Identification of the El Niño Effect on Lake Toba's Water Level Variation

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Abstract. Lake Toba is located in the province of North Sumatra, Indonesia which is the largest lake in southeast Asia and is the largest volcanic-type lake in the world. The lake's countenance level is decreased and this can have a negative impact on utilization of power plants and agricultural irrigation. This study will see whether the water level is decreased due to the influence of El Niño activity. The methods used are statistical and descriptive analysis. The data used is the water level of Lake Toba in period of 1957-2016, precipitation data uses NOAA Climate Prediction Centre (CPC) data with a resolution of 0.50° × 0.50° from January 1957 to December 2013 (56 years) to analyze rainfall anomalies. El Niño's activities have an effect on Lake Toba water level, where the moderate El Niño > 12 months duration resulted in a reduction of 1.5-2 m, while the strong El Niño with a duration of > 10 months resulted in a decline of 2-2.5 m.

Keywords: Lake Toba, El Niño, CPC, Water Level.

1. Introduction
Lake Toba is located in North Sumatra Province, Indonesia. The lake is the largest volcanic lake in the world [1, 2] formed since 1.3 million years ago [2]. The ancient eruption of Mount Toba was stated as the eruption of the largest volcano in the world [3, 4]. Lake Toba's surface area is 1,124 km², while its land area is 2,486 km² (see Figure 1). The surface of the lake is at an altitude of 903 m above sea level with a length of approximately 50 km and a width of about 27 km, with a flat depth the mean is 228 m [5, 6]. Lake Toba functioned as a water transportation infrastructure, community water source [7] and the main one as a hydroelectric power station to supply electrical energy needs [8].

Nowadays, Lake Toba faces an environmental crisis. There are some problems of widespread deforestation, drought, decreased water levels, water quality, and loss of biodiversity [9]. The decline in the level of water level of Lake Toba occurred quite significantly, especially in 1984 to 1987 [10] and in 1997 El Nino activity resulted in a long dry season in Indonesia which resulted in a decrease in rainfall in the Lake Toba watershed, resulting in the decline of Lake Toba water level [7, 11, 12]. Indications of the effect on decreasing lake water level, in general, are due to the role of climate variability, one of which is El Nino [13].
Figure 1. Lake Toba catchment area [14].

The atmospheric component associated with El Niño is called "Southern Oscillation." Scientists often refer to the phenomenon where the atmosphere and oceans collaborate with ENSO stands for El Niño - Southern Oscillation. Under El Niño conditions, sea surface temperatures in the East Equatorial Pacific are hotter than normal conditions. Whereas during La Niña conditions, sea surface temperatures in the East Equatorial Pacific are lower than normal conditions as shown in Figure 2 [15]. The Oceanic Niño Index (ONI) is obtained by calculating the average anomaly of sea surface temperature in the Niño region of 3.4 (190° East – 240° East and 5° N – 5° S) based on the El Niño definition of Figure 3 [15]. ENSO is a combined phenomenon of atmospheric ocean interactions that causes annual climate variations in the world [16]. The ENSO event itself was caused by the process of interaction of the atmospheric ocean in the Pacific region which not only changed the direction of atmospheric circulation but also the pattern of currents and climate in the Indonesian maritime continent [17].

Figure 2. ENSO conditions [18].
The intensity of ENSO is divided into three categories, namely: El Niño Weak with an index range of 0.5–1 °C, El Niño Moderate with an index range of 1–2 °C, and El Niño is strong with an index range of > 2 °C. Weak La Nina with index range (-0.5) - (-1) °C, Moderate La Nina with index range (-1) - (-2) °C, and La Nina Strong with index range < -2) °C [20].

Indonesia received negative influences from ENSO from April until its peak in August and September. The effect will disappear in December. The influence of ENSO occurred in almost all regions of Indonesia except for the northern part of Sumatra and parts of Kalimantan [21]. The strong El Niño has a different effect in each region in Sumatra, the El Niño influence is stronger in the southern region of Sumatra than in the northern part of Sumatra [22]. The active impact of El Niño affects the decrease in rainfall in the DJF, JJA and SON periods in the East Coast, East Slope and Mountains regions with an average percentage decrease in annual rainfall of up to 7% [23].

This study aims to identify and explain the effect of El Niño on rainfall in the Lake Toba catchment area which is indicated to cause a decrease in rainfall and an impact on the decline in Lake Toba's water level.

2. Data and Methods

This study uses Oceanic Niño Index (ONI) data to determine the time and duration of El Niño events. ONI was obtained from the SST (Sea Surface Temperature) anomaly results in the Niño region 3.4 (190° - 240° E and 5° N - 5° S). El Niño is identified with an index value > 0.5 which occurs for 5 consecutive months. To see the activity, the duration of ONI with an SPL anomaly >1 °C will be classified into 4 classifications including: duration < 3 months, 3-6 months, 7-12 months and >12 months. Monthly rainfall data uses NOAA Climate Prediction Center (CPC) data with a resolution of 0.50° × 0.50° from January 1957 to December 2013 (56 years) to analyze rainfall anomalies in the regions of Indonesia (6°N-11°S and 95°-141°E), North Sumatra (0.8° S-4.66° N and 96.66°-100.8° E) and Lake Toba catchment areas (2.18°-2.95° N and 98.43°-99.28°E).

Lake Toba water lavel data for the 1957-1980 period were obtained from the Lake Toba and Sungai Asahan Hydrology books [7], while the 1981-2016 period was obtained from PT Inalum. The data variation of Lake Toba water level are analyzed whether there is a significant relationship to rainfall anomaly data in the Lake Toba catchment area. Monthly climate data is used to show the local characteristics of Lake Toba watershed, while observational rainfall data around Lake Toba watershed is used to make corrections rather than NOAA CPC data.

3. Results and Discussion

3.1. Oceanic Niño Index Analysis

ONI analysis results show that in the period 1957-2016 there were 15 El Nino events where generally in moderate category with a percentage of 60%, the strong category 27% and a weak 13%. The moderate El Nino is happened in 1957/58, 1963/64, 1965/66, 1968/69, 1987/88, 1991/92, 1994/95, and 2002/03. The strong El Nino is happened in 1972/73, 1982/83, 1997/98, and 2015/16, while the weak El Nino is happened in 1977/78 and 2004/05.

Duration of ONI which has anomaly temperature > 1 °C was done to show the strength of El Nino activity. The duration < 3 months occurred in 1977/78, 1993/94, and 2006/07, the duration 3-6 months occurred in 1963/64, 1968/69, 1994/95, 2002/03, 2009/10, the duration of 7-12 months occurred in 1965/66, 1972/73, 1982/83, and 1997/98, while the duration for > 12 months occurred in 1987/88 and 2015/16 (see Figure 4).
Figure 4. Oceanic Niño Index (ONI) during 1957-2016 period.

3.2. Rainfall Anomaly of ENSO period

The results of rainfall anomaly analysis in Indonesia based on NOAA CPC data shows that during the active El Nino period, a decrease in monthly rainfall ranged from 0-100 mm occurred in 1957, 1963, 1965, 1972, 1982, 1987, 1991-1994, 1997, and 2002. Significant decreases in rainfall occurred in 1972, 1983 and 1997. In this period an increase in monthly rainfall ranged from 0-150 mm, increased rainfall occurred in 1973, 1983, 1988, 1995, 1998-1999, 2007 and 2010, a significant increase occurred in 1998-1999 and 2010 as shown in Figure 5.

Figure 5. Rainfall anomaly in Indonesia during 1957-2013 period.

The analysis of rainfall anomaly in the North Sumatra region based on NOAA CPC data shows that in the active El Nino period, a decrease in monthly rainfall ranged from 0-100 mm occurred in 1958, 1963, 1982, 1992, 1994, 1997 and 1998. The decreasing rainfall significantly occurred in 1963 and 1997. Generally, in this period there was an increase in monthly rainfall in North Sumatra. Increasing in monthly rainfall ranged from 0-150 mm are occurred in 1957, 1965, 1966, 1983, 1987, 1988, 1999, 2003, 2007 and 2010. A significant increase occurred in 1999 and 2007 as shown in Figure 6.
Figure 6. Rainfall Anomaly in North Sumatra during period of 1957-2013.

The analysis of rainfall anomaly in the Lake Toba catchment area based on NOAA CPC data shows in the active El Nino period, decreasing in monthly rainfall ranged from 0-150 mm occurred in 1958, 1963, 1968, 1977, 1991, 1992, 1995, 1997/98 and 2015. Significant decrease in rainfall occurred in 1997 and 2015. Here, the NOAA CPC data has been corrected by manual rainfall observation data. In this period the area has also an increase in monthly rainfall ranged from 0-150 mm, occurred in 1957, 1965/66, 1972/73, 1978, 1987/88, 1993/94 and 2016 (see the Figure 7).

Figure 7. Rainfall anomaly in the Lake Toba catchment area during period of 1957-2016.

3.3. Climate conditions of Lake Toba catchment area
Climate conditions of Lake Toba catchment area represented by the Parapat Geophysics Station. The area is classified as a wet tropical climate with temperatures ranging of 18-28 °C. The average minimum temperature is 18.4 °C, the average maximum temperature is 27.1 °C, and the average temperature is 21.5 °C. The average annual high rainfall is 175-225 mm. Lake Toba catchment area is equatorial rain type with peak rain (rainy season) occurring in April and November, while the rain valley (dry season) occurs in February and June. The data are shown in Figure 8.

Figure 8. (a) Air Temperature, (b) Normal rainfall catchment area of Lake Toba.
3.4. Analysis of trends in water levels and rainfall in Lake Toba catchment area

The analysis of Lake Toba’s water level showed a declining trend with a downward trend of 2.4 cm per year. In the period of 1957-1984 the average height of the water level was around 905.01 m, whereas in the period 1984-2016 the average height of the Lake Toba water level decreased by around 904.01 m. The water level decline occurred in the period of 1986/87, 1990/91, 1997/98, 2001/02, 2006/07, 2011, and 2015/16. Significant decreases occurred in 1986-1988 and 1997/98 with decreases of 2-2.5 m. Annual rainfall in the Lake Toba catchment area shows the same pattern as the reduction in rainfall in the period 1986, 1997/98 and 2015. There is a good correlation between rainfall and Lake Toba's water level as shown clearly in Figure 9.

![Graph showing water level and rainfall trends](image)

Figure 9. There is similar pattern between water level and rainfall trend in the catchment area of Lake Toba. The Toba water level tend to decrease significantly during this period.

4. Conclusions

- The downward trend in Lake Toba's water level ranges from 2.4 cm/yr in the period of 1957-2016
- In the period 1957-1983 there was no indication of the influence of El Nino, whereas in the period 1984-2016, El Nino activity was indicated to have an effect on the decline in Lake Toba's Water Level
- El Nino affects the decrease in rainfall in the Lake Toba catchment
- El Nino is indicated to have an influence on Lake Toba's Water Level in 1987-1988, 1997-1998 and 2015-2016
- Strong El Nino with a duration of > 12 months has an impact on the decrease in Lake Toba Water Level by 1.5-2 m
- El Nino Very strong with a duration of > 10 months has an impact on the decrease in Lake Toba's water level by 2-2.5 m

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