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.
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 km² 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.](image)

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).
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_20170324_01_T1 | 14 May 2016       |
| LC08_L1TP_113060_20160514_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.

| 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 |
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:

\[
AWEI = 4 \times (\rho_{band2} - \rho_{band5}) - (0.25 \times \rho_{band4} + 2.75 \times \rho_{band7})
\]  

(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:

\[
AWEI = 4 \times (\rho_{band3} - \rho_{band6}) - (0.25 \times \rho_{band5} + 2.75 \times \rho_{band7})
\]  

(2)
Table 3. Comparison of Landsat 7 ETM+ imagery bands with the Landsat 8 OLI imagery bands.

| Band name               | Res (m) | Wavelength (μm) | Band name               | Res (m) | Wavelength (μm) |
|-------------------------|---------|-----------------|-------------------------|---------|-----------------|
| Band 1 (blue)           | 30      | 0.43–0.52       | Band 1 (blue)           | 30      | 0.43–0.45       |
| Band 2 (green)          | 30      | 0.52–0.60       | Band 2 (blue)           | 30      | 0.45–0.51       |
| Band 3 (red)            | 30      | 0.63–0.69       | Band 3 (green)          | 30      | 0.53–0.59       |
| Band 4 (near infrared)  | 30      | 0.77–0.90       | Band 4 (red)            | 30      | 0.64–0.67       |
| Band 5 (shortwave infrared) | 30   | 1.55–1.75    | Band 5 (near infrared)  | 30      | 0.85–0.88       |
| Band 7 (shortwave infrared) | 30   | 2.09–2.35    | Band 6 (shortwave infrared) | 30   | 1.57–1.65       |
| Band 8 (panchromatic)   | 15      | 0.52–0.90       | Band 7 (shortwave infrared) | 30   | 2.11–2.29       |
|                         |         |                 | 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 |
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| $\mu + 0.25\sigma$ |
| Acquired Date | RGB 654 | Threshold ($\mu + 0.25\sigma$) | Threshold ($\mu + 0.5\sigma$) | Threshold ($\mu + 0.75\sigma$) | Threshold ($\mu + 1\sigma$) |
|---------------|---------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 25/03/2015    | ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) | ![Image](image4.png) | ![Image](image5.png) |
| 28/05/2015    | ![Image](image6.png) | ![Image](image7.png) | ![Image](image8.png) | ![Image](image9.png) | ![Image](image10.png) |
| 31/07/2015    | ![Image](image11.png) | ![Image](image12.png) | ![Image](image13.png) | ![Image](image14.png) | ![Image](image15.png) |
| 03/10/2015    | ![Image](image16.png) | ![Image](image17.png) | ![Image](image18.png) | ![Image](image19.png) | ![Image](image20.png) |
| 06/12/2015    | ![Image](image21.png) | ![Image](image22.png) | ![Image](image23.png) | ![Image](image24.png) | ![Image](image25.png) |
| 27/03/2016    | ![Image](image26.png) | ![Image](image27.png) | ![Image](image28.png) | ![Image](image29.png) | ![Image](image30.png) |
| 14/05/2016    | ![Image](image31.png) | ![Image](image32.png) | ![Image](image33.png) | ![Image](image34.png) | ![Image](image35.png) |
| 17/07/2016    | ![Image](image36.png) | ![Image](image37.png) | ![Image](image38.png) | ![Image](image39.png) | ![Image](image40.png) |
| 19/09/2016    | ![Image](image41.png) | ![Image](image42.png) | ![Image](image43.png) | ![Image](image44.png) | ![Image](image45.png) |
| 24/12/2016    | ![Image](image46.png) | ![Image](image47.png) | ![Image](image48.png) | ![Image](image49.png) | ![Image](image50.png) |

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

![Spatio-temporal map of Limboto Lake inundation area](image)

**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 | Talumelito | Batudaa | Tabongo |
| 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.

References
[1] Kementerian Lingkungan Hidup RI 2015 Gerakan penyelamatan danau (GERMADAN) Limboto (Jakarta: KLH)
[2] Acharya T D, Yang I T, Subedi A and Lee D H 2017 Change detection of lakes in Pokhara, Nepal using landsat data MDPI Proceedings 1(2) 17
[3] Serbina L, and Miller H M 2014 Landsat and water—case studies of the uses and benefits of landsat imagery in water resources (Virginia: U.S. Geological Survey Open-File Report 2014–1108 61 p)
[4] Trisakti B, Tjahjaningsih A, Suwargana N, Carolita I and Mukhoriyah 2014 Pemanfaatan penginderaan jauh satelit untuk pemantauan daerah tangkapan air dan danau (Bogor: Crestpent Press)
[5] Wiweka, Suwarsono, Nugroho J T 2014 Pengembangan model identifikasi daerah tergenang (inundated area) menggunakan data landsat-8 Prosiding Sinasinderaja 2014 381
[6] McFeeters S K 1996 The use of normalized difference water index (NDWI) in the delineation of open water features Int. J. of Remote Sensing 17 1425
[7] Xu H 2006 Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery *Int. J. of Remote Sensing* **27**(No.14) 3025

[8] Feyisa G L, Meilby H, Fensholt R and Proud S R 2014 Automated water extraction index: a new technique for surface water mapping using landsat imagery *Remote Sensing of Environment* **140** 23

[9] Moradi M, Sahebi M and Shokri M 2017 Modified optimization water index (MOWI) for landsat-8 oli/tirs *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* **XLII-4/W4** 185

[10] Roy D P et al 2014 Landsat-8: Science and product vision for terrestrial global change research *Remote Sensing of Environment* **145** 154

[11] Ji L, Zhang L and Wylie B 2009 Analysis of dynamic thresholds for the normalized difference water index *Photogrammetric Engineering and Remote Sensing* **75** 1307

[12] Rokni K, Ahmad A, Selamat A and Hazini S 2014 Water feature extraction and change detection using multitemporal landsat imagery *Remote Sens.* **6** 4173