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Using Remote Sensing to Study Impact El Niño Southern Oscillation on Reservoir Level at Murum and Bakun Dam Hydropower, Sarawak

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Abstract: In the years 2015 and 2016 has happened El Niño phenomenon was one of the three worst in history that has been happened since 1908. The El Niño phenomenon is usually related to the drought in Southeast Asia, Asia Pacific, and the Caribbean. This study analyses the impact of El Niño in the year 2015/2016 on rainfall at Bakun and Murum Hydropower using the technique of remote sensing. Global Precipitation Measurement (GPM) satellite was applied to understanding, the impact of 2015/2016 El Niño on rainfall at Bakun and Murum Hydropower. The results of this study show that drought conditions are widespread have reduced the total amount of rainfall and reservoir level and led to unusually low lake levels in Bakun and Murum reservoirs. Better understand the hydrological response and the complexity of different methods. The study found the rainfall decrease 20 until 30 % from normal during neutral and reduced 25 until 30 meters above sea level the reservoir water level at Murum and Bakun dam during the El Niño 2015/2016. The impact approach can support the design of more adaptive management strategies for specific areas.

Keywords: El Niño southern oscillation, rainfall, reservoir, remote sensing

1. Introduction

El Niño Southern Oscillation (ENSO) is the most important driving influence Inter-yearly climate change rate (Li et al., 2021; McPhaden et al., 2006). ENSO affects drought during El Niño and the flood during La Niña in many parts of the world including Malaysia (Kemarau & Eboy, 2021; Liang et al., 2016; Li et al., 2021). This brings up prospects for the variability of ENSO-driven hydropower production of dams located in the affected watershed. Hydropower is

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the main resource of electricity production in a lot of parts of humankind and another dam development is estimated to ensure and expand its role in the future (Herwich et al., 2016; Hussain & Jing, 2019). Changes in temperature and precipitation because of El Niño affect the flow rate of freshwater or river ecosystems and change the supply and demand of water, thereby affecting human well-being, the economy, especially agriculture, ecosystems, and their services. In this case, the changes in the duration of the flow directly affect hydroelectric power production. Scientists have debated the effect of climate change on the available water resources of hydropower plants, for example (Hussain & Jing, 2019; Yusuf & Francisco, 2009) assessed the impact of hydrology on hydropower production by using an interdisciplinary approach that combines hydrology, economics, and hydropower administration consuming co-dependent numerical models. Based on streamflow, hydropower is responsive to total runoff and its variability and seasonality namely ENSO and monsoon (Collin et al., 2010; Boadi & Owusu, 2017). They're still not many studies on the impact of ENSO on hydropower particularly in Asia including Malaysia. Gannon et al., (2018) have done a study in eastern and southern Africa, Ng et al., (2019) a global scale. There still lacking study impact of ENSO on rainfall at watershed hydropower using technology remote sensing. This study was conducted to examine the impact of ENSO events especially during the El Niño 2015/2016 event on the amount of rainfall in the Bakun and Murum dam catchment areas. This study is very important because it can provide an overview of the effects of El Niño that bring natural disasters, namely prolonged drought which will lead to a decrease in electricity generation due to lack of rainfall which causes water levels in dams to decrease as is the case in Vota River Basin, Ghana (Boadi & Uwusu, 2017) and Sobrahinho dam, Brazil (Santos et al., 2022). This can help those responsible to channel assistance such as cloud seeding in the study area to decrease the risk of the effects of El Niño on water resources in Murum and Bakun hydropower plant.

2. Material and Method

Location of the study was conducted at Murum and Bakun dams in Sarawak. This study uses Global Precipitation Measurement (GPM) data, Oceanic Niño Index, and rainfall dataset. Important information about the study area and dataset will be discussed in-depth in the next paragraph.

Daily precipitation data can be taken from (NASA) National Aeronautics and Space Administration at internet site https://power.larc.nasa.gov/data-access-viewer/. The data is from a research course that has been supporting satellite systems and exploration for a long time, thereby providing data that is important to the research of environment and climate developments. These records contain long-term climatic average assessments of climatological quantities and surface solar flux. Besides, the daily average values of basic meteorological conditions and solar information are offered in a time-series format. These satellite-based and model-established creations are precise sufficient to supply trustworthy solar and weather-related source data in areas someplace ground measurement is scarce or non-existent.

Establishing ONI able to classification El Niño and La Niña incidents (Kemarau & Eboy, 2021). The ONI index was applied to understand the process and intensity of La Niña or El Niño in the Ocean Pacific. ONI develop based on a three-month sea temperature (SST) anomaly of 3.45° North - 5° South and 120° - 170° West in Niño area (Nino 3.45). The occurrence of El Niño is determined by the three-month average at +0.5°C or above, while the La Niña event is determined when the climate is abnormal or below −0.5°C (NOAA, 2019). For El Niño events, ENSO value levels are divided into 5 levels: weak (outlier value 0.5 to 0.9 SST), intermediate (1.0 to 1.4), (1.5 to 1.9) strong, and (≥2.0) extremely strong, and vice versa incident (Kemarau & Eboy, 2019). Corresponding to the classification of Tangang et al. (2008) and Kemarau and Eboy (2021), La Niña events happen when the value ONI surpasses a negative value of 0.5 and El Niño when the value ONI exceeds a positive value of 0.5. Table 1 indicates the ONI data utilized in this research paper from 2015 to 2016.

Table 1- Shows the ONI data used in this study

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2015	0.6	0.6	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.5	2.6
2016	2.5	2.2	1.7	1.0	0.5	0.0	-0.3	-0.6	-0.7	-0.7	-0.7	-0.6

Source: NOAA (2019).

Refer to table 2 denotes red-colored numbers with values above +0.5 imply El Niño while blue-colored numbers with values above -0.5 point to La Niña. The black number indicates the neutral phase.

GPM remote sensing satellite is a collaborative foreign mission of the Japan Aerospace Exploration Agency and National Aeronautics and Space Administration, as well as other international space agencies, aimed at regularly observing precipitation on the earth. It is a component of the National Aeronautics and Space Administration's Earth System mission platform and is used in conjunction with satellite collectors to deliver comprehensive worldwide coverage. The GPM objective is a global satellite structure that can provide the following generation of worldwide rain and snow studies. Building on the achievement of the Tropical Rainfall Measurement Mission, the idea of GPM focuses on the assignment of planetary satellites equipped with innovative radar and radiometer systems to quantify rainfall from space and serve as a reference standard to unify rainfall from satellites in investigation and operation. By improving the measurement of global precipitation, the GPM task is serving and sympathetic of the earth's water and energy cycles, advance the prediction of hazardous events that lead to natural disasters and catastrophes, and expand the existing ability to directly benefit from the use of accurate and timely precipitation information. This research will use 24 data GPM to achieve the research purpose.

3. Location of Study

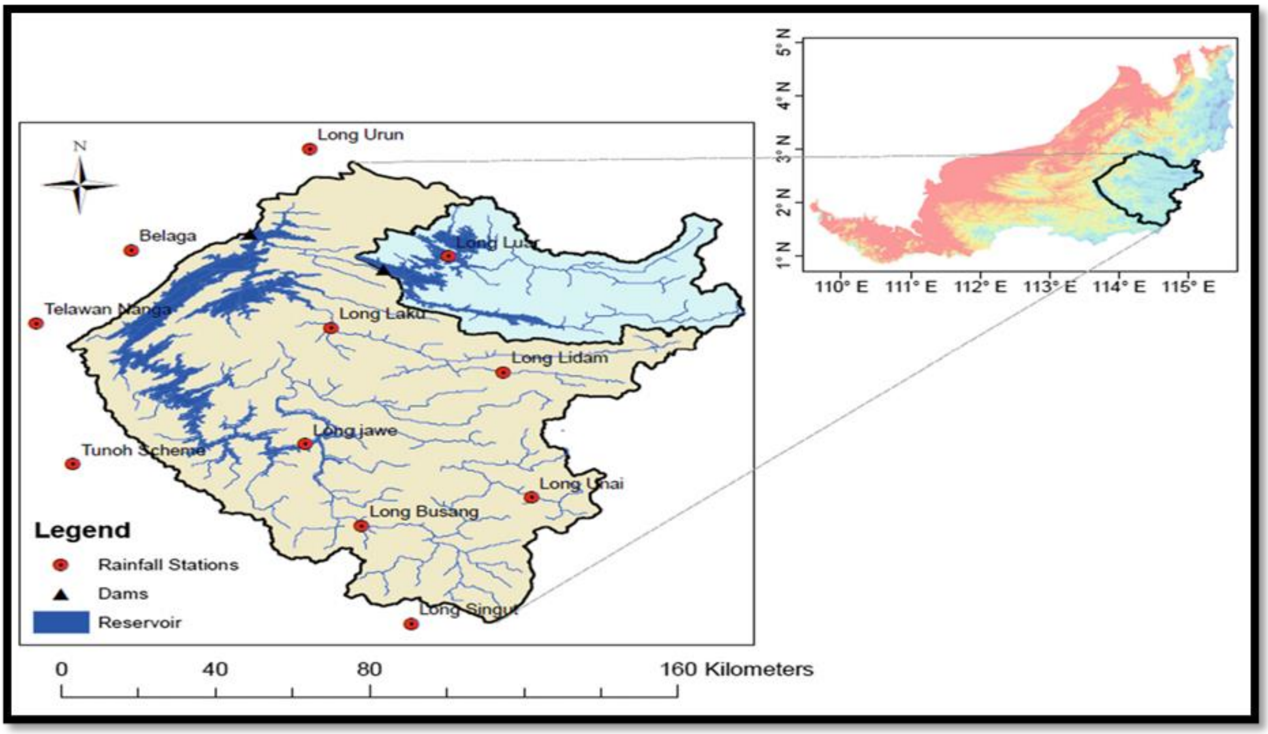

Fig. 1 - Location of study
Source: Hussain & Jing (2019)

Sarawak, Malaysia has established three larger hydroelectric power plants (Batang Ai Hydroelectric Power Plant, Bakun Hydroelectric Power Plant, and Murum Hydroelectric Power Plant). These energy sources account for approximately 75% of the state's total electricity generation. Diesel, coal, and natural gas power generation accounted for 3%, 10%, and 13% respectively (Hussain & Jing, 2019). The state's share of renewable energy production in the country is greater and will be further increased after Baleh Hydroelectric Power Plant is put into production. Once completed, Baleh Hydroelectric Power Plant will produce an additional 1,285 megawatts of renewable energy (Hussain & Jing, 2019). Murum Hydroelectric Power Plant is Sarawak's second-biggest hydroelectric power plant. It is positioned in the upper ranges of the Bakun Hydroelectric Power Plant on the Murum River and normalizes about 20% of the water volume in the Bakun Basin (Hussain & Jing, 2019). Bakun Hydroelectric Power Plant is one of the biggest hydropower plants in Southeast Asia, along with a full installed capacity of 2,400 Mega Watts (Hussain and Jing, 2019). The plant was put into operation in 2012 to provide energy to the Sarawak state. Bakun Dam is 205 meters high concrete-faced rockfill dam with a side gate spillway with four radial gates that can discharge floodwater in extreme flood events. Bakun Hydroelectric Power Plant has a ground-based power station consisting of 8 Francis turbines, each with 300 Mega Watts. Bakun Reservoir is Malaysia's largest freshwater storage reservoir, with a surface area of approximately 640 km², a storage space facility of 37 billion cubic meters, and a full water supply of 228 meters above sea level. A catchment area of 14,850 km² drains into Bakun Reservoir to deliver water to Bakun Hydroelectric Power Plant (Hussain & Jing, 2019).

4. Result and Discussion

Established in figure 2, the trend of ONI for the period of the experience of El Niño 2015/2016 began in May 2015 when the value of ONI 0.8 increased to the highest of El Niño in December 2015 with an ONI value of 2.6. In January

2016 the ONI value decreased to 2.5 and continue to decline to a neutral rate of 0.5 in May 2016. The 2015/2016 El Niño incident is among the worst El Niño events since 1997/1998 (Hertwich et al., 2016; Glantz, 2008; Kemarau & Eboy, 2021). This raises questions to the author who prompts to study the extent of the impact of the El Nino event in 2015/2016 on hydropower dams in Malaysia, especially at Sarawak.

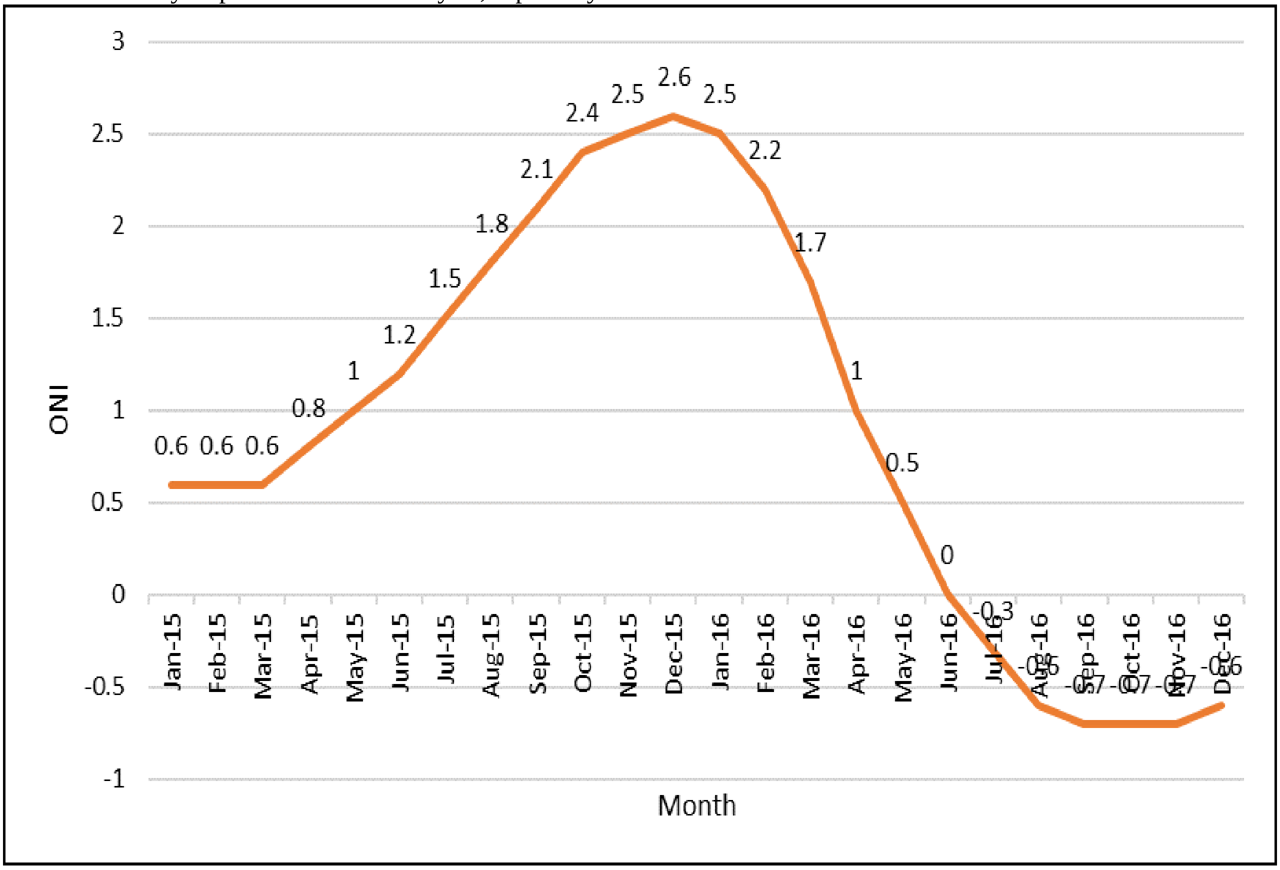

Fig. 2 - Value ONI in the year 2015/2016

The El Niño incident in 2015/2016 caused a drought in the field of north Sarawak which effect in Miri, Lawas, Limbang, and Baram (Kemarau & Eboy, 2021). Kemarau & Eboy (2021) stated the 2015/2016 El Nino event caused a decrease in total rainfall of 25% to 30%. The authors intend to evaluate the effect of a 25% - 30% decrease in rainfall volume on the Murum and Bakun hydropower plant dams. Hussain & Jing (2019) focus on the effects of climate change on water levels in the Bakun and Murum dams. However, there is still a lack of studies in the study of the effect of ENSO on the amount of rainfall distribution around the Murum and Bakun hydropower dams.

Referring to figure 3 explains the relationship of ENSO through ONI index with total rainfall in the water catchment area for Bakun and Murum dams. Figure 3 clearly shows the occurrence of ENSO through ONI has a significant impact on the amount of rainfall as per the findings of the study (Kemarau & Eboy, 2021). The impact of this El Nino event is also not limited to Sarawak similar findings were also found in Brazil (Moura et al., 2019; Santos et al., 2022), in Ghana (Boadi & Uwusu, 2017), in China (Li et al. al., 2021), Vietnam (Tham et al., 2022) and Indonesia (Irwandi et al., 2021).

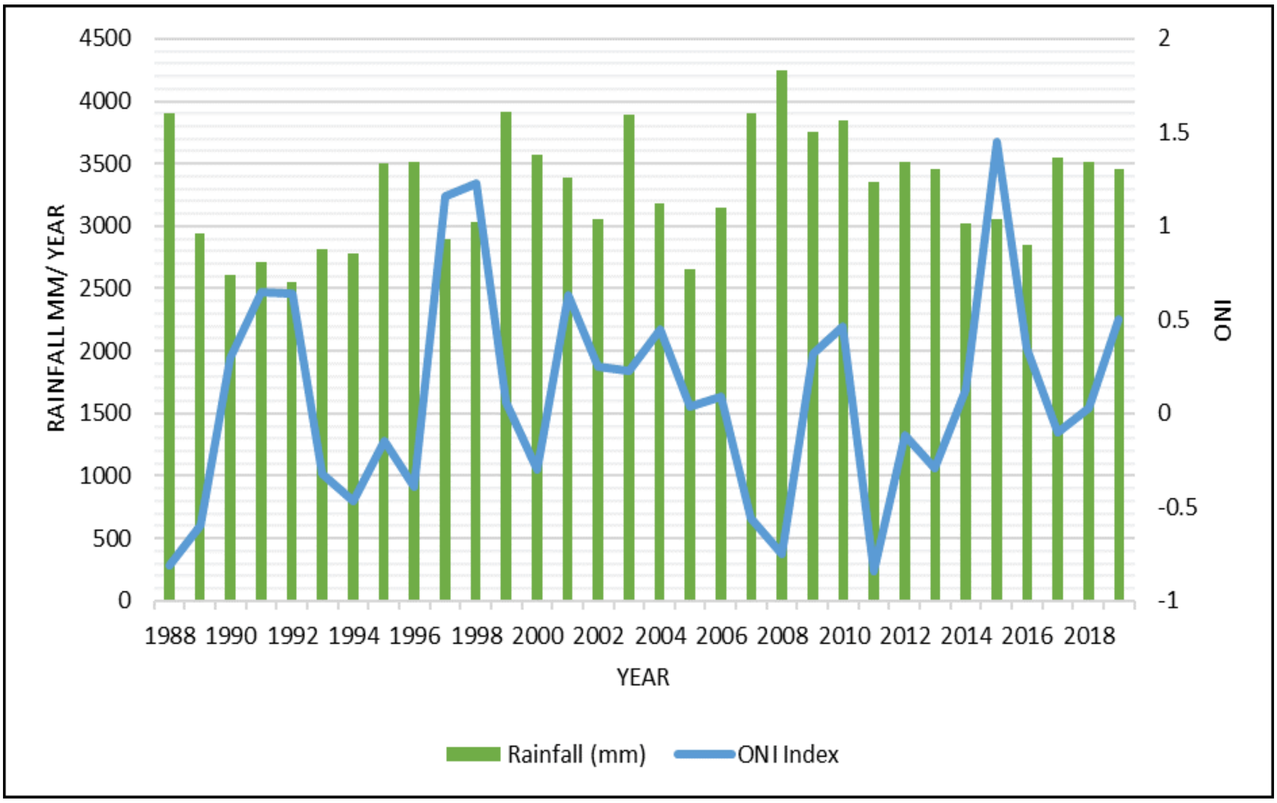

Fig. 3 - Pattern of Total Rainfall and ONI From 1988 until 2018

Referring to figure 3 it was found that the increase in the value of ONI led to a decrease in the amount of rainwater in the study area. For example, in 1997/1998 it was found that the value of the amount of rainfall decreased to 2890 mm a year and 3036 mm a year. The second example of El Niño 2015/2016 decreased by 3059 mm/year and 2844 mm a year. The La Niña incident was also found to cause an increase in the amount of rainfall as in 2008 where ONI was negative 0.9 which is 4241 mm a year, 1999 and 2000 was the amount of annual rainfall of 3911 mm a year, 3565 mm a year in the study area. The study found El Niño events caused a 25 to 30 % drop in annual rainfall. The findings of this study were found to have similarities with the results of a study in Brazil by Moura et al., (2019), Kuching, Sarawak made by Kemarau & Eboy (2021), in Ghana by Boadi & Uwusu (2017), Tham et al., (2022) in Vietnam and Irwandi et al., (2021) in Indonesia namely Lake Toba.

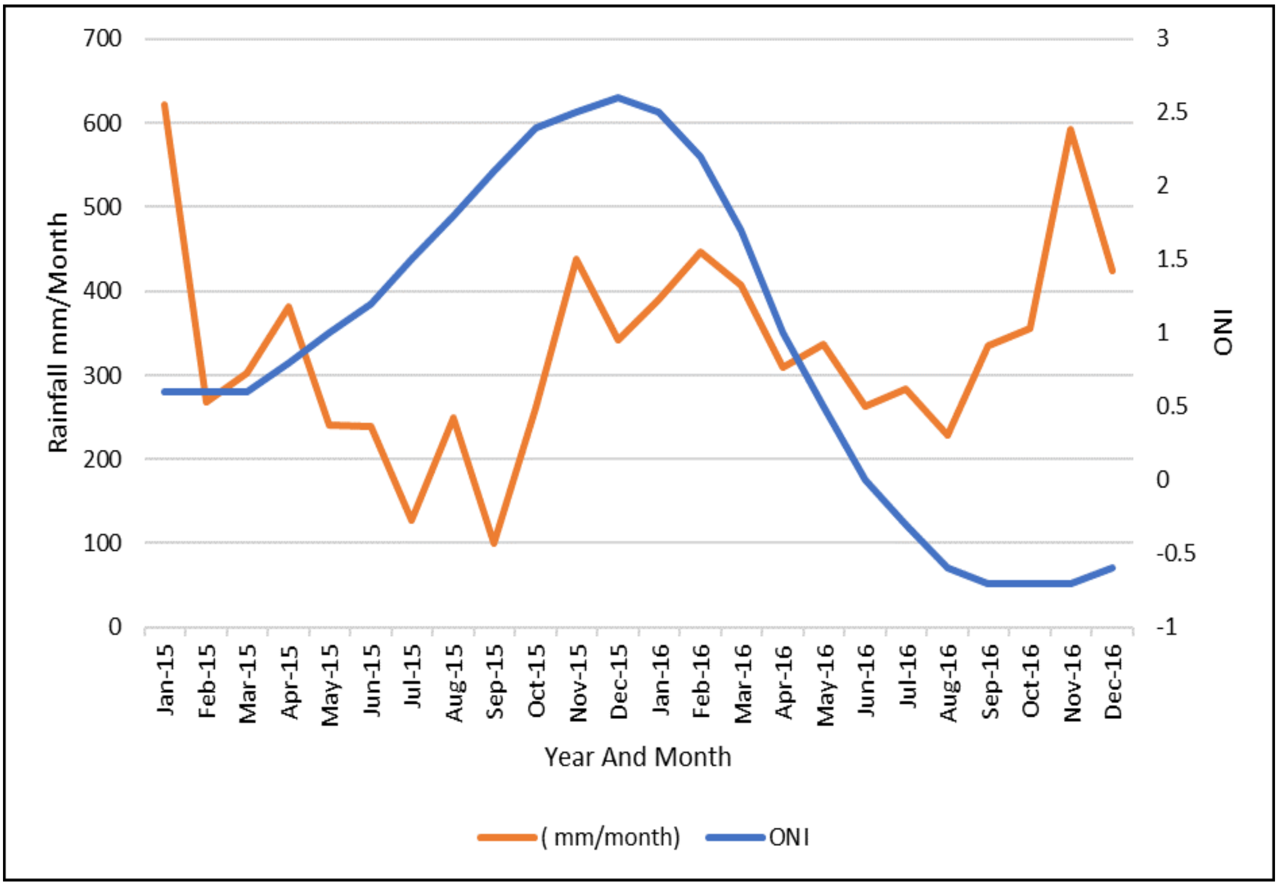

Fig. 4 - Value pattern of ONI and the amount of monthly rainfall in the study area

Refer to figure 4 found an increase in El Niño strength along with an increase in ONI led to a decrease in the number of monthly rainfalls such as from May 2015 to October 2015. However, in November and December 2015, the value of rainfall increased. This is due to the northeast monsoon incident. The study found El Niño events caused monsoons to slow to occur as monsoons occur from October to February. The results of this study are supported by the findings of Kemarau & Eboy (2021) who studied the effects of ENSO events, especially El Nino which caused the total rainfall to decrease by 25% -30% in all parts of Sarawak. Mahmud (2018) also found that the El Nino incident, especially in 2015/2016, caused the rainfall rate in the Kuching area to decrease by 30% -40% which caused forest fires in the Miri area due to higher temperatures than usual.

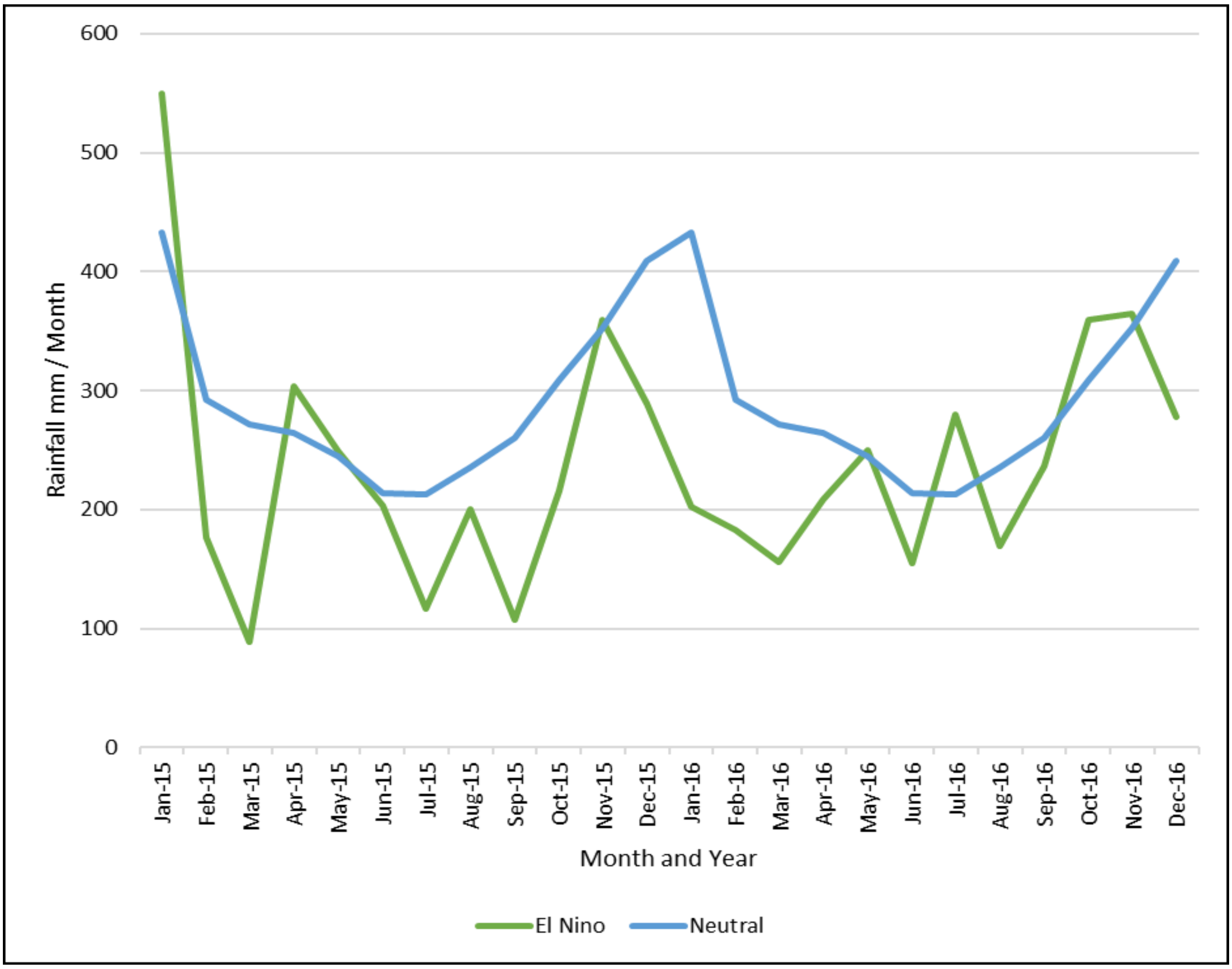

Fig. 5 - Pattern of the monthly amount of rainfall at neutral times and during the events of El Niño 2015/2016

Based on figure 5 shows the pattern of the amount of monthly rainfall is found to be different for the duration of El Niño and neutral incidents. El Niño incidents were found to cause an overall decline from May 2015 to May 2016. An in-depth explanation of the changes in the amount of monthly rainfall at normal times and El Niño will be explained in depth over the next stretch. Kemarau & Eboy (2021) and Boadi & Uwuzu (2017) also argue with the results of this study showing an increase in the value of the ONI index causes an increase in temperature value and a decrease in total rainfall (Kemarau & Eboy, 2021; Moura et al., 2019)

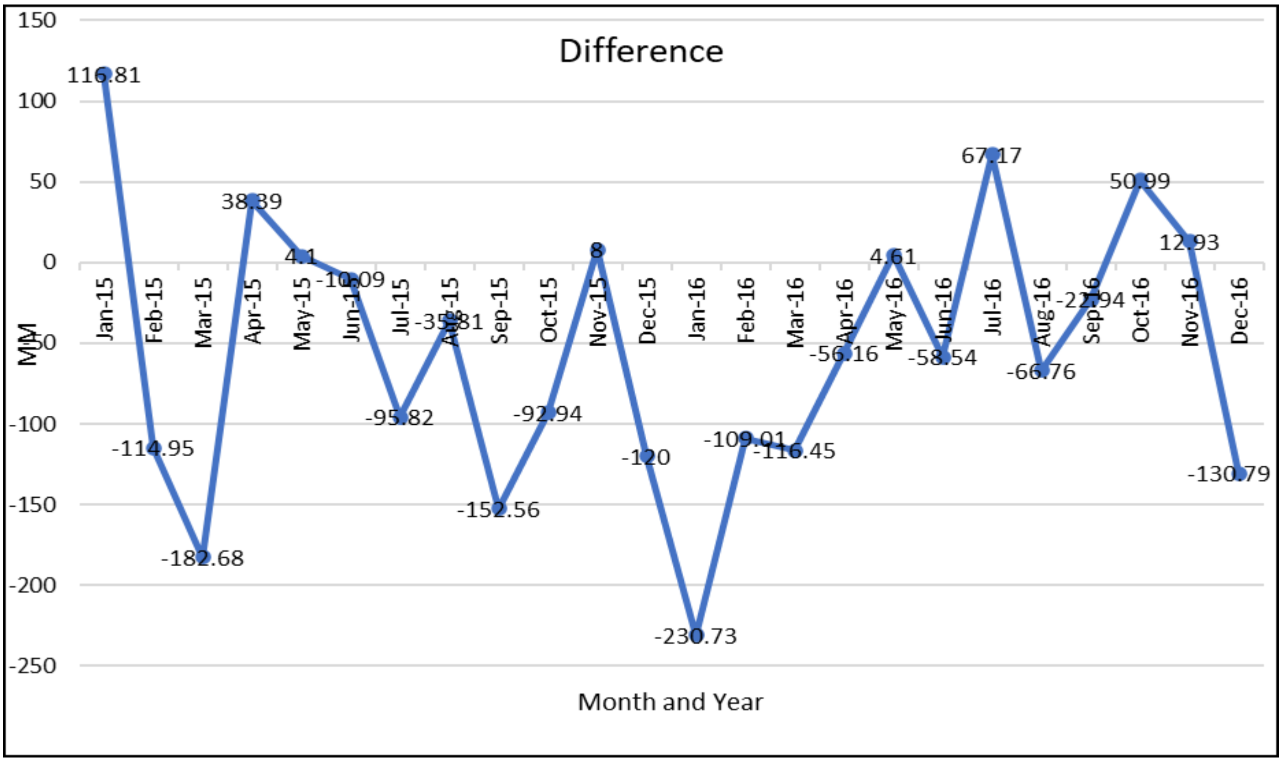

Fig. 6 - Change in Value The amount of precipitation from neutral time

Referring to the following figure 6 found El Niño events in 2015/2016 decreased as in February 2015 which experienced a difference of 114.95 mm, 182.68 mm in March, July to 95.82 mm, 35. 81 mm for August, 92.94 for October 2015, and 120 mm for December 2015. This decline continued in 2016 which was 230 mm in January 2016, 109 mm for February 2016, March 2016 which was 116.45 mm. Moten et al., (2014) and Moura et al., (2019) noted a decrease in the amount of rainfall due to El-Niño events shortening the northeast monsoon season. This explains why the value of total rainfall is less during El-Niño incidents. The relationship between temperature and rainfall amount was found to be similar to the findings of Moura et al., (2019) who conducted a study in the Amazon equatorial rainforest.

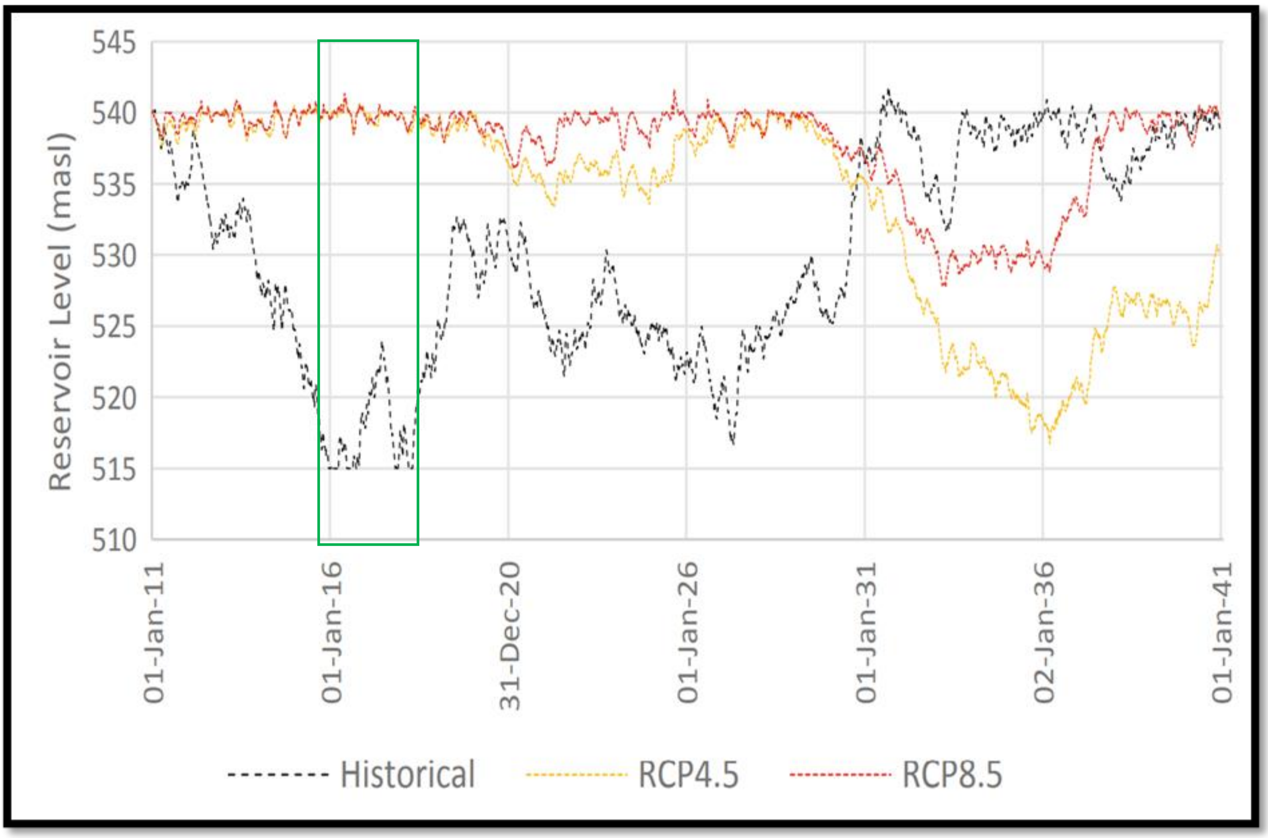

Fig. 7 - Murum basin water levels for operation for the duration of the 2020s under RCP4.5 and RCP8.5 contrasted with the standard period of 1976–2005

Source: Hussain & Jing (2019)

The study referred to Hussain & Jing (2020) who researched the effects of climate change on Murum basin water letter for operation during 2020. The water level of the Murum Reservoir varies between the minimum operating level (MOL) of 515 maximum and the full water supply (FSL) of 540 maximum. It has been pointed out that under the historical flow, the water level of the reservoir only reached the lowest water level for the operation of the reservoir (Hussain & Jing, 2019). The study found that the decline in level reservoirs experienced decreases in 2015 and 2016 (green square) especially on Jan 1, 2016, which is the ONI value of 2.5. The study found that the incidence of El Niño resulted in a decrease of 35 meters above sea level during the neutral time, in January 2011. A decrease of 25 to 30% of the total monthly rainfall resulted in a decrease of 35 meters above sea level for the Murum dam However, the occurrence of La Niña 2018/2019 using a rise in the level of the reservoir meter above sea level due to the increase in the amount of precipitation in the Murum dam. Stager et al., (2007) also found that the ENSO incident is an event that causes an increase and decrease in Lake Victoria, West Africa. This supports the findings of this study which explains the decline in water levels in the Murum dam in 2015/2016 during the El Nino event. In addition, Lei et al., (2019) can also be found with the results of the study of Stages et al., (2007) who obtained the findings to have the same pattern of decrease and increase due to ENSO in Lakes in the Tibetan Plateau.

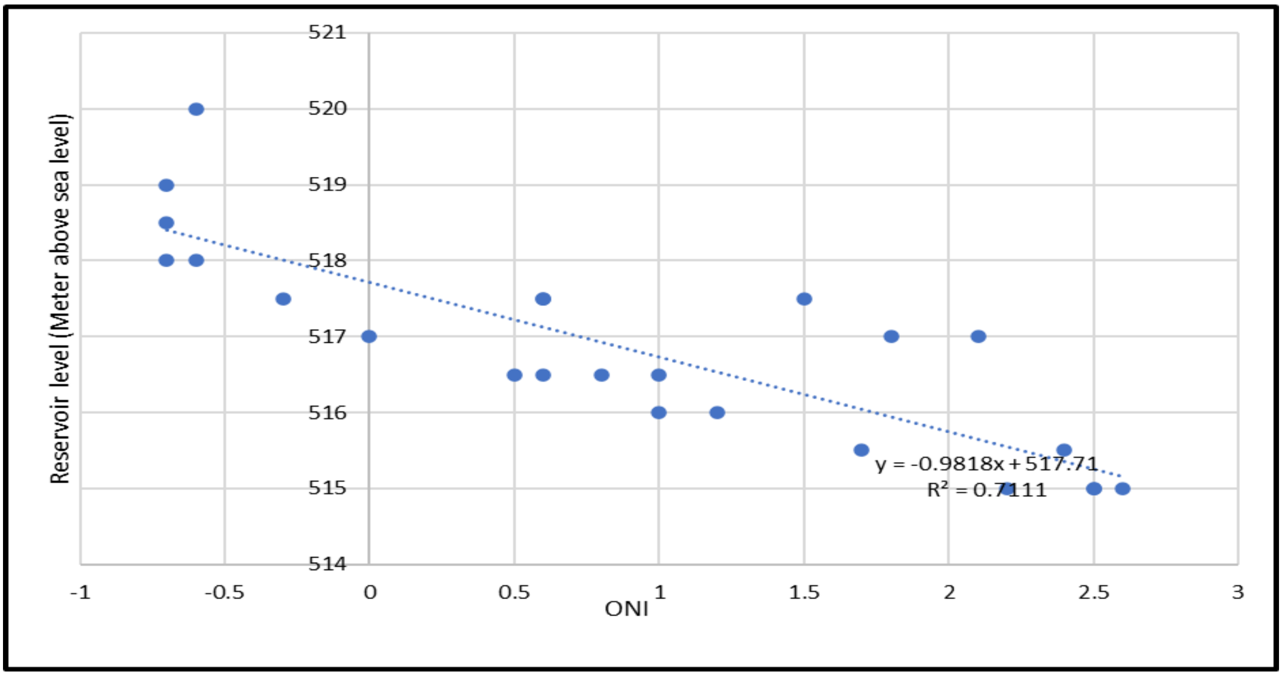

Fig. 8 - Correlation relationship between ONI and reservoir level for Murum dam

Based on figure 8, it is found that there is a negative relationship between ONI and the water level in Murum dam with a correlation coefficient value of 0.71 R^2. This explains that any increase in the value of ONI, especially when it exceeds the negative 0.5 that brings the El Nino event will cause the water level in the Bakun dam to decrease. Decrease in water level value in Bakun dam due to lack of rainfall during the El Nino event as happened in 2015/2016. The results of this study are also supported by the findings by Moura et al., (2019) who found that the El Nino event in Brazil caused reduced water flow because the El Nino event. In addition, Santos et al., (2022) also reported the same result that found that the El Nino event caused the water level in the Sobradinho dam, Brazil to decrease due to the total rainfall at that time decreasing 22.9% to 12.9%.

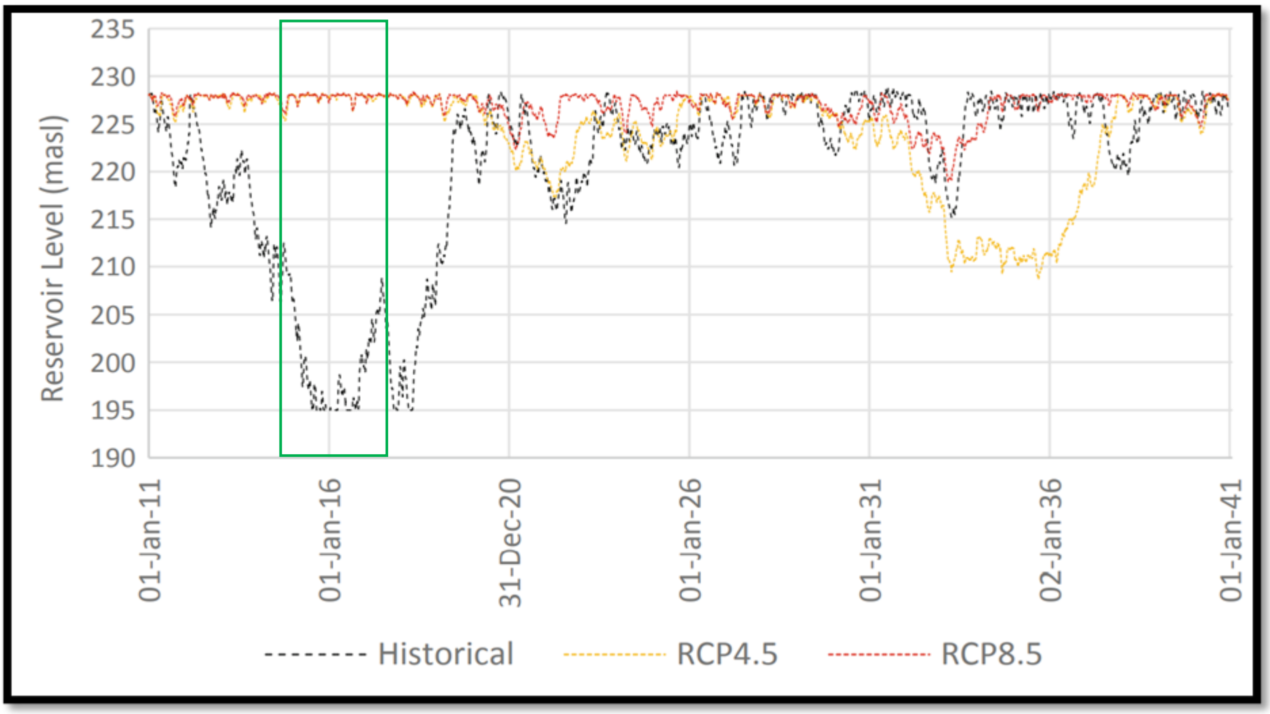

Fig. 8 - Bakun basin water levels for operation during the 2020s under RCP4.5 and RCP8.5 contrasted with the reference period of 1976–2005

Source: Hussain & Jing (2019)

The study referred to Hussain & Jing (2019) who researched the effects of climate change on Bakun reservoir water letter for operation during 2020. During the operation, the water level of Bakun Reservoir was designed to fluctuate between 195 meters above sea level MOL and 228 meters above sea level FSL. The working range of the Bakun Reservoir is very large, allowing the reservoir water level to fluctuate within the working range of 33 m. Like the Murum Reservoir, the water level of the Bakun Reservoir has reached the minimum operating level of 195 meters above sea level several times during the operation of the reservoir under the historical flow. The study found that the decline in level reservoirs experienced decreases in 2015 and 2016 (green square) especially on Jan 1, 2016, which is the ONI value of 2.5. The study found that the incidence of El Niño resulted in a decrease of 35 meters above sea level during the neutral time, in January 2011. A decrease of 25 to 30% of the total monthly rainfall resulted in a decrease of 30 meters above sea level for the Bakun dam. The rising pattern of reservoir levels meter above sea level increased in 2018/2019 during the La Niña incident. This is supported by Okonkwo et al., (2014) also reported an ENSO incident occurring in Lake Chad in Centre Africa. Okonkwo et al., (2014) explained that the El Nino event caused a decrease in water level in Lake Chad and the La Nina event increased the water level in Lake Chad.

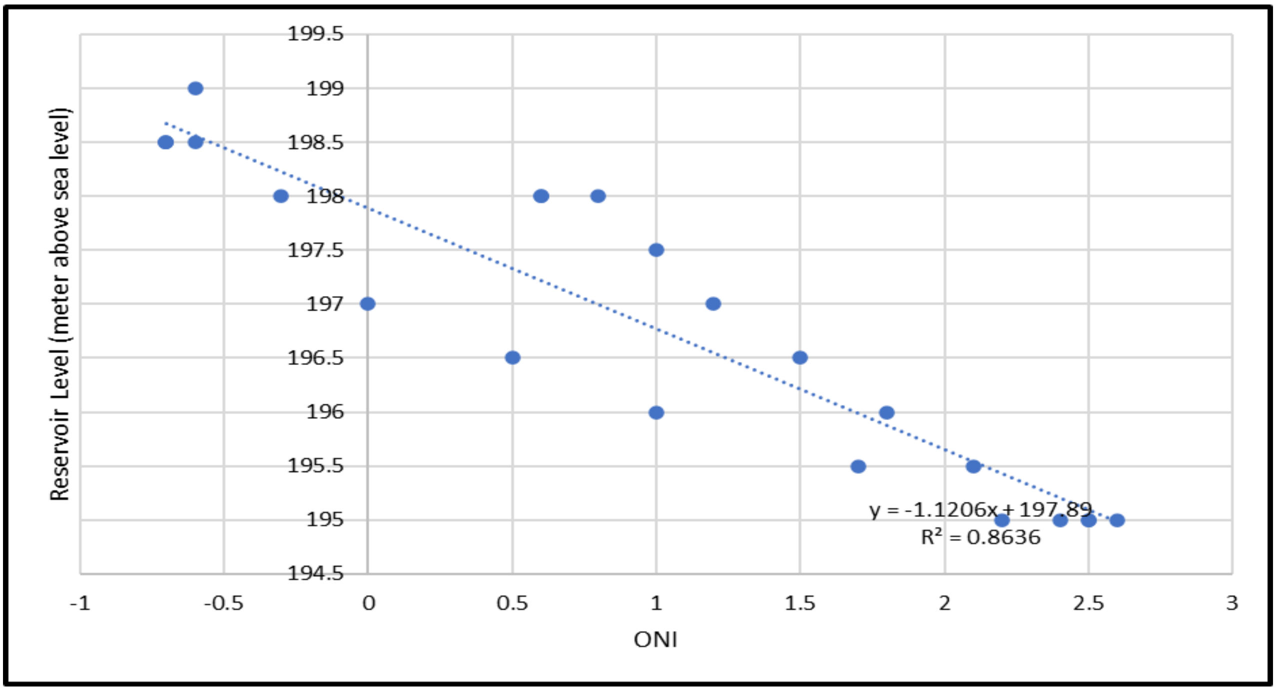

Fig. 9 - Correlation relationship between ONI and water level in Bakun dam

Figure 9 shows the correlation relationship between ONI with the water level in Bakun dam found a negative relationship with a correlation coefficient of 0.86 R^2. The findings of this study were found to be similar to the relationship between ONI and water level in Murum dam. The findings of this study were also found to have similarities with the findings of the study of Santos et al., (2022) found the occurrence of El Nino plays an important role in determining the water level in the Sobrahinho dam. Santos' study found that there was a relationship between the El Nino event and the water level in the Sobrahinho dam, Brazil with a negative test coefficient of 0.67 ($P\text{-value} < 0.05$). Santos' study also found that the El Nino event caused a decrease from 5000 Mega Watts to 2000 Mega Watts causing energy importers from outside to meet demand. In Ethiopia, Africa also reported ENSO incidents especially during El Nino events causing water level drop in Lake Hawassa (Belete et al., 2017).

5. Conclusion

The pattern of increase in reservoir level meter above sea level increased in 2018/2019 during this study. Successfully achieved the objectives of the study. Remote sensing technology has the capability of supplying rainfall data in rural areas such as the rainwater catchment areas of the Bakun and Murum dams. The finding of the study indicated that the effects of El Niño 2015/2016 reduced 20 to 30% of total rainfall in HEP Murum and HEP Bakun compared to the neutral current. The actor found that during the El Niño 2015/2016 incident, there was a decrease in the amount of annual rainfall by 20 to 30%. The actor caused a rainfall drop of 30 mals for the Bakun dam and 35 mals for the Murum dam. However, the value of the receiver level increased during the 2018/2019 La Niña incident. The event obtained the amount of rainfall in the studied district little time of the incident during the northeast monsoon which brought rain in October, November, December, and January. The study appeared the El Niño event 2015/2016 has slowed the impact of the northeast Monsoon event. Niña's incident.

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