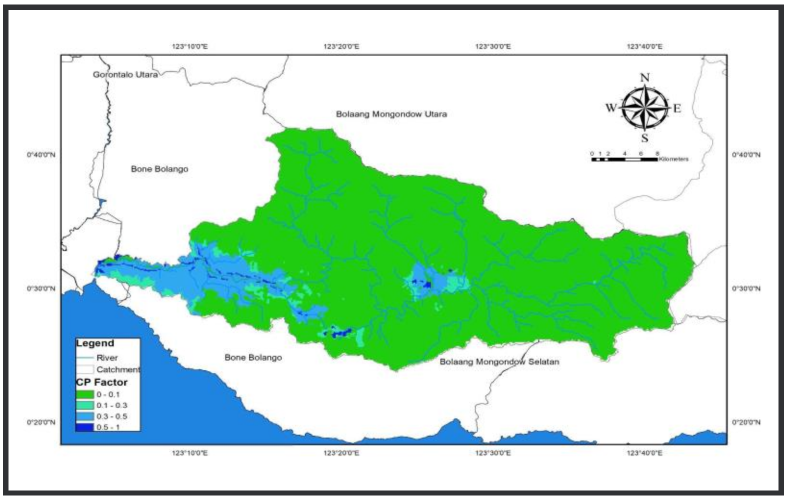

Figure 8. *CP* Factor Map of The Bone Watershed

4.2.5. Soil Loss (A)

To calculate the soil loss by using equation (1) which will be the raster calculation between each factor and the result as follow:

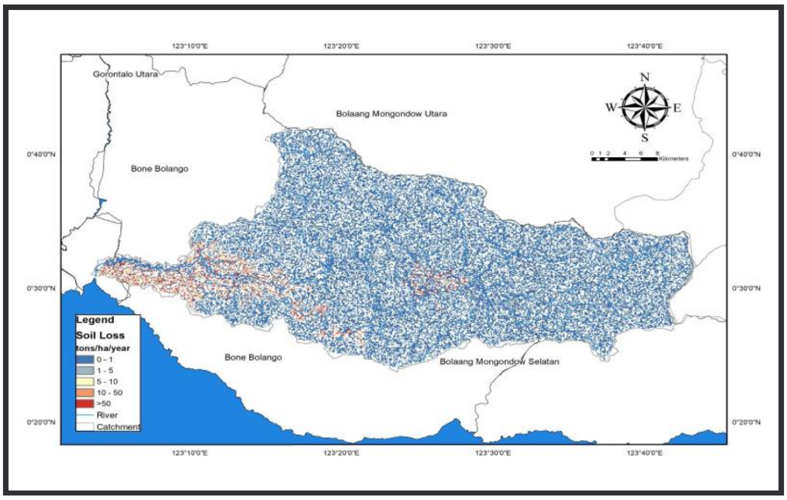

Figure 9. Soil Loss Map of The Bone Watershed

From the figure above we can see that the distribution of soil loss in The Bone Watershed is mostly in the range of 1 to 5 tons/ha/year. However, the highest value is more than 50 tons/ha/year. The value of soil loss that will be used to calculate carrying capacity is the average value of the watershed area which is converted to m^3/year by multiplying with sediment specific gravity. Sediment specific gravity was obtained by local soil investigation with an average value of 2.65 ton/m^3 (River Basin Association of Sulawesi II Gorontalo), so that the soil loss equals 1,131,833 m^3/year.

4.3. Carrying Capacity

4.3.1. Volume Changes of Bone River

Rivers have an indeterminate volume and change with time. The main thing that causes changes in the volume of the river's capacity is sedimentation. Sedimentation is sediment that settles in rivers due to the carrying of soil particles by surface water or commonly referred to as erosion. The bed changes evolution can be obtained using secondary data or field measurement data. The measurement data in question is in the form of satellite images from Google Earth which can describe the changes that have occurred in the Bone River from the top view in Figure 10.

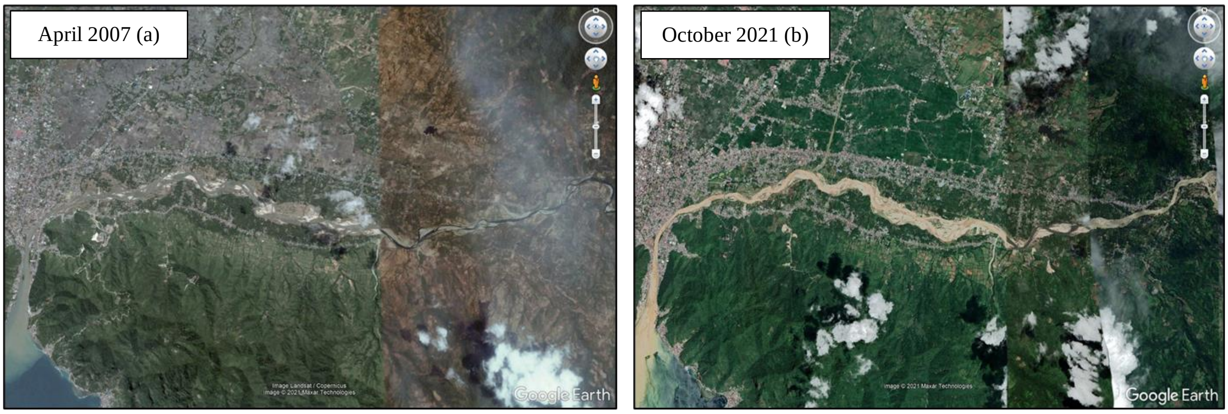

Figure 10. Satellite Image Comparison of Bone River from 2007 (a) to 2021 (b)

Based on images taken from Google Satellites, it can be seen that the changes are very clear that there is a fluvial morphology change. This image clarifies the procedure of bed deformation and morphological changes on alluvial river bed. The biggest changes can be seen in the Alale Weir segment to the downstream of the Bone River where there is a confluence between the main Bone River and the Tamalate canal. In this segment, the river meander of bone changes and forms new wider meanders in several locations.

The 2007 and 2021 changes of these satellite images also have topographic measurements of rivers. Thus, with this, changes in the volume of the Bone River from the Alale Weir to the Lower Bone River can be known. The topographic measurements for 2007 and 2021 were obtained from River Basin Association of Sulawesi II Gorontalo. The volume is calculated using the formula of the mean cross section method. It is commonly used to calculate the volume of river cross sectional groups. The mean cross section method that is used to calculate the volume of river in both 2007 and 2020 can be illustrated below.

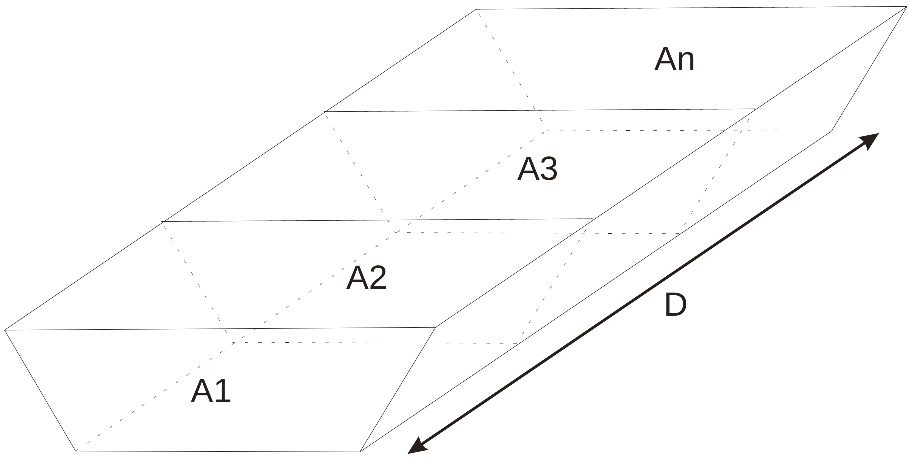

Figure 10. Illustration of mean cross section method

The basic formula of mean cross section method can be written below.

$$Volume = V = \left(\frac{A_1 + A_2 + A_3 + \cdots + A_n}{n}\right) \times D \quad (4)$$

Where A_1, A_2, A_3, A_n is the total area of cross-section 1 to n; n is the number of cross sections; D is the distance between cross-section 1 to n; and V is the mean volume of the cross-section. Using the formula mentioned above, the results of the volume calculation of Bone River and its changes are presented in the Table 7.

Table 7. Volume of Bone River Calculation

Year	Volume	Unit
2007	8,396,402	m^3
2021	6,244,599	m^3
ΔV (2007 - 2021)	2,151,803	m^3
ΔV Yearly	143,453	m^3/year

The table above provides the results of the calculation of the sediment that is deposited per year in the Bone River and the amount of it when divided evenly each year from 2007 to 2021. The total sedimentation in Bone River between the timeframe is 2,151,803 m^3. If the number is divided by 15 years, there is 143,453 m^3, the amount of river sediment that was deposited causes changes to river bed formation. Thus, it can be concluded that 143,453 m^3/year also represents the annual sediment transport rate in the Bone River.

4.3.2. Carrying Capacity

The sediment carrying capacity (SCC) is an index characterizing the interplay between the flow and sediment transport in a river. It is often used for predictions of the river bedform evolution. During the past decades, many studies have been dedicated to the SCC estimations, leading to numerous theoretical and empirical formulas that contribute to the understanding of the issue [14]. It is a comprehensive index characterizing the sediment carrying capacity of flow under the conditions of equilibrium of scouring and deposition [15].

The carrying capacity of the Bone River sedimentation is calculated by dividing the annual sediment transport rate obtained from changes in topographic measurements in 2007 and 2021 by the erosion potential of the land. By calculating the carrying capacity, the result of it equals the ratio of sedimentation deposition in the Bone River. Here is the concept formula of carrying capacity for this study:

$$\begin{aligned}&Carrying\ Capacity\\&= (\Delta V\{2007\ to\ 2021\})\ x\ (Total\ potential\ of\ land\ erosion\ \{2007\ to\ 2021\})^{-1}\end{aligned} \quad (5)$$

Where ΔV of 2021-2007 is the changes of river volume from 2007 to 2021; the total potential of land erosion is the total erosion obtained from the USLE method calculation in 15 years.

$$Carrying\ Capacity\ = (2{,}151{,}803)\ x\ (15{,}845{,}661.39)^{-1} = 0.126 = 12{,}67\% \quad (6)$$

The result represents a number without dimensional units. The carrying capacity value obtained is 0.1267 means that it's 12.67% of potential land erosion that was deposited in the Bone River. This value serves as the equilibrium value of the yearly sedimentation rate in the Bone River.

5. Conclusion and Recommendation

According to the results of the Bone River study, the USLE approach is 15,845,661.39 m^3 during a 15-year period from 2007 to 2021. Based on contour analysis, the volume changes in Bone River are 2,151,803 m^3. As a result, the sediment carrying capacity of the Bone River is 12,67%. However, the distribution of sedimentation in river bodies is unclear; this may be investigated further by modelling the 2-dimensional sedimentation rate with HEC-RAS to determine important sedimentation locations.

This research, combined with a topographical survey, should be calculated yearly to monitor the sediments in Bone River. Furthermore, the soil loss computation may be compared to another approach, such as RUSLE, to obtain the best results.

6. References

[1] Chow V T 1956 *Hydrologic studies of floods in the United States Int. Assoc. Hydrol. Sci*. **42** 134- 170.
[2] Taruna D A, Jaya I, Kosasih B, Adityawan M B and Kuntoro A A 2021 Proc. Int. Conf. on Flood Index Analysis of Bone River in Micro-Scale, Gorontalo City and Bone Bolango Regency (Surabaya) vol 7 (Surabaya: Indonesian Association of Hydraulic Engineer) p 10
[3] Juez C, Garijo N, Hassan M and Estela N R 2021 Intraseasonal-to-Interannual Analysis of Discharge and Suspended Sediment Concentration Time-Series of the Upper Changjiang (Yangtze River) J. Water Resources Research 57 10
[4] Kodoatie R J and Sugiyanto 2002 Banjir Beberapa Penyebab dan Metode Pengendaliannya dalam Perspektif Lingkungan (Yogyakarta: Pustaka Pelajar)
[5] Novitasari, Rohman M H, Ambarwati A A and Indarto 2019 Application of USLE and GIS to Predict Erosion Loss at Brantas Watershed. J. Teknik Pertanian Lampung 8(2) 65-152
[6] Wischmeier W H and Smith D D 1978 Predicting rainfall erosion losses a guide to conservation planning (Washington: US Department of Agriculture)
[7] Asdak C 2002 Hidrologi dan pengelolaan daerah aliran sungai (Yogyakarta: Gadjah Mada University Press)
[8] Suripin 2004 Pelestarian sumber daya tanah dan air (Yogyakarta: Penerbit Andi)
[9] Seta A K 1987 Konservasi sumber daya tanah dan air (Jakarta: Kalam Mulia)
[10] Ashiagbori G, Forkuo EK, Laari P and Aabeyir R 2014 Modelling Soil Erosion in the Densu River Basin Using RUSLE and GIS Tools J. Environ Sci Eng 56(3) 247-254
[11] Oliveira A H, Silva M A d, Silva M L N, Curi N, Neto G K and Freitas D A F d 2013 Development of Topographic Factor Modeling for Application in Soil Erosion Models, Soil Processes and Current Trends in Quality Assessment (KU Leuven: IntechOpen)
[12] Panagos P, Borrelli P, Meusburger K 2015 A New European Slope Length and Steepness Factor (LS-Factor) for Modeling Soil Erosion by Water. J. Geosciences 2015 5(2) 117-126
[13] Mitasova H and Mitas L Conf. Modeling Soil Detachment with RUSLE 3D Using GIS (Univeristy of Illinois: Urbana Campaign)
[14] Engelund F and Hansen E 1967 Comparison between similarity theory and regime formula (Denmark: Technical University of Denmark)
[15] Ni Z H, Qiang Z and Wu L C 2014 Determination of the Sediment Carrying Capacity Based on Perturbed Theory J. Scientific World. (2014)240858

Acknowledgments

Thanks are given to:

1. River Basin Association of Sulawesi II Gorontalo, Directorate General of Water Resources, Ministry of Public Works and Housing for providing assistance in the form of hydrology data and topography data.
2. All parties who cannot be mentioned one by one for the assistance that has been given