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INFLUENCE OF BASIN VOLUME AND LAND USE OF LAKE LINDU ON THE RAWA RIVER DISCHARGE

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ABSTRACT

Lake Lindu Watershed 546.05 km2 area is part of the Gumbasa watershed, where nine rivers flow into Lake Lindu and empties into the Rawa River. The purpose of this research is to find out the influence of lakebasin catch and change volume of Lake Lindu watershed to Rawa River discharge. The method used in this research is SCS method and HEC-HMS simulation. Changes in land use can be seen with the change of CN value in Lake Lindu watershed in 2008 and 2014 by 77.74 and 77.68; effective rainfall of 6.29 mm and 2.88 mm and discharge of 188.14 m3/s and 86.15m3/sec respectively. The opposite happened in 2008, where the rainfall is larger so that it produces large discharge too. Lake Lindu has basin volume of 1.197 million m³ for the deepest water depth of 65 m no significant effect on the discharge into Lake Lindu because the water does not overflow out lake.

Key words: Bathymetry, CN Value, Gumbasa Watershed, Land Use, Lake Lindu,

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1. INTRODUCTION

The Gumbasa watershed is part of the Palu watershed located in Central Sulawesi Province, Indonesia, with basin of 1,229.43 km² haves at Mount Masomba, Mount Nokilalaki and Lake Lindu, while Lake Lindu Watershed is part of the Gumbasa Watershed. The Lake of Lindu watershed is part of the Lore-Lindu National Park which is a protected forest located at varying heights from 0-2,700 m above sea level with a dominant height above 1,000 m above sea level. Its surface forms tend to be hilly and bumpy with a slope of 8-30%, which indicates that the surface flow can be large [1].

Some researches about lakes in particular the effect of land use change on a watershed lead to increased volumes of erosion and sedimentation in watersheds, and changes in river flow in lake outlets can be explained as follows:

The watershed is an area bounded by topographical separators that save, store and drain the rainfall water that falls on it into the main river that empties into the sea or lake [2]. In each watershed, land use change is often inevitable because of natural resource management activities; deforestation, shifting cultivation, forest conversion into plantation areas, and changes in large-scale treatment of land can affect river flow. This resulted in rain falling into the watershed not so much into the infiltration but it would become a river discharge [3].

Basically the lake has two main functions namely ecological function and socio-economic-cultural function. The ecological function of the lake is as a regulator of the water system, flood control and other functions. In addition, the lake also serves to regulate the hydrological system that is by balancing the flow of water between the upstream and downstream of the river, and supplying water to other water bags such as aquifers (groundwater), rivers and rice fields. Thus the lake can control and reduce the flood in the rainy season, and save it as a backup in the dry season [4].

The greatest threat to a lake is its sedimentation due to environmental damage to its tributary. The result of sedimentation research in Tempe Lake, South Sulawesi-Indonesia Province, is very concern which is marked by the increasing of sedimentation and the increasing of area of DAS that converted from vegetation to agriculture, that is 63.2 km^2 since 2000 until 2015 [5]. Based on the study of the rate of decline in the area of the lake reaches 1.48 km^2 per year and is estimated in the dry season of 2093 Lake Tempe will be lost [6].

Research on the damage of Limboto Lake ecosystem in Gorontalo-Indonesia Province is a management policy that has not been comprehensive and lack of coordination [7]. Other research done by [8] on the north shore of Lake Victoria, shows that settlements produce much more sediments between 17-87 ton/ha/year, whereas agricultural land use produces sediments between 0-27 ton/ha/year.

Lake that has been improved function that is Lake Toba, North Sumatra Province, Indonesia by making weir controlling Siruar. Control of outflow from Lake Toba to Asahan River so Lake Toba is no longer fully functioning as a natural lake. Siruar Dam is intended to support the Hydro Power Plant with a total installed capacity of 617.2 MW [9], while in terms of environment that the quality of Lake Toba water has been polluted, with the category of pollutants [10].

Besides the utilization of natural resources as described above, it is more important to control and maintain water sources in the rainy season especially in dry season and the balance of nature needs to be kept in mind. Therefore, the constructed wetlands could provide an alternative measure for flood prevention as well as an ecosystem for biodiversity [11], it is also important to maintain water quality from pollutants especially surface water [12]. Once the importance of water sources in terms of quantity also need to be considered that is by utilizing rain water as a source of raw water in areas with less water potential by using decomposer technology to be feasible for consumption [13].

If there is a change in flow of both the flow of the surface and the flood discharge in the river increases drastically the possibility of land use damage occurs in the upper watershed as it did in 2008 [14]. A study of the effect of land use on a watershed conducted by [3] in the Lesti watershed of Indonesia shows that CN value from 2002 to 2012 was an average increase of 1.03% with an average river flow of 18.54 m^3/sec.

2. RESEARCH SITES

The Lake Lindu watershed is part of the Gumbasa Watershed, where there are several rivers flowing into Lake Lindu, such as: Lembosa River, Tokaranu River, Salusuo River, Kalamoa River, Bomba River, Bose River, Langko River, Dongi River and several other small rivers. Generally the catch area originates on the eastern side of the lake with the only river as the outlet of the water discharge found in Lake Lindu is the Rawa River that flows into the Gumbasa River and merges with the Palu River. The average annual discharge of Rawa River reaches 15.42 m^3/sec [15].

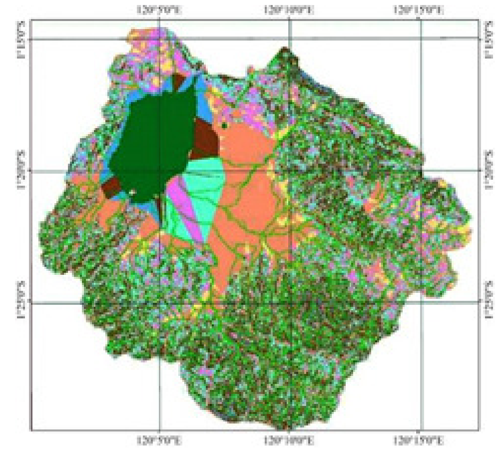

Figure 1 Research sites at watershed of Lake Lindu.

Lake Lindu watershed in terms of administrative located in the Sigi District, Central Sulawesi Province, Indonesia as a place of research, which entered the Lore Lindu watershed area, generally in the form of mountains, hills and land. Geographical position can be seen in Fig. 1.

3. MATERIAL AND METHODS

3.1. Calculation of the area and volume of the lake

The purpose of this research is to know the change of Lake Lindu River basin use to the Rawa River discharge as outlet from Lake Lindu; lake classification; the relationship between high water volume and the area of Lake Lindu. The measurement of the depth of Lake Lindu was done using echo sounder tools and the wide calculation used the volume approximation equation [16]:

$$V_x = \frac{1}{3} Z(F_y + F_x + \sqrt{F_y \, x \, F_x} \qquad (1)$$

Determination of the classification of the lake is based upon [17] the depth category of Lake Lindu can be seen in Table 1 and Table 2 below:

Table 1 Classification of lake size

No	Classification	Surface of water (km²)	Volume (million m³)
1	Big	10.000 – 1.000.000	10.000 – 100.000
2	Medium	100 – 10.000	100 – 10.000
3	Small	1 - 100	1 - 100
4	Very small	< 1	< 1

Table 2 Category of depth lake

No	Category	Depth (m)
1	Very shallow	< 10
2	Shallow	10 - 50
3	Medium	50 - 100
4	Deep	100 - 200
5	Very deep	> 200

3.2. Rainfall Region

In determining the average rainfall used Thiessen Polygon method, this method is suitable to be used if the distribution of rainfall stations in the area reviewed uneven [18].

$$P = \frac{P_1.A_1 + P_2.A_2 + P_3A_3 + ... + P_n.A_n}{A_1 + A_1 + A_3 + ... + A_n} \quad (2)$$

3.3. Analysis of land use

To determine the effect of land use change on Lake Lindu watershed is done by analyzing the land using the SCS method [19]. The implementation stages are as follows:

a) Data of land cover, soil type data and slope)

b) Calculated the value of the daily rain

$$P = \frac{\sum_{i=1}^{n} A_i.P_i}{A_{total}} \quad (3)$$

c) Calculated the value of effective rain

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (4)$$

d) Determining the value of CN Area Weighted

$$CN\ Area\ Weighted = \frac{Land\ area\,(km)^2\, x\, CN\ value}{The\ total\ area\ of\ land\,(km^2)} \quad (5)$$

e) Flood discharge design with HSS Nakayasu method with equation 6-10 [20], Other discharge calculations with HSS Nakayasu are performed with the HEC-HMS program.

$$Q_p = \frac{1}{3.6}\left[\frac{A\,R_e}{0.3T_p + T_{0.3}}\right] \quad (6)$$

$$T_p = tg + 0.8T_r \quad (7)$$

$$tg = 0.4 + 0.058L\ for\ L > 15\ km \quad (8)$$

$$tg = 0.21L^{0.7}\ for\ L < 15\ km \quad (9)$$

$$T_{0.3} = \alpha\, tg, \quad T_r = 0.5tg\ until\ tg \quad (10)$$

3.4. Daily rainfall distributed

Calculation of the time of concentration during rainfall is done by using Kirpich equation [21].

$$t_c = \frac{0.06628\, L^{0.77}}{I^{0.385}} \tag{11}$$

Calculated of the design rainfall (R_{24}) by assuming that the average rain does not fully occur for 24 hours, but is distributed within a few hours. Daily rain intensity will be converted into hour-time rain intensity using Mononobe equation [22].

$$I_t = \frac{R_{24}}{24}\left(\frac{24}{t_c}\right)^{2/3} \tag{12}$$

Calculate the hyetograph value by the formula

$$Hyetograph\ (mm) = \frac{Hyetograph\ (\%)}{100}\ x\ rain \max region \tag{13}$$

4. RESULT AND DISCUSSION

4.1. Measuring Physical Condition of Lake Lindu

A preliminary study has been conducted on the physical condition of Lake Lindu by performing direct measurements in the field of bathymetry measurements of the depth of Lake Lindu, bathymetry survey conducted on April 14 until April 25, 2017 by following the predefined sounding path. For each sounding path is done to capture water depth data every 50 m distance.

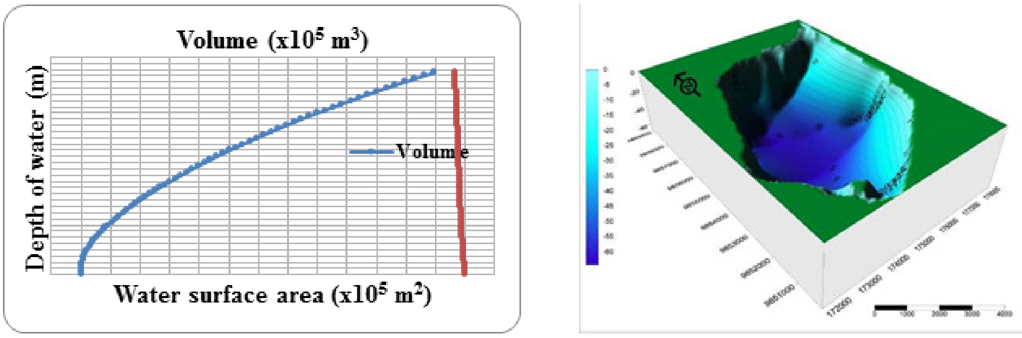

Fig. 2. Lake Lindu Condition (a) Graph relation of water depth to the volume and extent surface of water (b) Profil 3D bathymetry.

The calculation results of the bathymetry map as to the depth and extent of Lake Lindu obtained as the graph of the relationship between the volume, extent and height of water in the lake as shown in Fig. 2a, the 3D bathymetry profile of Lake Lindu in Fig. 2b. From Fig. 2a formulated the equation 14 is the relationship between the height and surface area of lake water, while the equation 15 relationship between lake water height to lake volume, these two equations are the basic equations for knowing the basic lake changes that will come.

$$F = (4.975h + 23) * 10^5 \tag{14}$$

$$V = (2h - 211) * 10^7 \tag{15}$$

The bathymetry measurements of Lake Lindu have total volume and lake area of 1,197,548.29 m³ and 34.89 km ², an average width of 4.5 km and an average length of 7 km. The average depth is 38.4 m and the deepest 64.8 m.

Based on Table 1 and Table 2, the classification of Lake Lindu is as follows:

Table 3 size classification of Lake Lindu

No	Description	Size	Information
1	Surface of water	34.89 km²	Small
2	Volume	1.198 million m³	Medium
3	The average depth	38.4 m	Shallow
4	The maximum depth	64.8 m	Medium

4.2. Result of calculation of rainfall region

The rainfall data used in this research is rainfall data from 3 (three) rain stations, namely: Palolo rain station, Kulawi rain station, and Wuasa rain station from 2002 to 2015. For land cover map data, slope map and map type of soil taken from [23].

The results of the annual maximum rainfall calculation as follows:

Table 3 The daily rainfall of maximum region

NO	Happened on	Rain station			Rain of region (mm)
		Kulawi	Palolo	Wuasa	
1	March 1, 2008	99.3	0	2.6	36.6
2	August 9, 2008	25.3	35.7	8.5	22.1
3	July 17, 2008	27.3	19.3	66.7	39.3
				Biggest	39.3
1	May 12, 2014	59.5	0	15.5	26.9
2	September 5, 2014	0	82.5	0	23.0
3	March 17, 2014	0	0	84.7	30.6
				Biggest	30.6

The calculations of the past hour-time hyetographs for 2008 and 2014 can be seen in Table 5 and Table 6.

Table 5 Calculation of hourly rainfall hyetograph of 2008

T_d	Δt	I_t	I_t x T_d	ΔP	P_t	Hyetograph	
hour	hour	mm/hour	mm	mm	%	%	mm
1	0 – 1	116.10	116.10	116.10	69.34	18.02	7.08
2	1 – 2	73.14	146.28	30.18	18.02	69.34	27.25
3	2 - 3	55.82	167.45	21.17	12.64	12.64	4.97
Amount				167.45	100.00	100.00	39.30

Table 6 Calculation of hourly rainfall hyetograph of 2014

T_d	Δt	I_t	I_t x T_d	ΔP	P_t	Hyetograph	
hour	hour	mm/hour	mm	mm	%	%	mm
1	0 – 1	131.64	131.64	131.64	69.34	18.02	5.51
2	1 – 2	82.93	165.85	34.22	18.02	69.34	21.22
3	2 - 3	63.28	189.85	24.00	12.64	12.64	3.87
Amount				189.85	100.00	100.00	30.60

4.3. Analysis of land use with SCS Method and HEC-HMS simulation

Values of CN can be determined from watershed characteristics such as land use type, hydrological conditions and soil types. On the digital map of Lake Lindu watershed shows land use in 2008 and 2014. Land use changes can be seen in Table 7 and Table 8.

Table 7 CN value for some land use in 2008

Land use	Condition of hydrology	Land group	CN value	Area of land (km^2)	CN *Area Weighted*
Shrubs	Bad	C	85	12,716	1.981
	Poorly		81	11,605	1.723
	Good		79	19,342	2.800
	Good	D	84	6,663	1.026
	Poorly		86	7,700	1.213
Forest	Poorly	C	77	0,089	0.013
	Less good		73	0,148	0.020
	Good		70	15,543	1.994
	Poorly	D	83	7,639	1.162
	Good		77	421,652	59.495
Garden	Good	C	72	8,732	1.152
	Good	D	79	6,549	0.948
	Good	D	79	10,915	1.580
Settlement		C	94	0,331	0.057
		D	95	0,166	0.029
Empty land	Good	D	90	0,655	0.108
	Less good		93	1,291	0.220
Irrigated rice field	Good	C	83	3,463	0.527
	Good	D	87	2,309	0.368
	Good		87	8,204	1.308
Fresh water/body water			100	0.342	0.063
Total				546,056	77.74

Table 8 CN value for some land use in 2014

Land use	Condition of hydrology	Land group	CN value	Area of land (km^2)	CN *Area Weighted*
Shrubs	Poorly	C	85	11,317	1.763
	Less good		81	12,070	1.791
	Good		79	16,181	2.343
	Good	D	84	6,197	0.954
	Less good		86	5,700	0.898
Forest	Poorly	C	77	0,085	0.012
	Less good		73	0,644	0.086
	Good		70	12,529	1.607
	Poorly	D	83	6,633	1.010
	Good		77	429,526	60.606
Garden	Good	C	72	9,081	1.198
	Good	D	79	8,876	1.285
	Good	D	79	10,478	1.517
Settlement		C	94	0,264	0.046
		D	95	0,182	0.032
Empty land	Good	D	90	0,635	0.105
	Less good		93	1,165	0.199
Irrigated rice fields	Good	C	83	4,672	0.711
	Good	D	87	3,447	0.550
	Good		87	6,024	0.960
Fresh water/body water			100	0.342	0.063
Total				546,056	77.68

An effective rainfall calculation with CN-Normal value or AMC II values for normal humidity conditions for 2008 and 2014 in Table 9.

Table 9 The calculation of effective rainfall

Year	**CN Area of weighted**	***S*** **(mm)**	I_a **(mm)**	***P*** **(mm)**	**Effective rainfall** P_e **(mm)**	**Discharge (m^3/dt)**
2008	77.74	72.73	14.54	39.30	6.29	188.14
2014	77.68	72.98	14.59	30.60	2.88	86.15

Land use change based on result of analysis with SCS method in 2008 and 2014 obtained CN Lake of Lindu watershed value: 77.74 and 77.68. Based on the results of analysis of CN values that exist in Lake Lindu watershed did not undergo significant changes. This happens because Lake Lindu watershed is a protected forest area which is still natural.

Calculation of Rawa River flood discharge using HSS Nakayasu method with HEC-HMS program for 2008 and 2014 with wide area of watershed (A) = 546.056 km^2, river length (L) = 28.334 km, effective rainfall year 2008 and 2014 (Re) = 6.29 mm and 2.88 mm, the result of the discharge calculation as in Table 9 and the HEC-HMS analysis and calculation as in Fig. 3.

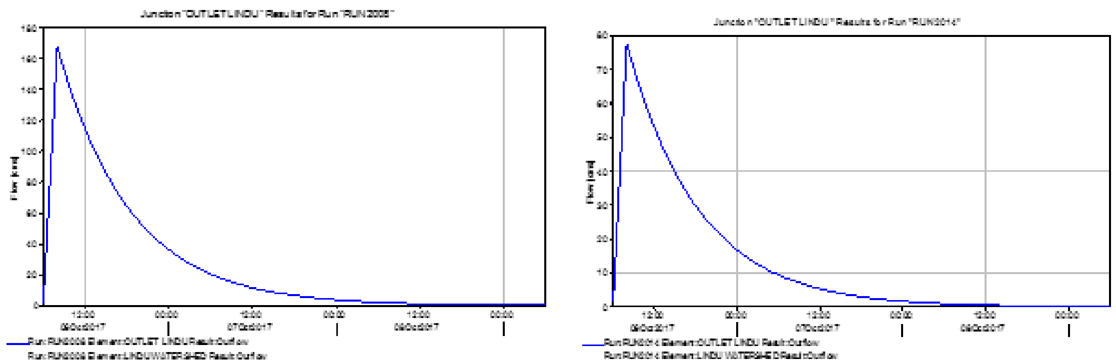

Fig. 3. HEC-HMS simulation of the discharge relationship with time (a) the result of 2008 (b) the result of 2014.

HEC-HMS simulation discharge values for 2008 and 2014 were Q = 162.6 m^3/sec and Q = 77.8 m^3/sec respectively. These results show that land use in 2008 and 2014 has no significant effect on the discharge that occurs due to small rainfall in 2014 resulting in a small discharge when compared to that in 2008 with large rainfall generating large discharge as well.

5. CONCLUSIONS

The conclusions obtained from the results of this study are as follows:

- Based on the bathymetry survey, Lake Lindu has a volume of 1.197 million m³, an area of 34.89 km², an average width of 4.5 km, an average length of 7 km, an average depth of 38.4m and a deepest 64.8m. While the equation for the relationship between the height and surface area of the lake water is $F = (4.975h + 23)*10^5$, and the equation of the relationship between lake water height and lake volume is $V = (2h-211)*10^7$, these two equations are the basic equations for knowing the basic lake changes that will come.
- Land use change can be seen with the change of CN value in Lake Lindu watershed in 2008 and 2014 with values of 77.74 and 77.68, effective rainfall of 6.29 mm and 2.88 mm, and discharge of 188.14 m^3/sec and 86.15 m^3/sec. This shows that land use does not have a significant effect on the discharge that occurs due to small rainfall in 2014 resulting in the discharge is also small when compared to that occurred in 2008 with large rainfall then the discharge is also large.

- Lake Lindu has not functioned optimally because of the absence of control buildings, so that the water is temporary, especially the water elevation that is below the basic outflow.
- By considering the volume of Lake Lindu, it is still able to accommodate the discharge into the lake, meaning the water does not overflow out the lake, because the carrying capacity of Lake Lindu is still good.

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Nomenclatures

Symbols	Definitions	Dimensions
A	Watershed	km^2
$A_1, A_2, A_3,.. A_n$	Area sub area representing each rain station	km^2
Ai	Basin	m^2
Atotal	Total area	m^2
F	Lake area	m^2
Fy	**Area on the Y direction contour**	m^2
Fx	**Area** on the Y direction contour	m^2
h	Height water	m
I	The average slope of the river	-
I_t	Rainfall intensity for duration t	mm/hour
L	The long of river	km
P	**The average regional rainfall**	mm
P_e	Surface runoff volume	mm
Pi	Daily rainfall	mm
$P_1, P_2, P_3, ... P_n$	The amount of rain each station observed	mm
Q_p	Discharge of flood peak	m^3/sec
R_{24}	Maximum rainfall for 24 hours	mm
R_e	Rainfall Effective	mm
S	The difference between rainfall and surface runoff	mm
t	Duration of rain	mm
$T_{0,3}$	The time from the flood peak to 0.3 times the peak discharge	hour
t_c	Time of concentration	hour
tg	The concentration time is based on the length of the river	hour
T_r	Time unit of rainfall	hour
T_p	The time from the beginning of the flood to the top of the hydrograph	hour
V	Volume of like	m^3
Vx	**Volume of contour**	m^3
Z	High difference between contours	m
Greek Symbols		
α	The coefficient of watershed characteristics	-

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