

Analysis of The Correlation Between Land Use Changes in Sub Watershed Wuno Toward Lifetime of Wuno Reservoir, Sigi District, Central Sulawesi Province

Wardani Yuliana¹, Suhartanto Ery¹, Haribowo Riyanto¹

¹ Water Resources Engineering Department, Universitas Brawijaya, Malang, 65145, Indonesia

uly86.yw@gmail.com

Received 03-01-2019; revised 11-01-2019; accepted 22-01-2019

Abstract. Wuno Reservoir is located in Sigi Biromaru District, Sigi Regency, Central Sulawesi Province. It is planned for 50 years. This analysis to know the condition of ideal land use so that the life time of the reservoir reaches 50 years. Trend of land use change, erosion and sediment rate estimation using the ArcSWAT model. During 2008-2016, natural forest land use showed a downward trend, while mixed gardens, shrubs, fields and settlements showed an increasing trend. The erosion rate in 2008-2010 increased by 72.5%, in 2010-2012 it increased by 1.45%, in 2012-2014 decreased by 0.09% and in 2014-2016 increased by 0.98%. In 2008-2016 Low BEHI area was reduced by 3.74%, medium BEHI was increasing by 14.11%, BEHI High increased by 16.57% and BEHI Very High increased by 12.64%. This shows that the rate of erosion and the extent of BEHI are influenced by changes in land use. Based on the results of analyzing the lifetime of the reservoir, changes in land use also affect the reduced useful life of the reservoir. Vegetative land conservation efforts are adjusting forest areas so that rate of erosion decreases by 62.75%. Mechanical land conservation efforts in the form of the construction of 6 check dams so that weight of sediment decreases by 89.24%.

Keywords: ArcSWAT, Land Use, Erosion Rate, Bank Erosion Hazard Index, Reservoir Lifetime.

1. Introduction

Erosion is a moving or transporting land or parts of land from one place to another by natural media [4]. The occurrence of erosion is determined by climatic factors (rainfall intensity), topography, soil characteristics, vegetation cover, and land use [9]. Land use changes have resulted in an increase in the value of land erosion, surface runoff, critical watershed condition and an increase in the amount of sediment which has resulted in a reduced lifetime of the reservoir [1, 2, 10, 12, 13, 14].

Wuno Reservoir is located in Oloboju Village, Sigi Biromaru District, Sigi Regency, Central Sulawesi Province. Wuno Reservoir utilizes the Wuno and Konju Rivers. Located in the Wuno Sub-watershed, Palu River Basin and included in the Palu Lariang River Basin. Its use is to meet the needs of irrigation water for 1,500 Ha of rice fields and 500 Ha of shallot farming, and to supply raw water needs [6, 7] with 50 years of lifetime. Increased erosion occurred in the Wuno Sub-watershed in 1992 to 2006 [5]. During the period of 1 (one) year the sediment potential in the Wuno River increased by

6,270 m³ [6, 7]. The Wuno river is suitable for raw water because there are not many residential areas. Residential areas sometimes have toxicity levels that are high enough to affect the aquatic habitat and these toxicity levels should be managed [8]. Increased erosion and sediment will have an impact on the reduced useful life of the reservoir [3].

Based on the results of analyzing, the rate of erosion and the extent of BEHI are influenced by changes in land use. Land use changes also affect the reduced useful life of the reservoir. Vegetative land conservation efforts are adjusting forest areas so that rate of erosion decreases by 62.75%. Mechanical land conservation efforts in the form of the construction of 6 check dams so that weight of sediment decreases by 89.24%.

2. Material and Methods

2.1. Material

The data used in this study include Daily 2002-2015 rainfall data, Palolo rain station and Sibalaya rain station, digital Elevation Model (DEM) map, land use map in 2008, 2010, 2012, 2014 and 2016, map of soil types, map of Central Sulawesi Province Forest Areas and soil samples for each land use and soil type

2.2. Methods

2.2.1. Hydrological Analysis Consistency Test

The data consistency test is conducted to find out whether there are data irregularities in the available rain data, so that it can be known whether the data is suitable for use in further hydrological analysis or not. In this study 2 (two) methods were carried out, namely (1) double mass curve; (2) Rescaled Adjusted Partial Sums (RAPS). Rainfall station location affects the consistency of data, this is indicated by the designed rainfall difference for each definite recurrence time is relatively small [11].

Homogeneity Test

A series of hydrological data presented chronologically as a function of the same time is called a periodic series. Generally published field data are debit data, rainfall data, etc., are basic data as hydrological analysis material. The data is arranged in the form of a periodic series, so that before being used for further analysis must be tested. Testing the data it means is: (1) Test of Absence of Trend; (2) Stationary Test; (3) Persistence Test. The three stages of testing are often referred to as data filtering (data screening).

Abnormalities Test (Outliers)

Outliers is data that deviates too far from other data in a data set. The existence of these data outliers will make the analysis of a series of data biased, or not reflect the actual. Outliers test done to find out whether the maximum data and minimum data from the available data sets are suitable for use or not.

2.2.2. Soil Water Assessment Tool Analysis (SWAT)

Measurement and estimation of erosion is difficult to do precisely because the process of events and the factors that influence them is very complex. But with some assumptions and simplifications, erosion measurement and estimation can be done with an acceptable level of approach. There are various ways of observing or measuring erosion that occur, among others, by direct observation in the field, interpretation of topographic maps and aerial photographs and direct measurements with experiments. In this study the erosion rate is calculated by the SWAT model. The SWAT model calculates erosion based on the USLE Modification formula [4]:

$$\text{sed} = 11.8 (Q_{\text{surf}} \times q_{\text{peak}} \times a_{\text{hru}})^{0.56} K \times C \times P \times LS \times \text{CFRG} \quad (1)$$

with:

- sed = sediment yield (ton)
- Q_{surf} = surface runoff volume (mm/ha)
- q_{peak} = peak discharge (m^3/sec)
- a_{hru} = Watershed area (ha)
- K = soil erodibility
- C = plant factors
- P = land management factors
- LS = slope factor
- CFRG = soil material roughness factor

2.2.3. Bank Erosion Hazard Index Analysis

The score of the erosion hazard value is stated in the Bank Erosion Hazard Index (BEHI), which is defined as follows [4]:

$$BEHI = \frac{\text{Potensial Erosion (ton.ha}^{-1}\text{.year}^{-1})}{T \text{ (ton.ha}^{-1}\text{.year}^{-1})} \quad (2)$$

With T is the magnitude of erosion that can still be left behind. The bank erosion hazard index can be determined as set out in the T Value Assessment Guide for Land in Indonesia (Table 1).

Table 1. Bank Erosion Hazard Index Classification

Bank Erosion Hazard Index Value	Classification
< 1.0	Low
1.01 – 4.0	Medium
4.01 – 10.0	High
> 10.01	Very High

2.2.4. Reservoir Lifetime Analysis

The lifetime of the reservoir is the time when the reservoir can be used to hold water and distribute it. Reservoir utilization age in terms of full dead storage by sediments. Deposition time from various elevations is cumulative to get the age of the reservoir. The lifetime of the reservoir can be calculated by the equation:

$$T = \frac{V}{(L \times S \times E)} \quad (3)$$

with:

- T = Lifetime of reservoir (year)
- V = Dead Storage Volume (m^3)
- L = Watershed area (km^2)
- S = Erosion intensity = V_s/L
- V_s = The average volume of sediment entering the reservoir (ton/year)
= W_s/γ_d
- W_s = The weight of the average sediment that enters the reservoir (ton/year)
- γ_d = The dry weight of the sediment deposits
= 0.963 ton/m^3
- E = Efficiency of reservoir catches

2.2.5. Land Conservation Direction

Vegetative methods or ways to utilize the role of plants in the effort to control erosion and/or preservation of soil, in the implementation can include the following activities: (a) Forest Restoration (reforestation) and reforestation, (b) planting cover crops, (c) planting crops in contour lines, (d) planting plants in strips, (e) rotating crops and (f) mulching and utilization of plant litter. In this research, vegetative handling efforts were carried out were forest restoration or forest area adjustment. Forest area adjustment refers to map of Central Sulawesi Forest Area.

Check Dam Building (Controlling Dam) is a building built in river grooves with construction of soil filling material reinforced with a waterproof coating. Check dam buildings have functions other than as sediment capture buildings, as well as building river bed control.

3. Result and Discussion

3.1. Hydrological Analysis

Consistency Test

The method of testing with the Dual Mass Curve method is to compare the long-term annual rainfall data from a raindrop station with the average rainfall data of a group of rain stations in the same period. If the test results state the data at a station is consistent, it means that there is no environmental change in the station's area of influence and no change in how to measure it during the recording of the data.

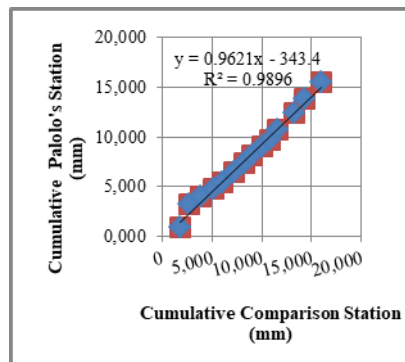


Figure 1. Double Mass Curve Chart of Palolo Station Rain Data

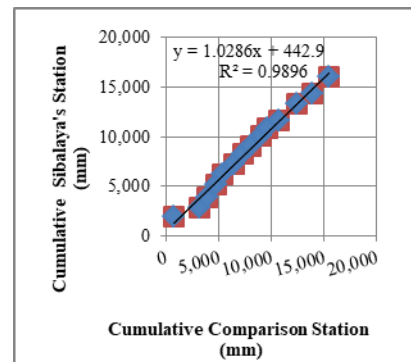


Figure 2. Dual Mass Curve Chart of Sibalaya Station Rain Data

Table 2. Consistency Test Results of Double Mass Curve Method

No	Rain Station	Consistency Test			Result
		Gradient (R2)	Linier Regression (y)	Angel Gradient (Tg α)	
1	2	3	4	5	6
1	Palolo	0.9896	$y = 0.9621x - 343.4$	43.89°	Consistent
2	Sibalaya	0.9896	$y = 1.0286x + 442.9$	45.81°	Consistent

From Figure 2, Figure 3 and Table 2 it can be concluded that the rainfall data at Palolo and Sibalaya Stations is consistent data.

If the rain station that affects the study area is less than 3 (three), then the test of the consistency of rainfall data is done by the method RAPS (Rescaled Adjusted Partial Sums). The recapitulation of the results of the consistency test of the RAPS method is presented in Table 3.

Table 3. Consistency Test Results RAPS Method

No	Rain Station	Consistency Test RAPS Method				Result
		Q/n ^{0.5} count < Q/n ^{0.5} table dan R/n ^{0.5} count < R/n ^{0.5} table				
		Q/n ^{0.5} count	Q/n ^{0.5} table	R/n ^{0.5} count	R/n ^{0.5} table	
1	2	3	4	5	6	7
1	Palolo	0.72	1.07	0.96	1.26	Consistent
2	Sibalaya	0.55	1.07	0.88	1.26	Consistent

From Table 3 above shows that value Q/n^{0.5} count < value Q/n^{0.5} table and value R/n^{0.5} count < value R/n^{0.5} table, so that it can be concluded that the rainfall data at Palolo and Sibalaya Stations is consistent data.

Homogeneity Test

In this study, the annual rainfall data of the rain station were tested for the absence of trends with the Spearman method using 2-sided T-Test. Recapitulation of test results is presented in the following.

Table 4. Trend Absence Test Results

No.	Rain Station	Trend Absence Test		Result
		(t count < t table)		
		t count value	t table value	
1	2	3	4	5
1	Palolo	-1.367	2.179	Trend Absence
2	Sibalaya	0.391	2.179	Trend Absence

From Table 4 above shows that the value of t arithmetic < value of t table, so it can be concluded that the rainfall data on Palolo and Sibalaya Stations includes independent data (Rt and Tt are not interdependent). Periodic series is called stationary if the values of the statistical parameters (mean and variant) are relatively unchanged (stable) from the period or the time series. If one of the statistical parameters is found to change from the part of the period or the amount of time available, the periodic series is called not stationary. Non-stationary periodic series indicates that the data is not homogeneous or not the same type. Testing the variance value from the periodic series can be done with the F-Test. Recapitulation of test results is presented in the following.

Table 5. Stationary Test Results

No	Rain Station	Stationary Test				Result
		F count < F table dan t count < t table				
		Variability Stability		Stability of average value		
		F count	F table	t count	t table	
1	2	3	4	5	6	7
1	Palolo	2.24	3.79	-0.41	2.18	homogeneous
2	Sibalaya	0.61	3.79	0.37	2.18	homogeneous

From Table 5 above shows that the calculated F value $<$ F table value and t count value $<$ t table value, so it can be concluded that the rainfall data at Palolo and Sibalaya Stations has a variant and a stable average.

The persistence test is an independent test of each value in a periodic series. First, the number of serial correlation coefficients must be calculated with the Spearman Method, then the calculation of the persistence test with the T-Test is carried out. Recapitulation of test results is presented in the following.

Table 6. Recapitulation of the Test of Presence

No	Rain Station	Presence Test (t count $<$ t table)		Result
		t count value	t table value	
1	2	3	4	5
1	Palolo	-0.330	2.201	random
2	Sibalaya	-1.405	2.201	random

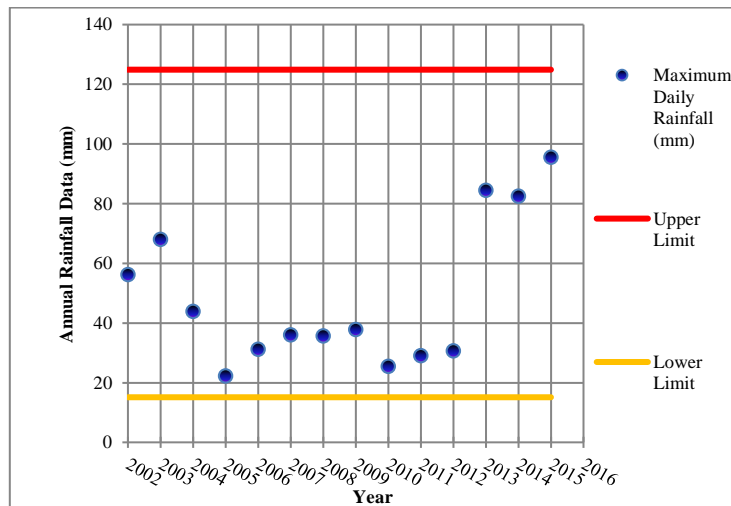


Figure 3. Palolo Station Outliers Test Chart.

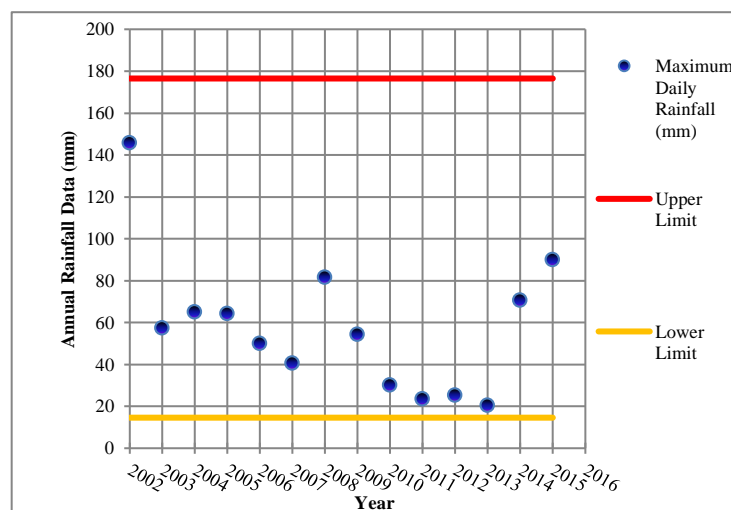


Figure 4. Sibalaya Station Outliers Test Chart

From Table 6 above shows that the value of t count $<$ t table value, so it can be concluded that the rainfall data at Palolo and Sibalaya Stations shows the absence of trends, variants and homogeneous/stable/same type, and are random (randomness), independent.

Abnormalities test (Outliers)

Outliers test is used to find out whether the maximum data and minimum data from the available data sets are suitable for use or not. From Figure 3 and Figure 4 it is found that the rainfall data for Palolo and Sibalaya Stations is still in the range of thresholds. So, it can be concluded that the rain data is of high quality.

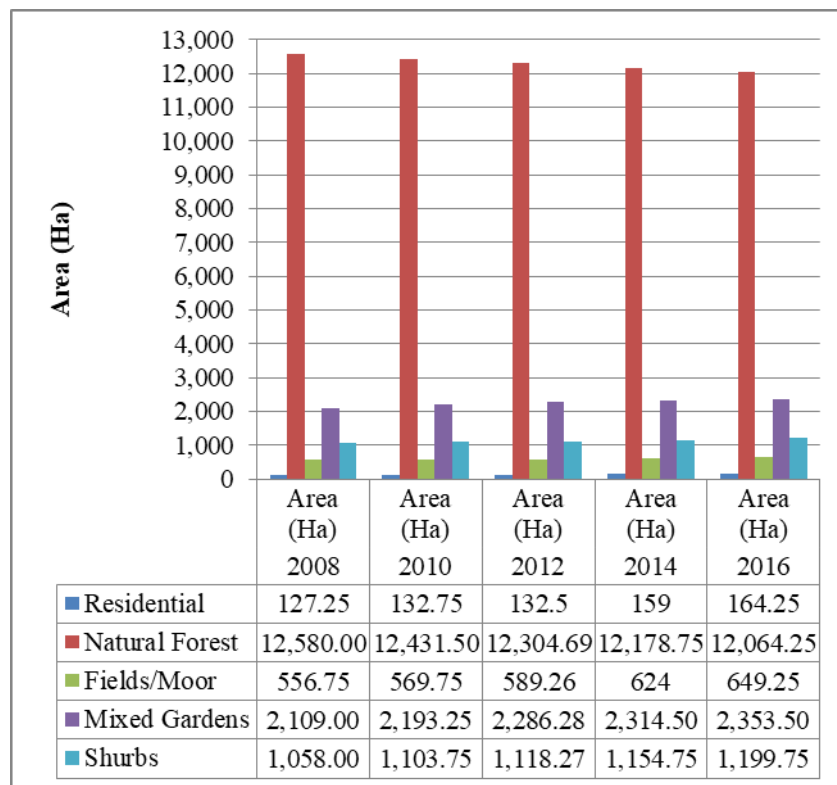


Figure 5. Land Use Changes Graphic

In 2012 up to 2014 the area of natural forest that was converted into residential, natural forest, fields/moor, mixed plantations and shrubs covering an area of 125.94 Ha. The biggest change became shrub land area of 36.48 Ha (28.97%). In addition to being a field/moor area of 34.74 Ha (27.58%), it became a mixed plantation of 28.22 Ha (22.41%) and a settlement of 26.5 Ha (21.04%).

Year 2014 to 2016 the area of natural forest that has changed function into residential, natural forest, fields/moor, mixed gardens and shrubs covering an area of 148.5 ha. The biggest change was the scrub land area of 45 Ha (39.30%). Besides that, it is a mixed garden covering 39 Ha (34.06%), being a dry field area of 25.25 Ha (22.05%) and a settlement of 5.25 Ha (4.59%) (Figure 5).

Erosion Rate

The SWAT simulation results, the erosion rate value continues to increase in each year period. The increase in erosion rate in 2010 was 72.5%, the period of 2010-2012 was 1.45%, 2012-2014 decreased by 0.09% and the period of 2014-2016 increased by 0.98%. It can be concluded that the period of 2008-2010 occurred over land conversion on Natural Forest land. New land clearing on 148.5 ha of Mixed Crops, Shrub Shrubs, Farms/Settlements and Settlements. The biggest switch functions to be a mixed garden of 84.25 Ha (Figure 6 and Figure 7).

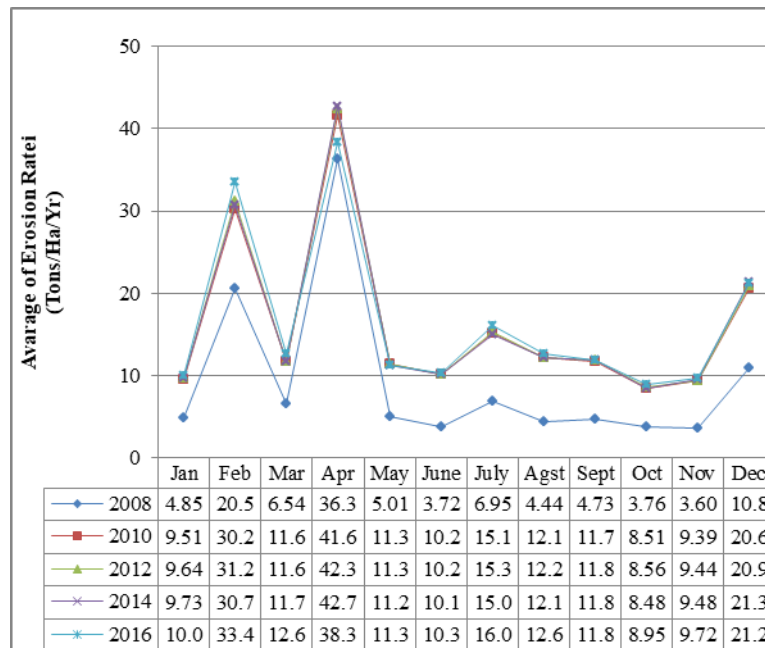


Figure 6. Graph of Monthly Erosion Rate Comparison of 2008, 2010, 2012, 2014 and 2016

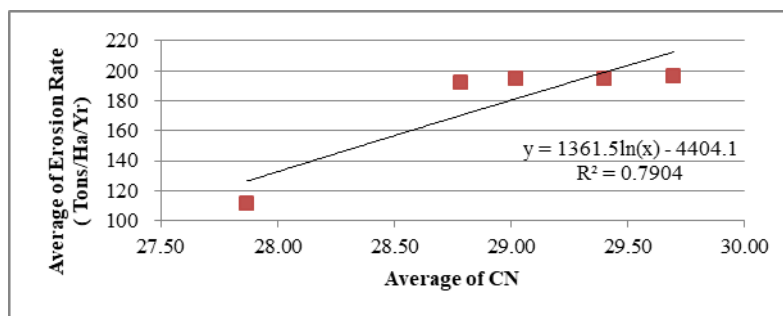


Figure 7. Relation Graph of Changes in Land Use to the Average Erosion Rate

In this study an analysis of changes in land use to the extent of BEHI was carried out. Changes in land use in this case are indicated by CN values. From the analysis, it was found that the increase in CN value resulted in an increase in the average erosion rate. So, it can be concluded that changes in land use that occur in the Wuno Sub-watershed greatly affect the rate of erosion that will occur.

Sediment

From the SWAT simulation results it can be seen that there was an increase in the amount of sediment during 2008 to 2016. The largest increase occurred in the period 2008-2010, the amount of sediment produced increased by 114.6%. The period of 2010-2012 increased by 1.04%, 2012-2014 increased by 1.65% and 2014-2016 increased by 1.85% (Figure 8).

3.2. Bank Erosion Hazard Index Analysis

The magnitude of the erosion hazard value is stated in the Bank Erosion Hazard Index (BEHI), which is defined by the potential erosion value (tons/ha/year) divided by the amount of erosion that can still be left. From the results of the 2008 BEHI classification, it can be seen that there are 4 (four) classes of erosion hazard indices in the Wuno Sub-watershed, namely Low, Medium, High and Very High.

From the table above, it can be seen that BEHI is very high, all of which occurs in the land use field/upland, Settlements, Mixed Crops and Shrub Shrubs, while Low BEHI takes place entirely in the use of Natural Forest lands. This shows that land use is very influential on BEHI (Table 7).

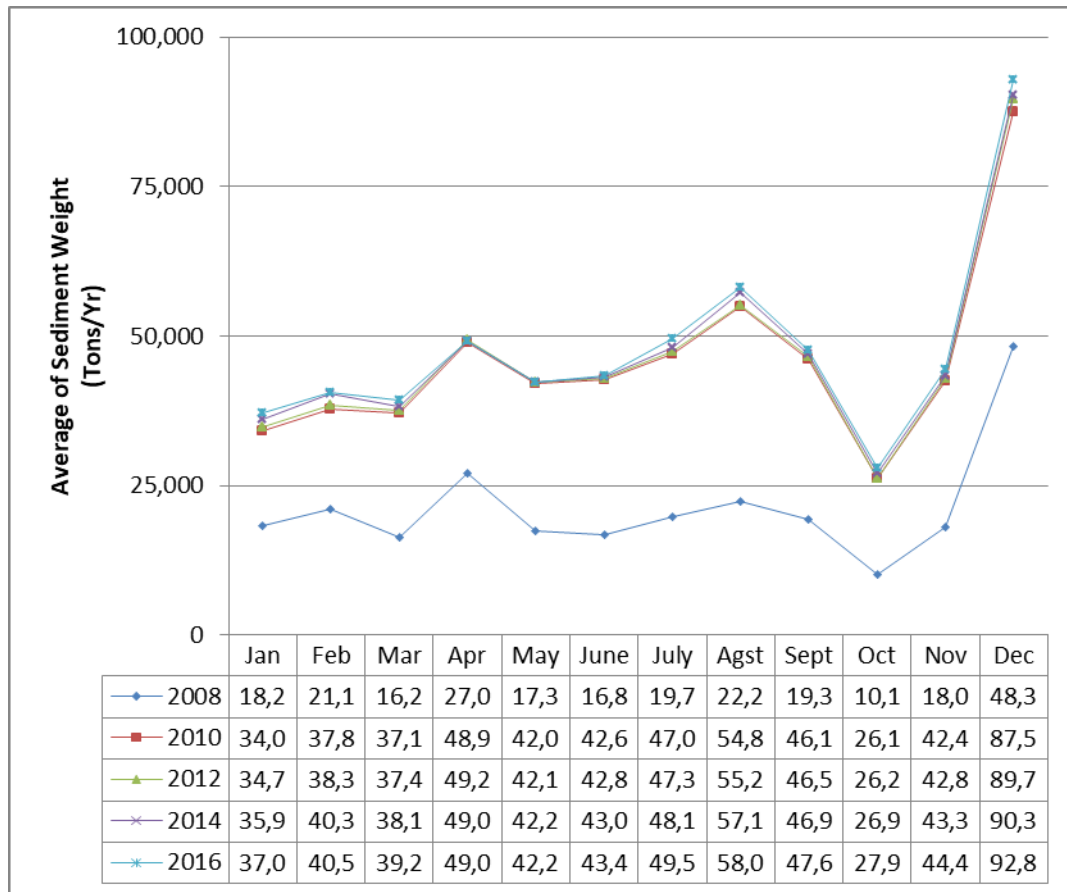


Figure 8. Graph of Monthly Sediment Weight Comparison of 2008, 2010, 2012, 2014 and 2016

Table 7. Recapitulation of BEHI

No	BEHI	2008		2010		2012		2014		2016	
		Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%
1	2	3	4	5	6	7	8	9	10	11	12
1	Low	12,906.50	78.55	12,769.70	77.72	12,638.80	76.92	12,523.00	76.22	12,424.00	75.61
2	Medium	1,239.35	7.54	1,297.06	7.89	1,346.44	8.19	1,372.03	8.35	1,414.21	8.61
3	High	477.46	2.91	512.83	3.12	535.12	3.26	555.54	3.38	556.56	3.39
4	Very High	1,807.69	11.00	1,851.41	11.27	1,910.64	11.63	1,980.43	12.05	2,036.23	12.39
Sum		16,431	100	16,431	100	16,431	100	16,431	100	16,431	100

In this study an analysis of changes in land use to the extent of BEHI was carried out. Changes in land use in this case are indicated by CN values. From the analysis, it was found that the increase in CN value resulted in an increase in the BEHI of Medium, High and Very High. On the contrary, the increase in CN value has an effect on the decrease in the Low BEHI area. So, it can be concluded that changes in land use that occur in the Wuno Sub-watershed are very influential on the BEHI area that will occur (Figure 9 – 17).

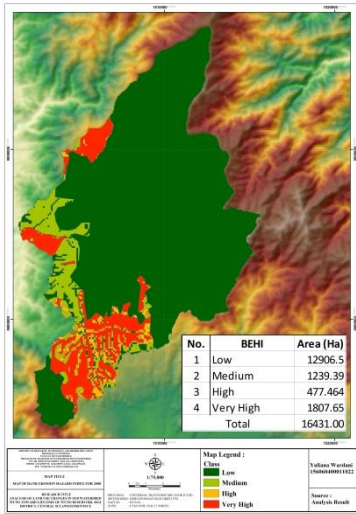


Figure 9. BEHI Land Use Distribution Map for 2008

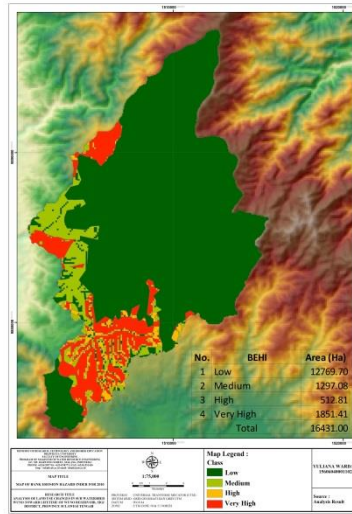


Figure 10. BEHI Land Use Distribution Map for 2010

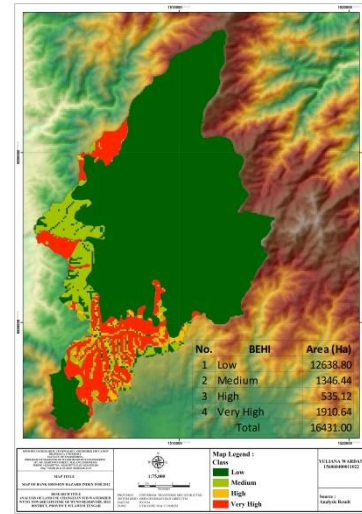


Figure 11. BEHI Land Use Distribution Map for 2012

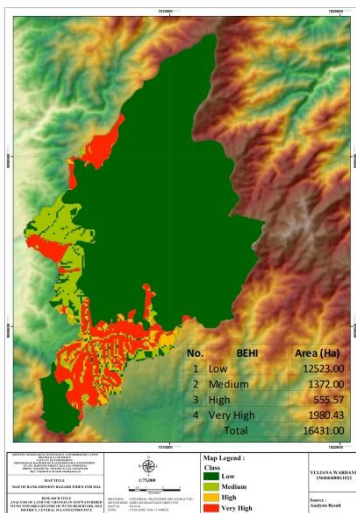


Figure 12 BEHI Land Use Distribution Map for 2014

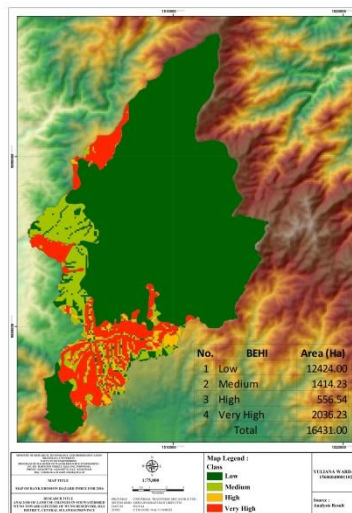


Figure 13. BEHI Land Use Distribution Map for 2016

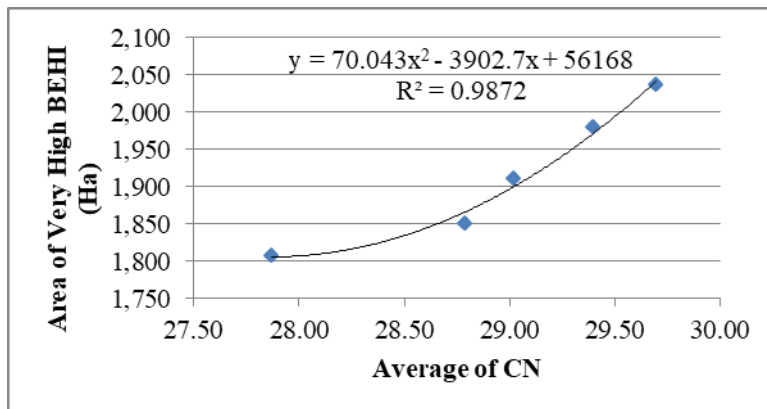


Figure 14. Graph of Relation of Changes in Land Use to Very High BEHI.

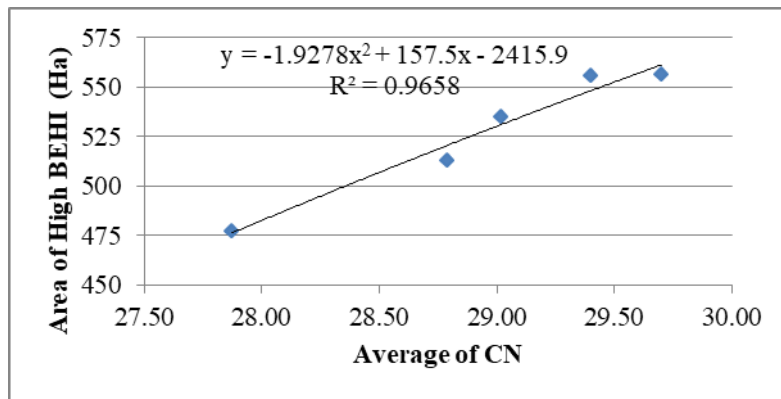


Figure 15. Graph of Relation of Changes in Land Use to High BEHI

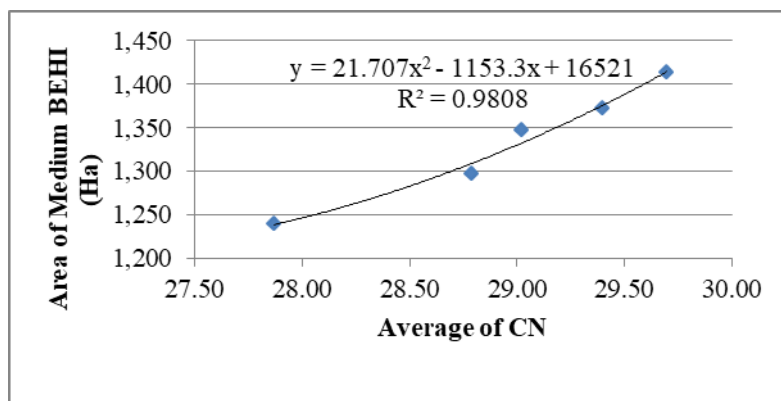


Figure 16. Graph of Relation of Changes in Land Use to Medium BEHI.

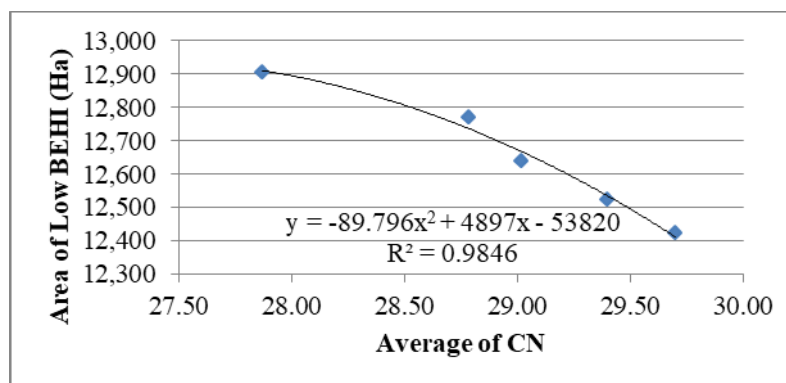


Figure 17. Graph of Relation of Changes in Land Use to Low BEHI.

3.3. Reservoir Lifetime Analysis

The parameters used to calculate the useful life of the reservoir are the volume of dead reservoir (m^3), area of watershed (km^2), average weight of sediment entering the reservoir (ton/year), content of dry sediment deposits ($0.963 \text{ ton}/m^3$) and sediment capture efficiency. In addition to sediment capture

efficiency, other parameters are known. To calculate the efficiency of sediment capture, the Brune method and Churchill method are used.

From the nomogram of Brunne and Churchill equations, the sediment trapped is 98% of the volume of sediment entering the reservoir. So that the sediment released is only 2%.

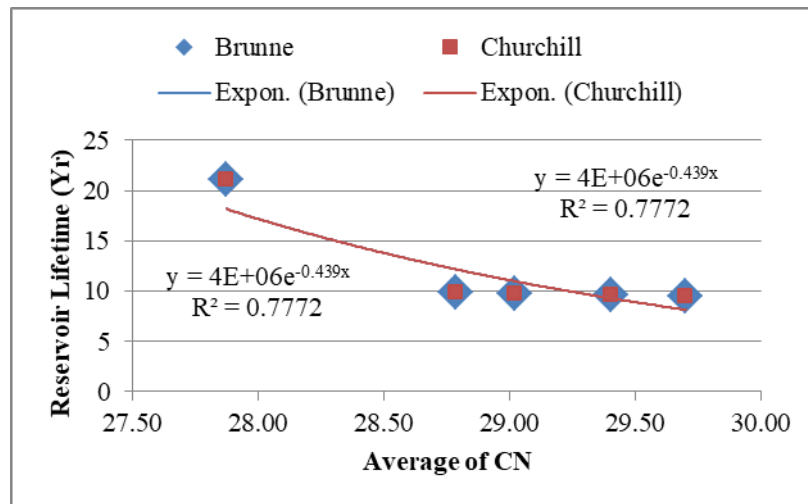


Figure 18. Graph of Relation of Changes in Land Use to Reservoir Lifetime.

From the calculation above, it was found that the Wuno Reservoir Use Age using the Brune Method was 9.52 years while using the Churchill Method was 9.52 years (Figure 18). In this study an analysis of changes in land use to the useful life of reservoirs was carried out. Changes in land use in this case are indicated by CN values. The useful life of the reservoir is shown using the Brune and Churchill methods.

3.4. Land Conservation Direction Vegetative Method

In this research, vegetative handling efforts were carried out were forest restoration or forest area adjustment. Adjustment of forest area refers to map of Forest Areas of Central Sulawesi Province. The results of overlaying the Map of the Central Sulawesi Province Forest Area with land use in 2016, there is a mismatch of forest functions. On the Map of the Central Sulawesi Province Forest Area the land designated as Limited Production Forest, but in the field is a mixed garden and shrub. In addition there is a land designated as Protection Forest, in the field is used as a mixed garden. To determine the extent to which the effectiveness of vegetative methods in reducing sedimentation that occurred in the Wuno Sub-watershed, a simulation was carried out based on the Map of the Central Sulawesi Province Forest Area.

From the simulation results, the amount of sediment produced is 209,942.15 tons/year. The amount of sediment decreased by 353,605.52 tons/year (62.75%) compared to 2016. Where the amount of sediment in 2016 was 563,547.67 tons/year. This has a positive impact on the amount of sediment entering the reservoir. The smaller the amount of sediment that enters the reservoir every year will certainly extend the useful life of the reservoir.

Mechanical Method

Based on the reservoir utilization age, the useful life of Wuno Reservoir is 9.52 years, while the reservoir is planned to be operational for 50 years. By trial and error, to reach the age of 50 years plan, the weight of sediment that can enter the reservoir every year is 105,000 tons/year from the total

weight of sediment in 2016 of 563,547.67 tons/year. Thus, the sediment that must be prevented from entering the reservoir is 458,547.67 tons/year (Figure 19).

Placement of buildings or locations of sediment control structures is placed in areas that contribute large sediments to the river based on sub-watersheds that have a high and very high erosion hazard index. At the sub-watershed outlet with a high and very high erosion hazard index, a check dam will be planned.

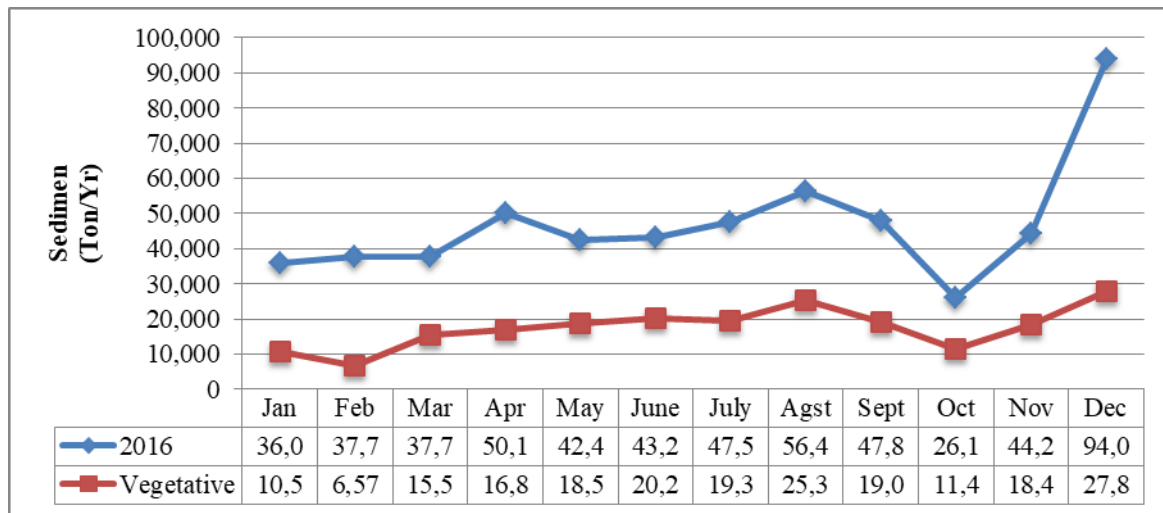


Figure 19. Comparison of 2016 Land Use Sediment Amounts with Vegetative Land Management.

From the analysis results obtained 6 (six) check dam locations with the total volume of sediment collected is 502,920.12 tons/year or 484,312.07 m³/year (Figure 20).

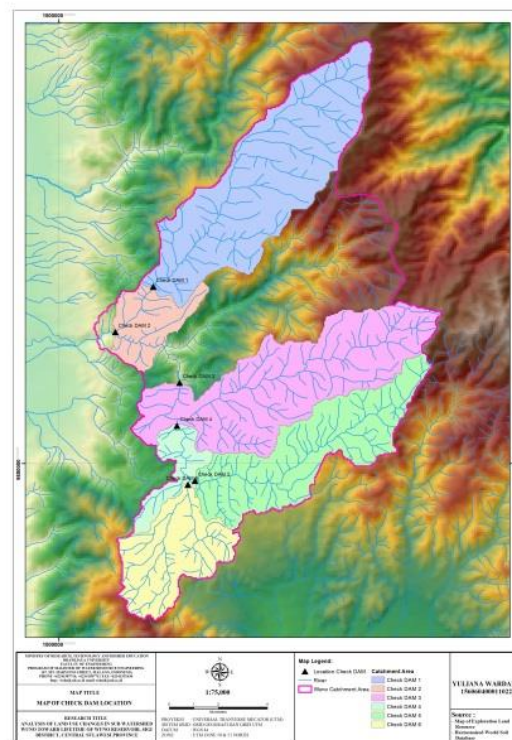


Figure 20. Map of Check Dam Location.

4. Conclusions

Based on the results of analyzing, the rate of erosion and the extent of BEHI are influenced by changes in land use. Land use changes also affect the reduced useful life of the reservoir. Vegetative land conservation efforts are adjusting forest areas so that rate of erosion decreases by 62.75%. Mechanical land conservation efforts in the form of the construction of 6 check dams so that weight of sediment decreases by 89.24%.

References

- [1] Achsan. 2015. *Analisis Kecenderungan Sedimentasi Waduk Bili-Bili Dalam Upaya Keberlanjutan Usia Guna Waduk*. Thesis. Jurnal Teknik Pengairan 6 (1), p 30-36.
- [2] Ahmed Moustofa Ahmed Moussa. 2012. *Predicting The Deposition In The Aswan High Dam Reservoir Using A 2-D Model*. Ain Shams University, 4, p 143-153
- [3] Asmaranto, R., Suhartanto, E., Yuanita, M. 2012. *Aplikasi Model AVSWAT 2000 untuk Memprediksi Erosi, Sedimentasi dan Limpasan di DAS Sampean*. Jurnal Teknik Pengairan 2 (1), p 79-85.
- [4] Arsyad, Sitanala. 2006. *Konservasi Tanah dan Air*. Bogor: IPB Press
- [5] Balai Pengelolaan Daerah Aliran Sungai dan Hutan Lindung Palu Poso. 2006. *Erosi DAS Wuno Tahun 1992 – 2006*.
- [6] Balai Wilayah Sungai Sulawesi III. 2015. *FS Waduk Wuno*.
- [7] Balai Wilayah Sungai Sulawesi III. 2016. *DD Bendungan Wuno*.
- [8] Haribowo, R., Yoshimura, M., Sekine, M., Imai, T., Yamamoto, K., Higuchi, T., Kanno, A. 2017. *Behavior of toxicity in river basins dominated by residential areas*. Contemporary Engineering Sciences 10 (7), p 305-315.
- [9] Kartasapoetra G., et all. 1987. *Teknologi Konservasi Tanah dan Air*. Jakarta: PT. Bina Aksara.
- [10] Md Shahriar Pervez, Geoffrey M. Henebry. 2015. *Assessing the impacts of climate and land use and land cover change on the freshwater availability in the Brahmaputra River basin*. Journal of Hydrology: Regional Studies, 3, p 285-311.
- [11] Suhartanto, E., Haribowo, R. 2011. *Application Of Kagan-Rodda Method For Rain Station Density In Barito Basin Area Of South Kalimantan, Indonesia*. Journal of Applied Technology in Environmental Sanitation 1 (4), .
- [12] Suharyanto, A., Suhartanto, E., Pudyono, P. 2013. *The Use of Satellite Remote Sensing Data and Geographic Information Systems on Critical Land Analysis*. AGRIVITA, Journal of Agricultural Science 35 (2), p 119-126.
- [13] Sulfandi. 2015. *Studi Pengaruh Perubahan Tataguna Lahan Di DAS Mamasa Terhadap Usia Guna Waduk PLTA Bakar*. Jurnal Teknik Pengairan 7 (1), p 139-149.
- [14] Temesgen Gashaw, Taffa Tulu, Mekuria Argaw, Abeyou W. Worqlu. 2018. *Modeling the hydrological impacts of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia*. Science of The Total Environment, 619–620, p 1394-1408.