Weather and Water Level Monitoring System for Hydrometeorological Analysis in the Lake Toba Region

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Abstract. Lake Toba is the largest volcanic lake in Southeast Asia that has a multi-sectoral role, both for the benefit of local communities and for national and even international interests. Lake Toba as a tourist destination where in 2020 the Toba Regency Central Statistics Agency recorded the number of passenger and freight ship visits on lake transportation reaching 7,809 visits. Lake Toba is also useful in the energy sector because there are 3 (three) Hydroelectric Power Plants (PLTA) in the Lake Toba area, namely Siruar Dam, Siguragura Dam and Tanga Dam. Fish farming using Floating Finger Cages (KJA) generates economic value for 12,300 workers. This sector contributes to the Gross Regional Domestic Product (GDP) of 32.28% in 2020. Therefore, the presence of weather information is important to support these sectors. With the hydrometeorological study of the Lake Toba area, it is hoped that it will support the preservation of Lake Toba in the spatial plan for the development of Lake Toba. To meet these needs, a weather monitoring system has been built in the Lake Toba area using components in the form of data loggers, sensors and support systems in the form of communication and power supply. The data obtained from January 2021 to August 2022 consists of data on rainfall, water level and wind direction and speed. Wind direction and speed data are used to support transportation activities, especially ship crossings that take place in the Lake Toba area. Rainfall and water level data were processed using the Spectral Analysis method to obtain the periodicity of weather parameters. The highest spectral peak for rainfall parameters was obtained in the period of 18.3 bases (183 days) or about 6 months. As for the water level parameter, the spectral peak occurred in a period of 4,379 h (163 days) or about 6 months. These results indicate that the weather and hydrological conditions at the location are dominated by the movement of the Intertropical Convergence Zone (ITCZ) to the north and south. The results of the analysis of wind direction and speed data show that the dominant wind direction is from the southeast with the highest recorded speed of 1–4 knots.

Keywords: Hydrometeorology · Lake Toba · Realtime · Weather

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1 Introduction

Lake Toba is the largest volcanic lake in Southeast Asia which has a multi-sectoral role, both for the benefit of local communities and for national and even international interests [10]. The Indonesian government has designated Lake Toba as one of five Super Priority Tourism Destinations (DPSP). The determination of the Lake Toba area as one of the super priority tourism destinations is a natural thing considering the natural beauty of Lake Toba which lies in seven regencies, namely Simalungun, Toba Samosir, North Tapanuli, Humbang Hasundutan, Dairi, Karo, and Samosir. Even Lake Toba has been designated by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as the 209th UNESCO Global Geopark (UGG) on (2/7/2020) in France. According to the Toba Regency Central Statistics Agency, in 2020 the number of visits by passenger and freight ships on lake transportation reached 7,809 visits. Meanwhile, the number of tourists who came to Lake Toba in 2020 reached 217,729 people. Lake Toba also serves to provide more than 1000 MW of electricity. The power plants that use this source are PLTA Sigura-gura and PLTA Tangga and PLTA Asahan [8]. Other sectors that also contribute are the agriculture, forestry and fisheries sectors. This sector contributes to GRDP of 32.28% in 2020.

The Lake Toba area and its natural resources and ecosystems need to be preserved to support sustainable development. The existence of weather information is important to support transportation and tourism activities, with a hydrometeorological study, it is hoped that it will be an important step for the efforts of spatial planning of Lake Toba in accordance with the Presidential Regulation of the Republic of Indonesia No. Lake Toba area.

In a study [8] entitled the influence of climate on the decrease in water level of Lake Toba, a statistical analysis was carried out regarding climate parameters, especially rainfall in the Lake Toba Catchment Area, which was represented by 15 stations/climate posts with a data period of 1981–2016. This study provides information that there is a significant relationship between rainfall and the water level of Lake Toba with a correlation ranging from 0.2–0.7. In a subsequent study [7] entitled "The effects of ENSO, climate change and human activities on the water level of Lake Toba, Indonesia: a critical literature review" quantitatively and qualitatively analyzed the factors that cause variations in water levels in Lake Toba and the results obtained that there is a decrease in rainfall in the rainy season due to El Nio Southern Oscillation (ENSO) and a continuous increase in maximum and average temperature. These are some of the impacts of climate change on Lake Toba.

The water level of lake toba is very sensitive to meso-scale weather, which is a source of rainwater and forest conditions around the hilly and mountainous ridges that become catchment areas and regulators of water flow to lake toba, so it is necessary to do real- time monitoring to assess fluctuations in water level. From time to time over a long period [13]. Much research on the design of the automatic weather station (aws) has been carried out, such as using arduino and raspberries, as well as designing aws using other processing systems. The development of the internet of things (IoT) allows data from aws that has been designed not only to be displayed on personal computers at meteorological stations but can be accessed on various types of devices using the internet. Several studies have discussed sending was data using the internet network, such as sending using file transfer protocol (ftp) and message queuing telemetry transport (mqtt) [17]. Subsequent research on measuring the water level of lake toba [13] in balige was carried out using ultrasonic type sensors and permanent and continuous observation methods, data communication using the general packet radio service (gprs) network, with cloud computing graphical-based displays. The goal of this research is to create a data analysis of rainfall and water level using spectral analysis methods. The spectral analysis method produces the periodicity value needed for the analysis of the dominant weather disturbance phenomenon in lake toba. Wind direction and speed data analysis was also carried out using the windrose analysis method to determine the dominant wind direction and the highest wind speed. The data that is processed in the analysis is obtained from the results of monitoring the in-situ instrumentation that has been built.

2 Method

This study uses data from observations of weather parameters in the form of rainfall data, water level, wind direction and speed from the weather monitoring system that was built to be further used for hydrometeorological studies in the Lake Toba area.

2.1 Weather Monitoring System in the Lake Toba Area

A weather monitoring system is an instrumentation system that is built to be able to make observations on changes in weather parameters. The weather monitoring system built in the Lake Toba area is located in three locations around Lake Toba. The three locations of the weather monitoring system can be seen in Fig. 1, which is located at the Port of Balige, Port of Sippinggan, and Port of Simanindo. Figure 2 shows one of the weather monitoring systems that have been built at Simanindo Port. This weather monitoring system consists of sensors to measure weather parameters, a power supply system (batteries, regulators, solar panels), data loggers, and communication modules.

Figure 3 shows a block diagram of a weather monitoring system consisting of input, process, and output sections. The input part of the weather monitoring system consists of a rain sensor, a water level sensor, and a wind direction and speed sensor. The rain sensor used is a rain sensor with the RM Young brand type 522003–30 tipping bucket

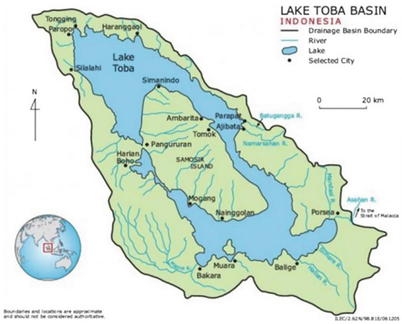


Fig. 1. Weather monitoring system installation location

Fig. 2. Built-in weather monitoring system

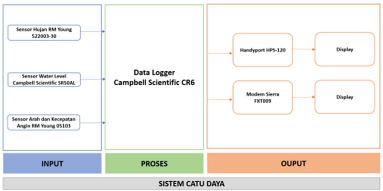


Fig. 3. Weather monitoring system block diagram

mode. The water level sensor used in this study is a Campbell Scientific brand water level sensor, type SR50A-L. The wind direction and speed sensor used in this weather monitoring system is the RM Young brand sensor type 05103. This wind speed sensor has a propeller mode, while measuring wind direction on this type of anemometer uses a potentiometer. The process part of the built-in weather monitoring system is the data logger. A data logger is an electronic device that converts or acquires electrical quantities from sensors, both analog and digital, then performs calculations and processes the data into measurement values. Data loggers generally consist of a Real Time Clock (RTC), memory, power supply port, communication port, Analog to Digital Converter (ADC), and an input/output port. The data logger used in this study is the Campbell Scientific Data Logger Brand Type CR6. Datalogger CR6 is a data logger that is easy to implement for field research [13]. The output part of this weather monitoring system is the handyport-120 radio, which is used to transmit data to the port display for further use by the port operator at the port. Whereas A Sierra FXT 009 modem is used to send data to the server for further display on a website- based display.

Figure 4 is a flowchart and block diagram of the system, where the measurement results from the sensor are analog outputs, processed and converted by a data logger into finished data that is ready to be sent to the server. Information from sensors received by the data logger is processed and the results of processing, in the form of data on water level, rainfall, wind direction and speed according to the timestamp, are displayed in real time on the port display using communication media in the form of Handyport-120

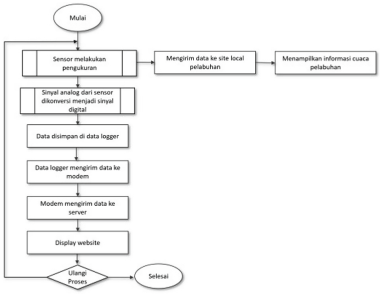


Fig. 4. Flowchart and block diagram of the system

and sent to the server in the form of string packets equipped with a location identity to be displayed on a website designed using the PHP, Javascript, HTML and CSS3 programming languages. Website-based data monitoring system to make it easier for users to find out data on rainfall, water level, wind direction and speed in real time or cumulatively based on the time span desired by the user so that it can be processed according to user needs.

2.2 Hydrometeorological Studies in the Lake Toba Region

Air circulation on the earth's surface occurs because of differences in solar heating and its relationship with the rotation of the earth to form a certain flow pattern. Certain cyclical phenomena, such as monsoon, Elnino, Madden Julian Oscillation (MJO), Intertropical Convergence Zone (ITCZ), and others, influence the movement of air masses, particularly in tropical areas such as Indonesia. The monsoon is a seasonal wind that affects the global climatological system and has a major impact on annual changes in seasons and on global atmospheric circulation in the tropics [9]. A MJO is a seasonal weather disturbance in the tropics with the characteristics of a jet stream, which always starts from the tropical waters of the Indian Ocean, at around 10oL – 10oL, in the form of a heat center moving towards the eastern Pacific Ocean. The MJO is called a "daily 40–50 wave", and is also called a "daily 30–60 wave" because the period of this wave occurs over a number of days. Meanwhile, the ITCZ moves south and north along with the sun, reaching its northernmost position in July and its southernmost position in January. ITCZ is located in the Indonesian region from October to April, which is the rainy season in Indonesia. This is because in the ITCZ area, the air tends to move upwards, so the area has a lot of convective clouds and rain. The movement of the air mass above can be determined by conducting an analysis based on data from weather parameters using analytical methods such as spectral analysis and windrose analysis. Spectral analysis is a method for finding the periodic part of a time series. Periodicity studies can provide information about the recurrence pattern of time series data carried out in the frequency domain so that it shows the periodic pattern. The concepts of the calculations carried out are, first time series data into a Fourier function, which is a harmonic function. In examining the periodicity of the data using spectral analysis, the time series data is expressed as a Fourier series, and then by mapping the spectrum function to the period, information about the periodicity contained in the spectral peaks will be obtained. This analysis was carried out on two parameters, namely rainfall and water level, to obtain the dominant periodicity value of these weather parameters so that we can find out the dominant weather disturbances that occur in the Lake Toba area. This study aims to determine the hidden periodicity in the span of 2 years and its effect on fluctuations in rainfall. This hidden periodicity is important to know because it is needed to determine the dominant disturbance phenomenon in the Lake Toba area. The analytical method used to process wind direction and speed data is windrose analysis. This analysis is used to obtain the distribution of the highest wind direction and the highest wind speed in a place. By using this analysis, the dominant wind direction and the highest wind speed in that direction will be obtained in the Lake Toba area.

3 Result and Discussion

The weather monitoring system built at the ports of Sipinggan, Simanindo, and Balige has produced complete and continuous data since 2021. Figure 5 shows data from the observations of the weather monitoring system located at Sipinggan Port. The second column shows the time of observation, and the first row shows the observed weather parameters.

Figure 6 (a) shows the display of the observed weather parameters. The location of the weather monitoring system can be selected according to needs according to user

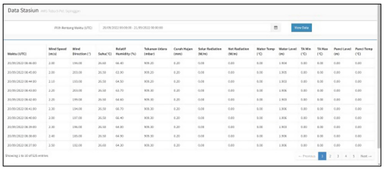
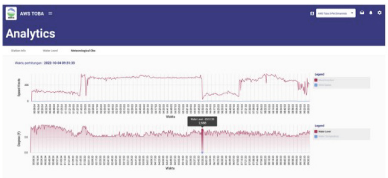
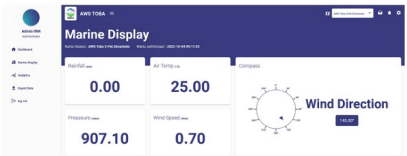


Fig. 5. Monitoring Result Data sent to the server



(a)



(b)

Fig. 6. Weather monitoring display

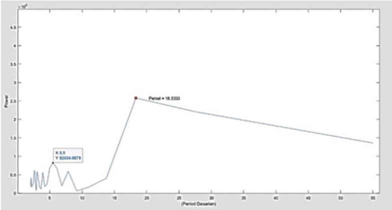


Fig. 7. The results of the analysis of rainfall data spectra

needs. Figure 6 (b) shows another view of the website that was built, namely the graphic display. Graphs that appear according to the location, parameters, and data range selected by the user.

3.1 Rainfall Data Analysis

The rainfall data used in this spectral analysis is data from observations made from January 2021 to August 2022. The results of the analysis of rainfall data using the spectral analysis method obtained the following results:

Based on Fig. 7, the highest spectral peak is seen at the 18.3 or 183rd base of the daily (semi-annual oscillation). The next highest peak occurs in the 5.5 or 55 daily base period rainfall in the Sumatran area. This oscillation is indicated as the MJO. According to [5], the MJO can affect the pattern of convective cloud activity and the pattern of weather elements in an area. In the Lake Toba area, the effect of this oscillation is still less dominant than the influence of the semi-annual oscillations.

3.2 Water Level Data Analysis

The water level data used in this spectral analysis is data from observations made from January 2021 to August 2022. The results of water level data analysis using the spectral analysis method obtained the following results:

Based on the picture above, the highest spectral peak is seen at 4,379.5 h, or 182.47 daily (semi- annual oscillations). The next highest peak occurred at 1094,888875, or 45.62 per day (Tables 1 and 2).

From the graph of the processed rainfall spectral analysis, two dominant peaks were observed, namely the highest dominant peak with a period of 183 days. This period

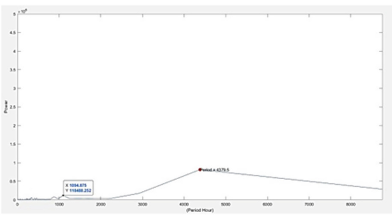


Fig. 8. Water level spectral analysis

Table 1. Dominant spectral peak of rainfall data

No.	Spectral Peak	Period (Daily)
1	Spectral Peak I	183
2	Spectral Peak II	55

Table 2. Dominant spectral peak water level data

No.	Spectral Peak	Period (daily)
1	Spectral Peak I	182, 47
2	Spectral Peak II	45,62

shows the existence of semi-annual oscillations, which are also known as semi-annual oscillations. According to Eddy Hermawan, this kind of period is an oscillation that is influenced by the movement of the ITCZ to the north and south during October–November and during March, April and May [3]. The second highest period observed was the 55- day period. This second highest peak indicates an oscillation in the range of 30–60 days, according to Arief Suryantoro in his research on the relationship of the MJO to the pattern of convective cloud activity and From the graph of the processed water level spectral analysis, two dominant peaks were observed, namely the highest dominant peak with a period of 182.47 daily. This period shows the existence of semi-annual oscillations, also known as semi-annual oscillations, which are the same as the rainfall parameters that are affected by the movement of the ITCZ.

The second highest period observed was the 45.62- day period. This second highest peak indicates an oscillation in the range of 30–60 days, the same as the rainfall parameter. This oscillation is indicated as a result of the Madden-Jullian oscillation (MJO).

3.3 Data Analysis of Wind Direction and Speed

The wind direction and speed data used in the windrose analysis is wind data from observations made from January 2021 to August 2022. The wind data used is hourly wind data with a total sample of 13,552 wind data points. From the windrose analysis, the following results were obtained:

Figure 9 shows the results of measurements of wind direction and speed, which were analyzed using windrose. The first dominant wind direction is from the southeast with the highest recorded speed of 1–4 knots. The second dominant wind direction was from the southwest, with the highest recorded speed of 7–11 knots, and the third dominant wind direction was from the north, with the most frequent wind speed of 1–4 knots.

Table 3 shows the distribution of wind directions that often occur in the lake toba area with data on wind direction and speed from 2021 to 2022.

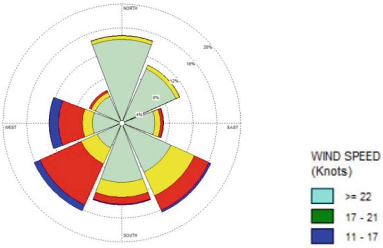


Fig. 9. Analysis of wind gusts on Lake Toba

Table 3. The distribution of wind direction and speed in the Lake Toba area

	Directions/Wind Classes (Knots)	1–4	4–7	7–11	11–17	17–21	>= 22	Total
1	337,5–22,5	1899	78	12	0	0	0	1989
2	22,5–67,5	1351	83	8	0	0	0	1442
3	67.5–112.5	756	120	69	4	0	0	949
4	112,5–157,5	1221	587	369	43	0	0	2220
5	157,5–202,5	1345	339	161	13	1	0	1859
6	202,5–247,5	616	396	1029	146	0	0	2187
7	247.5–292,5	672	223	543	206	5	0	1649
8	292,5–337,5	666	100	50	5	0	0	821
	Sub-Total	8526	1926	2241	417	6	0	13116
	Calms							406
	Missing/Incomplete							0
	Total							13522

4 Conclusion

A weather monitoring system has been built in the lake toba area, which is located at the ports of balige, sipinggan, and simanindo. Based on the results of monitoring, this system has produced data and information on rainfall, water level, wind direction and speed, which are displayed on local displays in each port and sent to the server. The results of data analysis using spectral analysis obtained that the dominant periodicity for the rainfall parameter occurred in the 183 day period (6 months) and for the water level parameter the dominant periodicity occurred at 182.47 daily (6 months). This shows that these two weather parameters oscillate semi-annually or semi-annually, which is influenced by the movement of the itcz to the north and south during october–november and during march, april and may. This shows that there is a relationship between these two weather parameters, as seen from the high and low rainfall, which has an impact on the rise and fall of water levels in lake toba. However, longer data sets are needed to get better analysis results. Meanwhile, for the analysis of weather parameters, wind direction and speed were obtained. The dominant direction was from the southeast, and the highest recorded wind speed was 1–4 knots.

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