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Comparative Studies Of Residual Water Level In Manado And Melonguane Coastal Area During Tropical Cyclone In 2021

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Abstract

North Sulawesi Province, directly bordering the Pacific Ocean, is located in an area with the highest level of tropical cyclone (TC) activity in the world. As a result, the province is vulnerable to the impacts caused by cyclones, including storm surges. The increase in water levels due to this event has the potential to cause coastal flooding. Previous studies in Manado have identified that sea level rise can be detected through residual water level (RWL), making studying the characteristics of RWL in North Sulawesi important. This research focuses on Manado and Melonguane, allowing for a comparison of characteristics. The data used includes tropical cyclone data from the China Meteorological Administration (CMA) and tidal data from the Geospatial Information Agency. The Unified Tidal Analysis and Prediction (UTide) method is used to identify RWL. The analysis was carried out by using a t-test to compare data at the two locations. The results showed that RWL at those locations had significant differences with Melonguane having the higher value between them. Generally, the increase in RWL in Melonguane occurs shortly after the cyclone period, while the RWL in Manado maximum increases 86 hours after TC's first occurrence.

Keywords: tropical cyclone; residual water level; UTide.

INTRODUCTION

North Sulawesi Province is one of the regions in Indonesia that directly borders the Pacific Ocean. According to Schreck et al. (2014), the waters of the Pacific Ocean are the region with the most active cyclone events. During 42 years (1972 - 2020), 60.5% of tropical cyclones that affected Indonesia occurred in the West Pacific Ocean (Ningsih et al., 2023). The high frequency of tropical cyclone events certainly has an impact on the areas crossed by their trajectories. For example, the Philippines experiences many extreme events such as floods and landslides due to rain and storms produced by tropical cyclones (Santos, 2021).

Another impact that tropical cyclones can cause is storm surges. The rise in sea level due to storm surges has caused coastal areas to become vulnerable to flooding. This is like what happened with Tropical Cyclone (TC) Pam in 2015, where the event caused flooding and damage in Tuvalu, Kiribati and Wallis, and Futuna, which is more than 1,000 km from TC Pam's path (Hoeke et al., 2021). Increases in sea level generally caused by storms are usually the most significant source of flooding in coastal environments (Torres & Nadal-caraballo, 2021). Based on this incident, the urgency to study changes in sea level around the coast is high because it can be a reference in mitigating flood disasters.

As an area located on the coast and directly bordering the Pacific Ocean, North Sulawesi is vulnerable to coastal flooding, especially in Manado City. Wibowo et al. (2018) found that the Manado reclamation area experienced land subsidence and groundwater levels. This is in line with research by Triana & Janottama (2021) which projected that Manado, along with other coastal cities in Southeast Asia, will experience a higher rate of sea level rise than the global average. These factors, according to Nicholls et al. (2021), make Manado vulnerable to coastal flooding.

A study regarding the analysis of coastal flood events in Manado has been carried out by Azani & Efendi (2023), specifically on the 2021 event. Based on this research, the most influential factors in coastal flood events in Manado are non-astronomical factors such as strong winds which are also supported by maximum tides of the New Moon phase. These factors can be identified from the residual water level.

Residual water level (RWL) is the water height determined by subtracting astronomical tides from the total water level (Murty et al., 2014). RWL can significantly change water levels during storms (Tehranirad et al., 2020). RWL has been assessed to identify sea level rise due to meteorological factors including tropical cyclones. As done by Ningsih et al. (2020) during TC Nicholas in 2008, TC Nicholas played an important role in producing RWL variability in Indonesian coastal areas.

Insight into the characteristics of RWL can contribute to reducing the impact of disasters that might occur, especially in coastal areas. This research examines the characteristics of RWL during tropical cyclone events in the Northwest Pacific. Apart from Manado City, which is an important area in North Sulawesi, the RWL study will also be carried out in Melonguane as a comparison with events in Manado because it is located close to the trajectory of tropical cyclones.

METHODS

The study area is in two locations, namely on the Manado coast and the Melonguane coast. The Manado coastal area was chosen as the research location because this area is the center of economic activity in North Sulawesi (Koyongian et al., 2019). Meanwhile, the Melonguane coast was chosen because it is closest to tropical cyclone events, especially in North Sulawesi. The research was carried out based on cyclone data that occurred in the Northwest Pacific in 2021. Tropical cyclone data itself was limited to tropical cyclones that were located at coordinates 120 - 140ºE and 5 - 15ºN. The research location is shown in Figure 1.

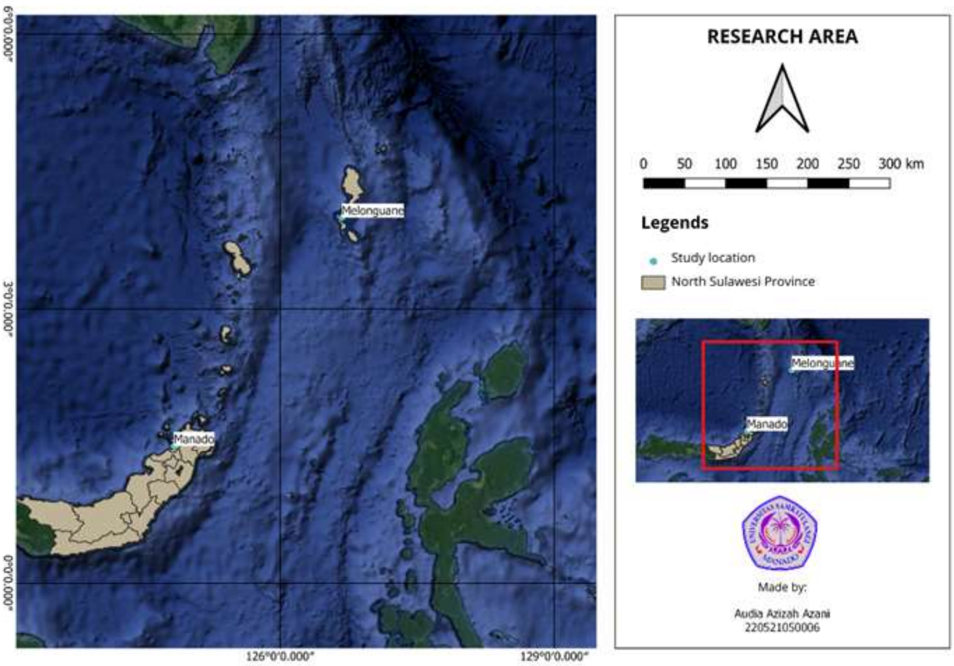

Figure 1. Research area

Filtered tropical cyclone data is obtained from the China Meteorological Administration (CMA) Tropical Cyclone Data Center website (Lu et al., 2021; Ying et al., 2014) which can be accessed on https://tcdata.typhoon.org.cn/en/zjljsjj_zlhq.html. After the tropical cyclone has been filtered, tidal data is then obtained from the Geospatial Information Agency (http://ina-sealevelmonitoring.big.go.id/ipasut/) according to the time of occurrence of the tropical cyclone. The data is then filtered into astronomic tides and residual tides using Python re-implementation of the Matlab package Unified Tidal Prediction and Analysis or UTide (Codiga, 2011) using the equation (Foreman et al., 2009) (see formula 1).

To identify the RWL from remote forcing, the total RWL is then reduced by the RWL from local factors, namely wind set-up and inverted barometer effect, as done by Ningsih et al. (2011, 2020). The change in water level due to local wind setup as formulated in (Bowden, 1983) see formula 2. Meanwhile, change in sea level due to inverted barometer effect is given by (Bowden, 1983) Formula 3.

$$h(t_j) = z_0 + at_j + \sum_{k=1}^{n} f_k(t_j) A_k \cos[V_k(t_j) + u_k(t_j) - g_k] + R(t_j) \quad \text{........ 1}$$

Where:

$h(t_j)$	:	the water level measurement at time t_j
Z_0	:	the constant background water level
A	:	the linear trend coefficient for arbitrary sampling and multi-constituent inferences
$f_k(t_j)$, $u_k(t_j)$	:	nodal corrections for amplitude and phase, respectively, for constituent *k* at time t_j
A_k, g_k	:	the amplitude and phase lag of constituent *k*
$V_k(t_j)$	:	the astronomical argument for constituent *k* at time t_j
$R(t_j)$	:	the nontidal residual

$$\Delta\eta = C \frac{\tau_{SX}}{g\rho h} \Delta x \quad \text{.......... 2}$$

Where:

$\Delta\eta$	:	change in sea level (m)
C	:	Koefisien, 1 < C < 1.5
τ_{SX}	:	*Wind stress*
g	:	gravitational acceleration (m/s^2)
ρ	:	the density of water (kg/m^3)
h	:	the mean of water depth (m)
Δx	:	fetch (m)

$$\Delta\eta = -\frac{1}{g\rho} \Delta p_a \quad \text{............ 3}$$

where Δp_a is the change in atmospheric pressure.

RWL calculations are carried out for the Manado and Melonguane areas respectively. After the data at the two locations is obtained, a t-test comparison is carried out to determine the comparison between the RWL in Manado and Melonguane during the 2021 tropical cyclone period using SPSS software. Apart from carrying out the t-test, the RWL at the two locations will also be compared using graphs processed in Python.

RESULTS AND DISCUSSION

Northwest Pacific Tropical Cyclones in 2021

Tabel 1 shows list of Northwest Pacific Tropical Cyclones in 2021. According to filtered data, there are 7 tropical cyclones that occurred around the determined coordinate. The duration of a cyclone is around 3 – 8 days, with the shortest cyclone being TC Nyatoh and the longest being TC Surigae. TC Surigae is also the most significant TC with a minimum pressure of up to 895 hPa and maximum winds reaching 72 m/s so this TC is also in the Super-Typhoon category (Lu et al., 2021). Apart from that, there is one unnamed cyclone whose cycle is only in the tropical depression phase (Nameless). The TC only has a minimum pressure of 1002 hPa with a maximum speed of 15 m/s.

These cyclones are then mapped as in Figure 2. Based on the mapped trajectory, cyclones usually start from the east of the Philippines or north of Papua and then head towards the Philippines. Among the seven cyclones, TC Surigae and TC Nyatoh did not pass directly through the Philippines and were located far from the waters of North Sulawesi. However, according to Kusumawardani et al. (2021), Typhoon Surigae still influences oceanographic conditions in the Sangihe-Talaud waters or the northern part of the North Sulawesi region.

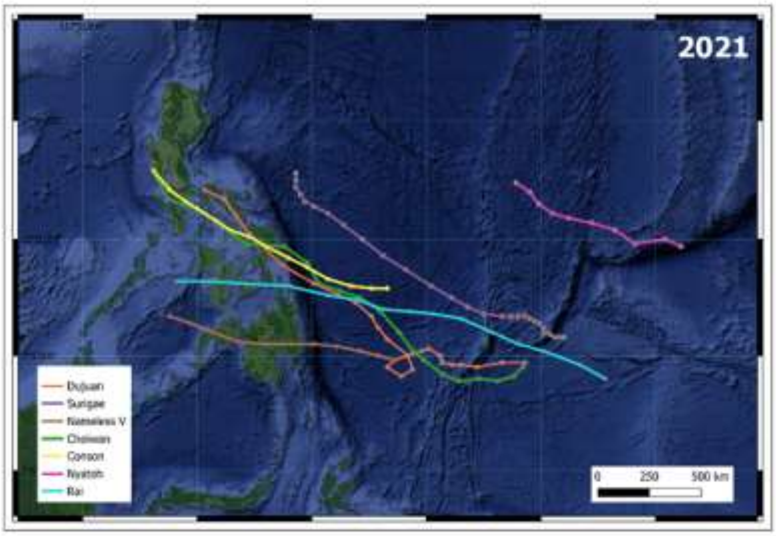

Figure 2. Tropical Cyclone trajectories in 2021

Table 1. List of Northwest Pacific Tropical Cyclones in 2021

NO	TC Name	Start Time	End Time	Minimum Pressure (hPa)	Maximum Wind (m/s)
1	DUJUAN	16 February 2021, 12.00 UTC	22 February 2021, 18.00 UTC	990	23
2	SURIGAE	12 April 2021, 18.00 UTC	19 April 2021, 12.00 UTC	895	72
3	NAMELESS	12 May 2021, 12.00 UTC	15 May 2021, 00.00 UTC	1002	15
4	CHOI-WAN	29 May 2021, 00.00 UTC	02 June 2021, 18.00 UTC	995	20
5	CONSON	05 September 2021, 06.00 UTC	08 September 2021, 12.00 UTC	990	28
6	NYATOH	29 November 2021, 00.00 UTC	01 December 2021, 06.00 UTC	985	28
7	RAI	13 December 2021, 12.00 UTC	17 December 2021, 00.00 UTC	915	62

Independent Sample T-Test Comparison of Residual Water Level

A t-test is then performed to compare the average RWL at both locations. The results are shown in Table 2 and Table 3.

Table 2 shows a comparison of the average RWL in the two locations, where the number of samples each amounts to 51841 data with the average RWL in Melonguane being higher than in Manado with RWL -0.0075 m and -0.0515 m respectively.

Based on Table 3, the two groups of RWL data have significant differences, as evidenced by the value of F = 12322.949 and the value of p = 0.000 or p < 0.001 (Landau & Everitt, 2004). Because p < 0.001, the t-test for Equality Means uses the "Equal variances not assumed" column (Islam et al., 2021). Thus, we get a sig value (2-tailed) or p value = 0.000, which indicates that it is unlikely to get a t value of -120.21 if there are no real differences between groups. In addition, a negative t value indicates that the RWL in the second data group (Melonguane) is greater than the RWL in the first data group (Manado). This confirms that there is a significant difference in value between RWL in Manado and Melonguane.

Table 2. Descriptive statistics of Residual Water Level in Manado and Melonguane

	Location	N	Mean	Std. Deviation	Std. Error Mean
RWL	Manado	51841	-0.0515	0.07379	0.00032
	Melonguane	51841	-0.0075	0.03863	0.00017

Tabel 3. Independent Sample T-Test Result of Residual Water Level in Manado dan Melonguane

		Levene's Test for Equality of Variances		t-test for Equality Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% Confidence Interval of the Difference Lower	Upper
RWL	Equal variances assumed	12322.9	0.00	-120.21	103680	0.000	-0.04397	0.00037	-0.0447	-0.0433
	Equal variances not assumed			-120.21	78266.913	0.000	-0.04397	0.00037	-0.0447	-0.0433

Residual Water Level Comparison

Apart from carrying out the T test, the RWL of Manado and Melonguane are also compared by making a comparison graph. Among the seven cyclone cases, only TC Dujuan could not be compared due to missing tidal data in Melonguane. In general, it appears that the RWL in Melonguane is higher than in Manado.

At the time of TC Dujuan (Figure 3), Manado's RWL during the cyclone period was below 0 m and only experienced an increase three days after the cyclone or on February 26 2021 with the highest value of 0.17 m. Meanwhile, during TC Surigae (Figure 4), RWL in Melonguane increased to 0.0931 m on April 13 2021 at 00.00 UTC or when TC Surigae had just entered the research area, while RWL Manado was still below 0. RWL in Manado rose to 0.037 on April 16 2021 at 11.00 UTC or three days after TC Surigae entered.

Figure 5 is a comparison of RWL in Manado and Melonguane during TC Nameless and Choi-Wan. The pattern of increase in RWL in Melonguane was the same as in previous cyclone events, namely right after a new cyclone entered the research trajectory, with an increase in RWL as high as 0.0164 m on the first day of TC Nameless (May 12 2021, 12.00 UTC) and 0.0208 m on the first day of TC Choi-Wan (May 29 2021, 00.00 UTC). The RWL in Manado took one hour after TC Nameless, namely May 12 2021 13.00 UTC, to rise to 0.0164 m, and it took 12 hours after TC Choi-Wan (May 29 2021, 12.00 UTC) to rise to 0.0054 m. However, the higher increase in RWL in Manado occurred when TC Choi-Wan was just about to leave the research area, namely on June 2 2021 with a height of 0.125 m.

Figure 6 shows a comparison of RWL during TC Conson. Unlike in previous cases, the RWL in Manado immediately increased to 0,0463 m, while in Melonguane needed 8 hours to increase to 0,0244 m. For the last two cases, namely

TC Nyatoh and TC Rai (Figure 7), the RWL in Manado was always below 0 during the second period of the cyclone. RWL only experienced an increase 68 hours after TC Nyatoh (December 01 2021) by 0.0092 m and on the last day of TC Rai (December 17 2021) or exactly 86 hours after the first occurrence by 0.0123 m. Meanwhile in Melonguane, the RWL during the TC Nyatoh period immediately reaching 0.0489 on November 29 2021. Meanwhile, during the TC Rai period, the RWL did not experience a significant increase, only around 0.0288 m on December 13 2021 or 8 hours after the cyclone entered.

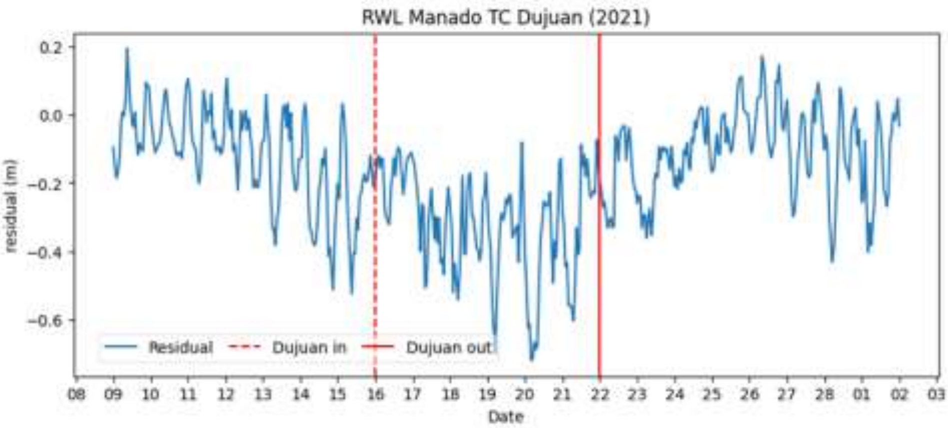

Figure 3. RWL Manado during TC Dujuan (2021)

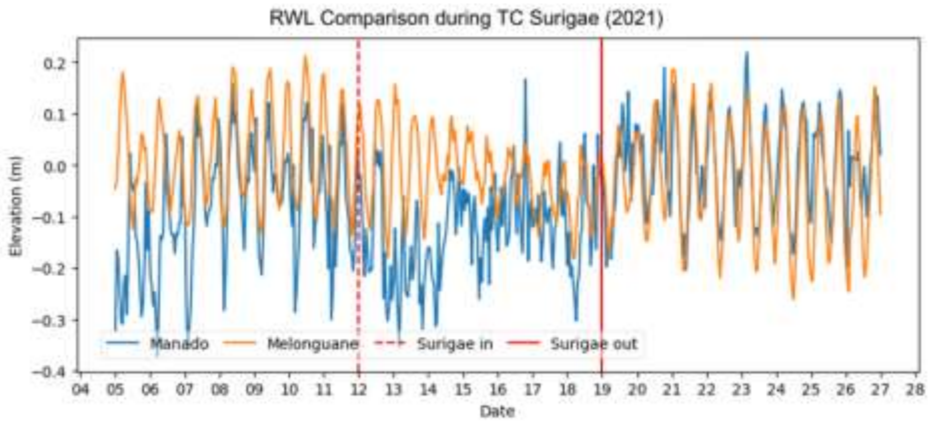

Figure 4. Comparison between RWL in Manado and Melonguane during TC Surigae (2021)

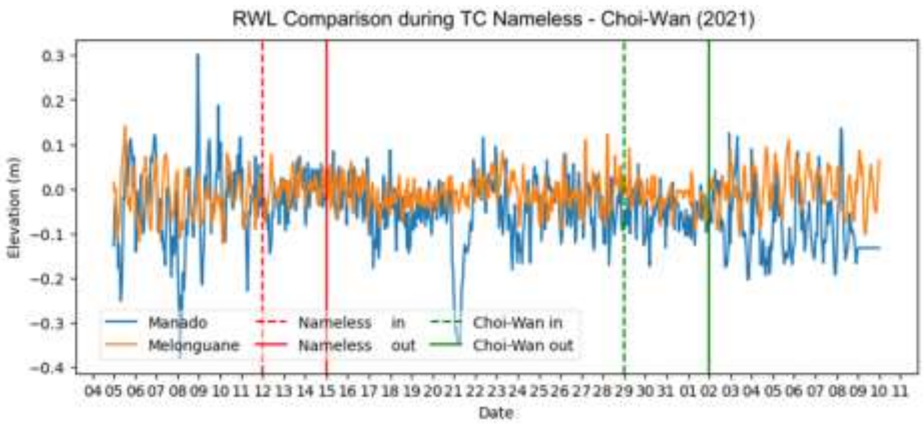

Figure 5. Comparison between RWL in Manado and Melonguane during TC Nameless and Choi-Wan (2021)

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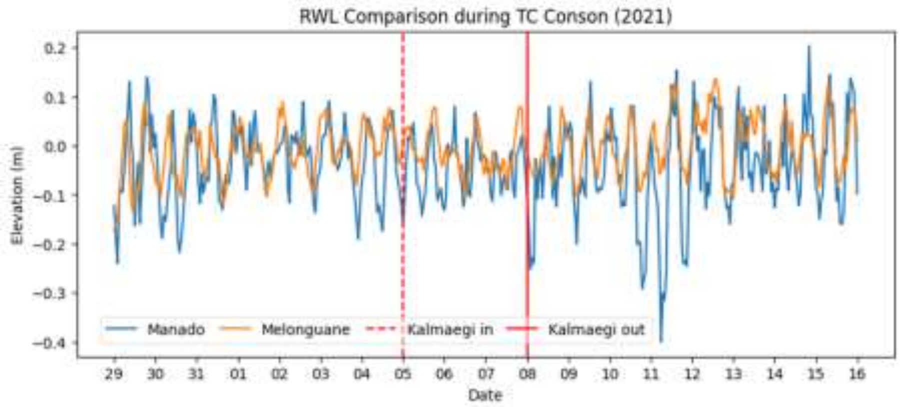

Figure 6. Comparison between RWL in Manado and Melonguane during TC Conson

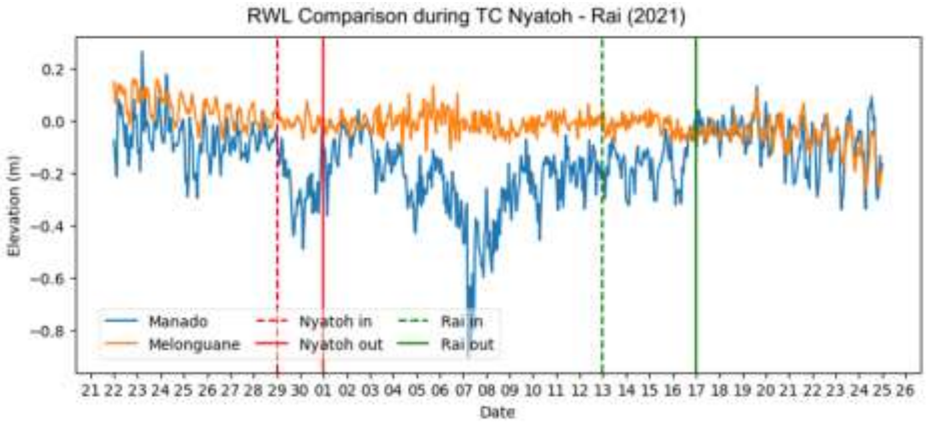

Figure 7. Comparison between RWL in Manado and Melonguane during TC Nyatoh and Rai (2021)

Based on the case studies that have been described, the RWL in Melonguane generally experiences an immediate increase during the tropical cyclone period or shortly after the tropical cyclone has entered the trajectory area. Meanwhile, the RWL in Manado experienced a decrease several times during the tropical cyclone period. RWL in Manado then began to increase a maximum of 86 hours after TC's first occurrence, except for TC Conson which experienced an immediate increase. There is a delay in the increase in RWL in Manado compared to Melonguane due to Manado's position being further from the cyclone's trajectory. This is in line with research by Windupranata et al. (2018) when examining significant wave increases in the Lampung to Bali region during the tropical cyclone Cempaka (2017) which stated that the further away from the location of the tropical cyclone, the lower the increase in wave height. However, a comprehensive investigation into varied RWL conditions in Manado during the occurrence of TC Conson is imperative for further study.

CONCLUSION & SUGGESTION

Conclusion

The RWL in Manado and Melonguane has been investigated during the tropical cyclone period in the Northwest Pacific in 2021. Based on the t-test, there is a significant difference between the RWL in Manado and Melonguane, with the higher average RWL in Melonguane. Furthermore, during a tropical cyclone, the RWL in Melonguane experiences a faster increase than in Manado with the increased occurrence on the day when the tropical cyclone has entered the trajectory area, while the RWL in Manado increases the fastest one hour and maximum 86 hours after the tropical cyclone entered the study area.

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Suggestion

More case studies need to be conducted to ascertain the characteristics of RWL in Manado and Melonguane. Further study also needs to be conducted on the immediate increase of RWL in Manado during TC Conson. Then, it is also necessary to study whether an increase in RWL during tropical cyclones can cause coastal floods in the study area.

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