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Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: S Eraku *et al* 2019 *J. Phys.: Conf. Ser.* **1317** 012111

IOP Conf. Series: Journal of Physics: Conf. Series **1317** (2019) 012111 doi:10.1088/1742-6596/1317/1/012111

Analyzing Limboto lake inundation area using landsat 8 OLI imagery and rainfall data

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Abstract. Limboto Lake is a natural lake located in Gorontalo Province. The condition of the lake is increasingly critical due to environmental damage and slowly loses its function. This study used Landsat 8 OLI imagery and rainfall data in the period of January 2015 to December 2016. The spatio-temporal map of the inundation area of Limboto Lake was obtained through automatic extraction method of water features with water index formula using GIS and Remote Sensing software. Analysis results based on Landsat 8 OLI image data showed that there was a large fluctuation in Limboto Lake inundation area during the study period. The largest inundation area is 4,043 ha and the smallest is 1,440 ha. This shows that the area of Limboto Lake inundation area can widen and shrink by almost 3 times. The results of analysis of rainfall data showed that large fluctuation in the Limboto Lake inundation area has a moderate correlation with the amount of rainfall that occurs. Rainfall which is the source of surface runoff and filling the Limboto Lake basin no longer has a major influence on the fluctuation of the Limboto Lake inundation area, only by 35%, there is an accumulation of other factors by 65% which is the cause the condition of large fluctuations in the Limboto Lake inundation area.

1. Introduction

Limboto Lake is a natural lake located in Gorontalo Province. The condition of the lake is increasingly critical due to environmental damage and slowly loses its function. Various efforts have been made by the regional and central government to save the lake from extinction. The most recent effort carried out by the Gorontalo Provincial Government is to include the Limboto Lake region as a Provincial Strategic Area through the stipulation of Regional Regulation (PERDA) No. 9 of 2017 concerning Spatial Planning for Limboto Lake Provincial Strategic Area, and proposes the establishment of Limboto Lake area as a National Strategic Area for the benefit of the sustainability of the lake's functions and environmental carrying capacity.

The condition of the lake where the water supply comes from rainfall directly and from the river which empties into it, will make the inundation area or water surface area of Limboto Lake very influenced by changes in the season. The average annual rainfall in the area around lake Limboto reaches 1,426 mm. Small monthly rainfall of 100 mm occurs for 3 months, namely in August, September and October. While large rainfall from 100 mm occurs for 9 months, namely in January - July and November-December [1]. Thus there will be seasonal fluctuations in the Limboto Lake inundation area depending on climatic conditions and this is important to be monitored periodically.

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Periodic monitoring of lake conditions is an important part of efforts to save Limboto Lake. Through periodic monitoring we can see and study the characteristics of lake conditions comprehensively. Changes over time can be monitored while analyzing what causes these changes.

In the remote sensing and geographic information system framework, the use of satellite imagery to monitor and manage water resources has been carried out [2-5]. And this technique has proven effective in monitoring changes over time the object of water resources being studied. Accordingly, in this study we propose the use of satellite imagery data within the framework of remote sensing and geographic information systems to monitor changes in Limboto Lake inundation areas. With the aim of the study was to analyze changes in the Limboto Lake inundation area using Landsat 8 OLI multitemporal imagery and find out the relationship between these changes and the rainfall that occurred.

2. Study area

The study area was around Limboto Lake covering about 89 km^2 broad, administratively mostly located in Gorontalo District and a small part of Gorontalo City with the following coordinates 122° 56' 14.97" E - 123° 1' 28.44" E and 0° 32' 38.21" N - 0° 37' 38.14" N (Figure 1). The delimitation of the study area was carried out to focus the study only on the areas inundated by Limboto Lake water as the study object. In addition, it also to saves time and resources when processing image data used in this study.

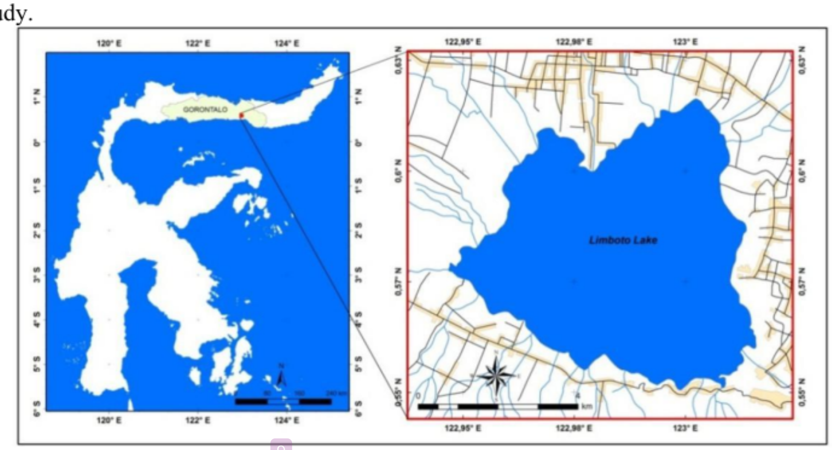

Figure 1. Map of the study area.

3. Data set

3.1. Landsat 8 OLI imagery

Ten scenes of Landsat 8 OLI imagery with different acquired date were used in this study (Table 1). The imagery used was selected from the period of January 2015 to December 2016. The free of cloud interference around the Limboto Lake is the basis for image selection.

3.2. Rainfall data

The rainfall data used is monthly rainfall from the 5 rain stations closest to the study location and represent the direction of origin of the rivers that lead to Limboto Lake (Figure 2). The five rain stations are Talumelito, Batudaa, Tabongo, Hepuhulawa and Biyonga. Period of data taken between January 2015 and December 2016 (Table 2).

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Table 1. Landsat 8 OLI scenes used in this study.

Name of Landsat 8 OLI Scene	Date acquired
LC08_L1TP_113060_20150325_20170411_01_T1	25 March 2015
LC08_L1TP_113060_20150528_20170408_01_T1	28 May 2015
LC08_L1TP_113060_20150731_20170406_01_T1	31 July 2015
LC08_L1TP_113060_20151003_20170403_01_T1	03 October 2015
LC08_L1TP_113060_20151206_20170401_01_T1	06 December 2015
LC08_L1TP_113060_20160327_20170327_01_T1	27 March 2016
LC08_L1TP_113060_20160514_20170324_01_T1	14 May 2016
LC08_L1TP_113060_20160717_20170323_01_T1	17 July 2016
LC08_L1TP_113060_20160919_20170321_01_T1	19 September 2016
LC08_L1TP_113060_20161224_20170315_01_T1	24 December 2016

Table 2. Rainfall data used in this study.

	Rainfall (mm)									
Month	**Talumelito**		**Batudaa**		**Tabongo**		**Hepuhulawa**		**Biyonga**	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
January	103.2	166	86.1	92.8	170.2	117.5	87.9	0	90.5	122.8
February	90	8.7	28.3	2.2	69.6	0	84.4	8.4	50	0
March	61.2	7	37.5	1	69.8	0	30.3	0	36	0
April	156	137.3	88	100.7	105.6	208.4	209.9	126.5	56.1	0
May	143	394.1	133.5	132.6	258.9	186.5	111.4	258.6	152.2	270.1
June	65	155.6	82.1	101.8	226.6	167	59.5	193.5	176.2	233.9
July	0	114.8	0	43.6	0	81	44.2	149.6	0	180
August	0	12.3	0	0	0	5.5	0	25.5	0	21.3
September	0	227.3	0	107.6	0	174	0	126.9	0	307.7
October	55	350.2	3.6	52.5	7	350	46.3	170.7	183.4	516.8
November	196.3	80.4	86.9	2	134.4	80.5	188.3	89.6	320.7	142.5
December	103.4	127.2	13.5	0	30.6	156.5	0	110.3	1.3	199.9

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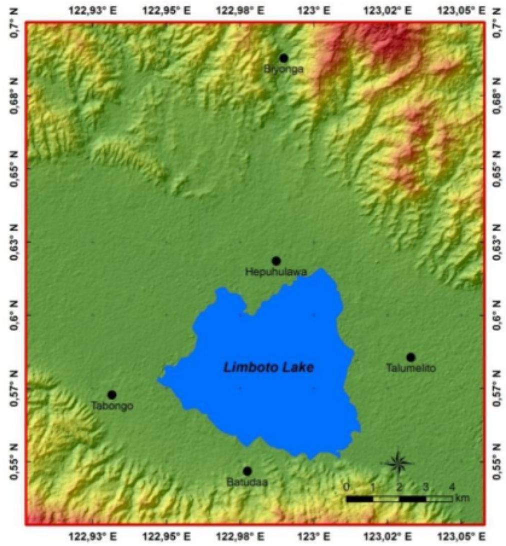

Figure 2. Map of rain station.

4. Methods

4.1. Image pre-processing

All scenes of Landsat 8 OLI imagery used in this study are downloaded from Landsat Collection 1 Level-1 (https://earthexplorer.usgs.gov/) where the pixel value is still a DN value. This DN value must be changed to reflectance value so that it can be used for the next stage. In this step, radiometric calibration and atmospheric correction are performed using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Hypercubes) method for all scenes of Landsat 8 OLI imagery used.

4.2. Delineation of inundation area

In this study, delineation of the boundary of Limboto Lake inundation area is done by automatic extraction using the water index formula. Several water index formulas have been proposed in previous studies e.g. NDWI (Normalized Difference Water Index) [6], MNDWI (Modified Normalized Difference Water Index) [7], AWEI (Automated Water Extraction Index) [8], MOWI (Modified Optimization Water Index) [9].

The water index formula used in the study is the AWEI formula. This formula has a good response to detecting water features with the background of urban areas [8,9]. The AWEI formula is as follows:

$$AWEI = 4 \times (\rho_{band2} - \rho_{band5}) - (0.25 \times \rho_{band4} + 2.75 \times \rho_{band7}) \quad (1)$$

The AWEI formula in equation (1) was developed using Landsat 7 ETM + imagery while in this study using Landsat 8 OLI imagery, it should be noted that the wavelength characteristics between Landsat 7 ETM + bands and Landsat 8 OLI bands were not similar. Comparison of bands on Landsat 7 ETM + with Landsat 8 OLI is presented in Table 3 [10]. From the results of the comparison obtained the AWEI formula for Landsat 8 OLI imagery is as follows:

$$AWEI = 4 \times (\rho_{band3} - \rho_{band6}) - (0.25 \times \rho_{band5} + 2.75 \times \rho_{band7}) \quad (2)$$

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Table 3. Comparison of Landsat 7 ETM+ imagery bands with the Landsat 8 OLI imagery bands.

Landsat 7			Landsat 8		
Band name	Res (m)	Wavelength (μm)	Band name	Res (m)	Wavelength (μm)
			Band 1 (blue)	30	0.43–0.45
Band 1 (blue)	30	0.45–0.52	Band 2 (blue)	30	0.45–0.51
Band 2 (green)	30	0.52–0.60	Band 3 (green)	30	0.53–0.59
Band 3 (red)	30	0.63–0.69	Band 4 (red)	30	0.64–0.67
Band 4 (near infrared)	30	0.77–0.90	Band 5 (near infrared)	30	0.85–0.88
Band 5 (shortwave infrared)	30	1.55–1.75	Band 6 (shortwave infrared)	30	1.57–1.65
Band 7 (shortwave infrared)	30	2.09–2.35	Band 7 (shortwave infrared)	30	2.11–2.29
Band 8 (panchromatic)	15	0.52–0.90	Band 8 (panchromatic)	15	0.50–0.68

4.3. Thresholding

The extraction of water features in the AWEI image produced using the thresholding technique. Most water indices have a stability weakness in setting a threshold value because the threshold value is not a constant value but a dynamic value [11]. Accordingly, to select a threshold value that separates water and non-water features is very difficult and requires a lot of time because it is usually done by trial and error before implemented.

In this study to select the threshold value is done by utilizing the AWEI image statistics. Based on the mean value (μ) and standard deviation (σ) it has been tried to select the threshold value. The average value of all AWEI images shows a negative value (Table 4) while the value of the water feature in the AWEI image was remarked as positive [12]. So that in this study the threshold value is taken by adding the average with the standard deviation to approach the positive value, but not more than once the standard deviation value. Several threshold values have been tried to be used in this study presented in Table 5.

Table 4. The statistic of the AWEI images.

Date acquired	Min	Max	Mean	Std
25 March 2015	-4.673	0.391	-0.641	0.480
28 Mei 2015	-3.756	0.559	-0.479	0.456
31 Juli 2015	-2.779	0.366	-0.624	0.459
03 Oktober 2015	-4.519	0.404	-0.976	0.597
06 Desember 2015	-3.633	0.585	-0.590	0.507
27 Maret 2016	-4.367	0.442	-0.883	0.530
14 Mei 2016	-3.003	0.716	-0.468	0.424
17 Juli 2016	-5.024	0.293	-0.579	0.405
19 September 2016	-4.523	0.789	-0.696	0.472
24 Desember 2016	-3.425	0.683	-0.373	0.433

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Table 5. Several threshold values that have been tried to be used in this study.

Date acquired	$\mu + 0.25\sigma$	$\mu + 0.5\sigma$	$\mu + 0.75\sigma$	$\mu + 1\sigma$
25 March 2015	-0.521	-0.401	-0.281	-0.162
28 Mei 2015	-0.365	-0.251	-0.137	-0.023
31 Juli 2015	-0.509	-0.394	-0.279	-0.164
03 Oktober 2015	-0.827	-0.677	-0.528	-0.379
06 Desember 2015	-0.463	-0.336	-0.210	-0.083
27 Maret 2016	-0.751	-0.618	-0.486	-0.353
14 Mei 2016	-0.362	-0.256	-0.150	-0.044
17 Juli 2016	-0.478	-0.376	-0.275	-0.173
19 September 2016	-0.578	-0.460	-0.342	-0.224
24 Desember 2016	-0.265	-0.157	-0.048	0.060

The threshold value generated for each AWEI image is 4, so that for the overall image used there are 40 threshold values that can indicate the object of water (Figure 3). Then a visual assessment is performed using the composite image RGB 654 to select the most appropriate threshold value that produces the best boundary of the Limboto Lake inundation area for each date acquired of Landsat 8 OLI imagery. The selected threshold value of visual assessment results presented in Table 6.

Table 6. A selected threshold value for each image.

Date acquired	Threshold
25 March 2015	$\mu + 0.75\sigma$
28 Mei 2015	$\mu + 0.5\sigma$
31 Juli 2015	$\mu + 1\sigma$
03 Oktober 2015	$\mu + 1\sigma$
06 Desember 2015	$\mu + 0.5\sigma$
27 Maret 2016	$\mu + 1\sigma$
14 Mei 2016	$\mu + 0.25\sigma$
17 Juli 2016	$\mu + 0.75\sigma$
19 September 2016	$\mu + 0.25\sigma$
24 Desember 2016	$\mu + 0.25\sigma$

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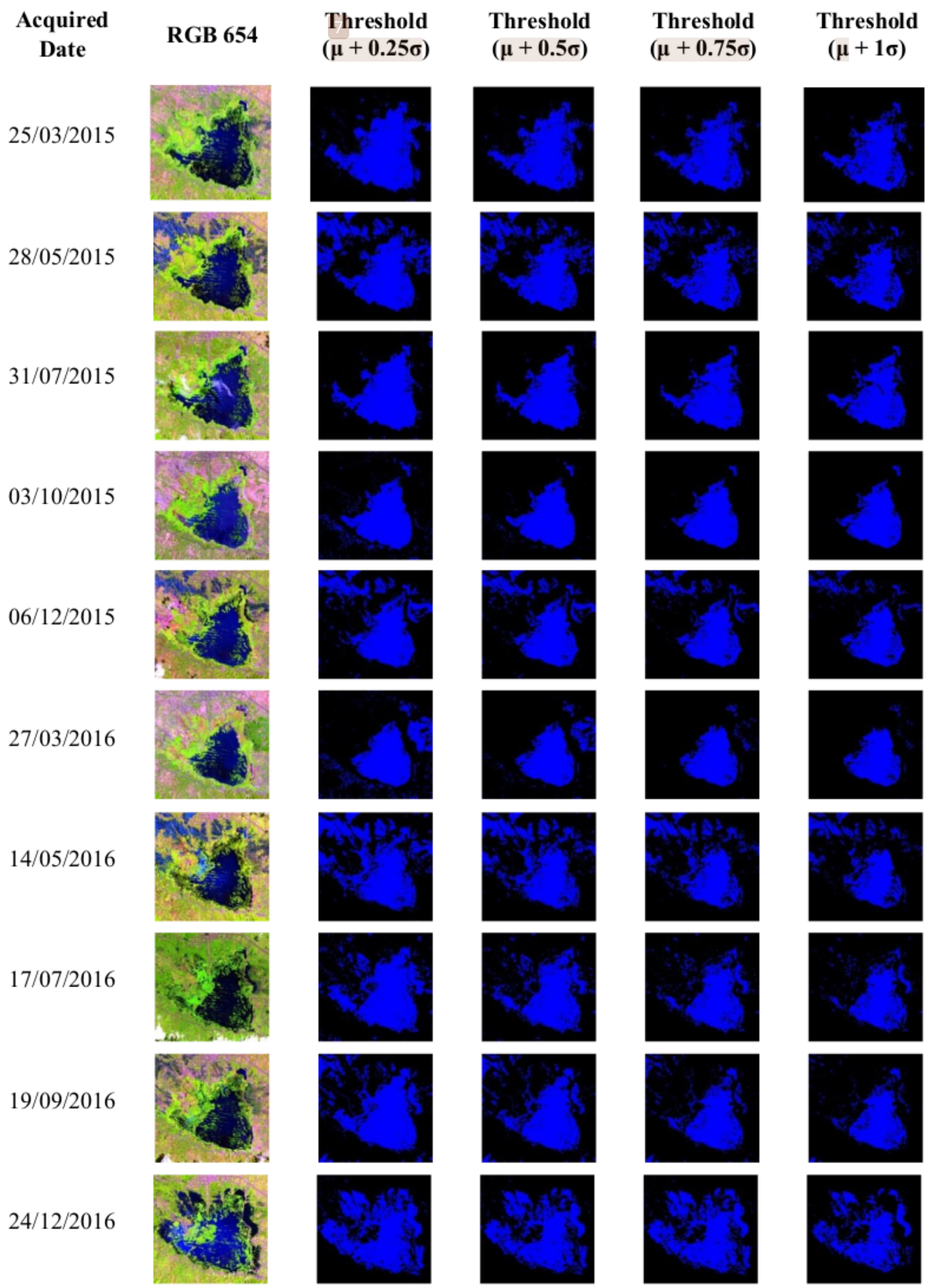

Figure 3. RGB 654 images and AWEI images based on threshold values have been tried to be used in this study.

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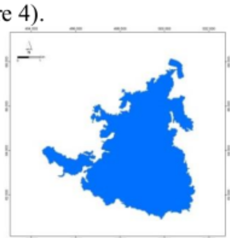
5. Results and discussion

5.1. Spatio-temporal maps of Limboto Lake inundation area

Map of Limboto Lake inundation area is produced by applying the selected threshold value (Table 6). Then it is processed by GIS software so that spatio-temporal map of the Limboto Lake inundation area is produced. In this study 10 maps were generated according to the amount of Landsat 8 OLI images used (Figure 4).



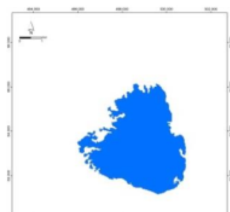
25 March 2015
Area = 2,250 ha

28 May 2015
Area = 2,132 ha

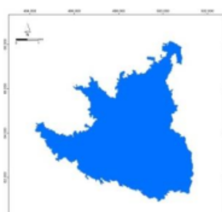
31 July 2015
Area = 2,106 ha

03 October 2015
Area = 1,741 ha

06 December 2015
Area = 1,902 ha

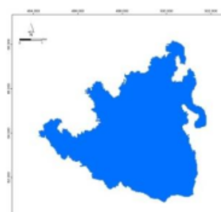


27 March 2016
Area = 1,440 ha

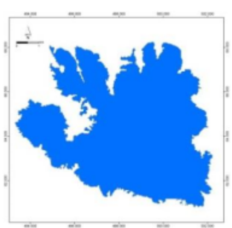


14 May 2016
Area = 1,741 ha

17 July 2016
Area = 2,075 ha



19 September 2016
Area = 2,745 ha



24 December 2016
Area = 4,043 ha

Figure 4. Spatio-temporal map of Limboto Lake inundation area.

The results obtained showed there are fluctuations in the inundation area of Limboto Lake. The narrowest inundation area was 1,440 ha which occurred in March 2016 while the largest inundation area was 4,043 ha which occurred in December 2016. This defines that the Limboto Lake inundation area can widen or shrink almost 3 times. A condition with large fluctuations, and this is not normal for healthy lakes.

If the annual mean value is calculated, in 2015 Limboto Lake has an average area of 2,026 ha, far smaller than the average area of 2016 which is 2,551 ha. Whereas for the average area for 2 years of the study period, the inundation area of Limboto Lake has an average area of 2,289 ha. Refer to the past time, according to data in 1990-2004 the average area of Limboto Lake was 3000 ha [1], so that based on analysis result in this study show there had been 711 ha shrinkage of the lake of for 12 years or Limboto Lake lost 59.25 ha of the inundation area for each year.

5.2. Relation of rainfall and inundation area

To find out the relationship between the amount of rainfall that occurs with the fluctuation of the inundation area of Limboto Lake, the correlation coefficient is calculated from these two variables. The rainfall used is monthly rainfall according to the acquired date of Landsat 8 OLI imagery and comes from 5 rain stations (Table 7).

Table 7. Monthly rainfall and inundation area.

Acquired Date	Inundation Area (ha)	Rainfall (mm)				
		Biyonga	Hepuhulaw a	Talumelit o	Batudaa	Tabong o
25 March 2015	2,250	36	30.3	61.2	37.5	69.8
28 May 2015	2,132	152.2	111.4	143	133.5	258.9
31 July 2015	2,106	0	44.2	0	0	0
03 October 2015	1,741	183.4	46.3	55	3.6	7
06 December 2015	1,902	1.3	0	103.4	13.5	30.6
27 March 2016	1,440	0	0	7	1	0
14 May 2016	2,453	270.1	258.6	394.1	132.6	186.5
17 July 2016	2,075	180	149.6	114.8	43.6	81
19 September 2016	2,745	307.7	126.9	227.3	107.6	174
24 December 2016	4,043	199.9	110.3	127.2	0	156.5

Calculation results produce correlation coefficients ranging from 0.25 to 0.7 (Table 8). Where rainfall in the three stations, Biyonga, Talumelito, and Tabongo showed a strong correlation with the fluctuation of the inundation area of Limboto Lake, the Hepuhulawa station showed moderate correlation and the Batudaa station showed a low correlation.

Spatially it can be analyzed that the rainfall occurring in the southern part of Limboto Lake has only a small effect on the fluctuation of the Limboto Lake inundation area, this is consistent with the fact that rivers from the south of Limboto Lake are generally in the form of dry rivers or seasonal rivers. Likewise, the strong-medium correlation of stations in the west, north and east, from this direction flow large rivers that flow throughout the year.

Table 8. Correlation between the monthly rainfall and inundation area.

Station	r_{value}	Category
Biyonga	0.65	H
Hepuhulawa	0.54	M
Talumelito	0.68	H
Batudaa	0.25	L
Tabongo	0.70	H

H = High Correlation, M = Moderate Correlation, L = Low Correlation

In general, the correlation between rainfall and the fluctuation of the Limboto Lake inundation area is moderate, meaning that increase in monthly rainfall will not necessarily expand the inundation area of Limboto Lake or the decrease in monthly rainfall will not necessarily shrink the inundation area of Limboto Lake. When the Limboto Lake water supply depends on the supply of surface runoff through rivers empties into the lake, there is should have a very strong correlation with the amount of rainfall that occurs. In fact, from the results of the analysis in this study, a very strong correlation did not occur. Even if the average of determination coefficient is calculated, the value is only 0.35, we can be seen that the rainfall factor only contributes 35% to the large fluctuation of the Limboto Lake inundation area. There is an accumulation of other factors by 65% which is the cause of the large fluctuation of the Limboto Lake inundation area.

6. Conclusion

Water resources in general and Limboto Lake in particular, which one of its functions to accommodate water reserves for human interest must be monitored periodically. By monitoring and then the results are analyzed it will be known more precisely what changes have occurred. One of the monitoring activities can be carried out in a remote sensing and geographic information system framework.

In this study, by utilizing Landsat 8 OLI imagery, the spatio-temporal map of the Limboto Lake inundation area can be produced. The results of the analysis showed that the inundation area of Limboto Lake could widen and shrink by almost 3 times. Rainfall which is the source of surface runoff and filling the Limboto Lake basin no longer has a major influence on the fluctuation of the Limboto Lake inundation area, only by 35%, there is an accumulation of other factors that had greater influence contribute on large changes in the inundation area or shrinkage of Limboto Lake.

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