The Impact of Tropical Cyclone Seroja to The Rainfall and Sea Wave Height in East Nusa Tenggara

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Abstract. Natural events following the activity of the Tropical Cyclone Seroja in April 2021 are investigated. During its active phase, Tropical Cyclone Seroja generated extreme rainfall events in some sub-provinces of East Nusa Tenggara (NTT): Ngada, Alor, Belu, Rote Ndao on 4 April, 2021, Kupang on 4 to 5 April, 2021, East Sumba on 4 to 6 April, 2021. Moreover, these extreme rainfall events triggered flood in Alor, East Flores, Lembata, The City of Kupang, Kupang, East Sumba, Malaka, Belu, and North Central Timor. The maximum sea wave height of the Indian Ocean at the Southern part of NTT was also increasing, from 4 meters on 1 to 2 April, 2021 up to 6 meters on 3 April, 2021, and rose to higher than 7 meters on 4 to 6 April, 2021. On 7 to 9 April, 2021, the sea wave height declined as the Tropical Cyclone Seroja moved to the Southwest of NTT.

1. Introduction

Tropical Cyclone (TC) is an atmospheric disturbance caused by non-frontal low-pressure system on synoptic scale. This system grew over warm waters with more than 26.5 °C temperature in convective area and the wind speed near their eye more than 63 km/jam or 34 knots. The life of tropical cyclone commonly between 3 hours to 18 days. The energy of TC is decay when entering the cold waters or entering the island. Tropical cyclones commonly occur in middle latitudes, but it is possible that these disturbances also occur in low latitudes such as in Indonesia, although the possibility of occurrence is rare. Tropical cyclones generally have direct and indirect impacts. Their direct impact is the meteorological conditions accompanied at the cyclone life such as increasing the precipitation [1,2,3], increasing the wind speed [4] and the extreme wave [5]. Indirect impacts are the further impacts due to the increase in meteorological activity, including floods [6], landslide [7,8], coastal erosion and ecosystem change [9], coastal flooding and also infrastructure damaged [5].

There have been at least 11 tropical cyclones occurred in Indonesia, including TC Durga (22 – 25 Apr, 2008), TC Kirrily (26 – 28 Apr, 2009), TC Anggrek (29 Oct – 05 Nov, 2010), TC Bakung (11-13 Dec, 2014), TC Cempaka (27 Nov -01 Dec, 2017), TC Dahlia (30 Nov – 2 Dec, 2017), TC Flamboyan (28 Apr–02 May, 2018), TC Kenanga (15 - 8 Dec, 2018), TC Lili (08-09 May 2019), TC Mangga (21–22 Mei 2020), and the most recent event was TC Seroja in South of Nusa Tenggara Timur on April 2-9 2021. Tropical cyclones event caused an extreme weather which have a large impact on coastal communities, such as fatalities, property damage, and the economic impact. The most important impact that really needs attention is the possibility of fatalities [10]. Indirect effect of TC is the increasing of...
significant wave height (SWH). The significant wave height is increasing about 2-3 meters in the southern Java when TC Cempaka and Dahlia occur [11].

The aim of this study is to investigate the indirect effect of TC Seroja especially in their impact to sea wave height and precipitation, so that it can be used as an additional reference for mitigating the impact of tropical cyclones in Indonesia.

2. Materials and Method

The data used in this research is rainfall observation data from the various meteorological stations around East Nusa Tenggara (NTT) to see the rainfall that occurred before and during the TC Seroja. We use weather parameter data such as cyclone trajectories to see the direction during TC Seroja, streamlined data to see the wind direction and air pressure differences in the area around the TC Seroja, and Sea Surface Temperature (SST) data on 1–10 April, 2021 to detect the beginning of the TC Seroja. We also used Himawari-8 satellite imagery data from the Japan Meteorological Agency and sea wave height data obtained from the output data of Wavewatch3 at positions 4°-14°S, and 116°-128°E, with the spatial resolution is 7 km, and the temporal resolution is 3 hours.

The method used in this study is a descriptive analysis of the processing result of weather data parameters around the East Nusa Tenggara to see the causes and effects of the TC Seroja.

3. Result and Discussion

3.1. The tropical cyclone occurrence

Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) has the responsibility to provide early warning of tropical cyclones in the area of 90°-125°E, and 0°-10° S. On April 3 2021, has disseminated an early warning regarding the formation of tropical cyclone (TC) 99°S seeds hence forward excerpted as TC Seroja.

At the growth stage, the low-pressure centre that was the precursor of the 99S seeds from the TC Seroja was identified on 27 March 2021, around the Banda Sea, NTT, but has not been declared as a tropical cyclone because it has not fulfilled several requirements to be declared a TC seed. The next day on 2 April 2021, at 07.00 WIB, it was confirmed as a TC seed with the code 99S. The location of this seedling is in the Sawu Sea, East Nusa Tenggara, precisely at 9.6°S 121.8°E, with an air pressure of 1004 hPa and wind speed of 25 knots. 99S seedlings are in the growing stage for approximately three days, which is between 2 to 4 April, 2021 (Figure 1.).

![Figure 1. Trajectory of Seroja Tropical Cyclone](image)

The results of the wind gradient analysis start from 1 to 4 April, 2021, issued by the BMKG, shows that there is a cyclonic circulation in the south of NTT, which triggers the formation of shear lines (wind...
bend areas) and causes a slowdown in air mass flow (Figure 2). This slowing of air mass flow causes the build-up of water vapour in the area around the wind bends, resulting in the accretion of convective clouds. In addition, the air masses that enter the NTT region come from Australia (eastern winds) and Asia (West Winds), but if it looks closely, the air masses that enter through the Indian Ocean south of Indonesia carry a lot of water vapour to the NTT area. A wind speed increasing also spotted in the cyclonic region of the south of NTT that reached 69 knots on 4 April, 2021.

Before reaching tropical cyclone intensity, the earlier four hours' cloud system showed a well-organized Cloud System Centre, a well-defined circular pattern, and dominant rainbands in the north and east of the system. The growth of convective clouds strengthens on 4 April 2021, 18.00 UTC, the type of system cloud pattern can be categorized as Curved Band. The band area was getting denser and, the centre circulation was visible. Starting on 8 April 2021, the convective system was increasing, and the Central Dense Overcast pattern was observed on April 10, where the TC Seroja reached its highest intensity.

![Figure 2. The Sirculation on wind gradient on 1 to 4 April, 2021 [13]](image)

TC Seroja began to weaken and entered a period of extinction since 11 April, 2021, at 19.00 WIB, along with this system entering the western Australian mainland, which is south of the city of Kalbarri. At the time of "landfall," TC Seroja was still in category three tropical cyclone intensity, with wind speeds of 70 knots. However, friction with the surface weakened this system so much that it became extinct as a centre of low pressure on 12 April, 2021, at 04.00 WIB on the mainland of southwest
Australia, precisely around the northeast of the city of Lake King. The evolution of the TC Seroja convective system can also be seen on Himawari satellite imagery from 4 to 12 April, 2021 (Figure 3).

A warm sea surface temperature (SST) (above 27°C) plays a vital role in the development of Tropical Cyclone. A warm SST is the primary energy source of TC. Figure 4 shows the SST anomaly in the Indian Ocean located in the southern part of Indonesia. The data used in Figure 4 were obtained from the Japan Meteorology Agency (JMA). Figure 4 shows the SST anomaly in the Java Sea, Flores Sea, and some areas of southern Banda Sea were low. Warmer SST occurred around the Seram Sea, some parts of the Northern Banda Sea, Halmahera Sea, northern Papua Sea and Southern Indian Ocean. In general, it can be seen that a warm SST was spreading from the south Indian ocean close to the southern coasts of Java, Bali, NTB and NTT. A warmer SST would potentially add some water vapour around the southern part of Indonesia. This process also increased the humidity of air on the surface and upper atmosphere. Eventually, the TC formation in the region of NTT was strongly sustained.

Figure 3. The evolution of the Seroja Tropical Cyclone convective system on 4 to 12 April, 2021 [14]
3.2. The Impact of Tropical Cyclone Seroja to Rainfall in NTT.

One of the significant impacts of TC Seroja is the occurrence of extreme rainfall and strong winds. The extreme rainfall caused flash floods that hit several areas around the watershed which washed away infrastructure especially local houses and casualties.

The red circle in Figure 5 shows the areas that are categorized as being included in the direct impact of TC Seroja named Critical Radius, it occurred on 2 until 5 April, 2021. on 7 April, 2021 was the last time TC Seroja had a direct impact on the East Nusa Tenggara. After that, the region still experienced the indirect impact of TC Seroja.

Figure 4. Sea Surface Temperature (SST) Anomaly in Indian Ocean on 1 to 10 April, 2021

Figure 5. Critical Radius (300 km from the center of Seroja) Seroja's direct impact on precipitation in the surrounding area on 4 April, 2021 at 18.00 UTC and 7 April, 2021 at 00.00 UTC.
Figure 6. Daily rainfall distribution on 3 to 10 April, 2021
Based on Antara News (Tuesday, 6 April, 2021), persistent rainfall and strong winds occurred again on 3 to 4 April, 2021, it is possible that this weather condition triggered the flash flood at 00.30 WIB which hit hundreds of houses in Waiwerang, Adonara Regency, East Flores Regency on Sunday 4 April 2021 at 01.30 WITA in the morning. At a press conference on 5 April, 2021, Doni Monardo stated that Seroja Tropical Cyclone had hit 10 regencies and 1 city in NTT, including Kupang City, East Flores Regency, Central Malacca Regency, Lembata Regency, Ngada Regency, Alor Regency, Sumba Regency East, Rote Ndao Regency, Sabu Raijua Regency, South Central Timor Regency, and Ende Regency. As of Monday, 5 April, 2021, at 14.00 WIB, there have been 68 deaths, 70 people are still missing, 15 were injured, 938 families or 2,655 people were affected by the flood. So far, 25 houses were heavily damaged, 114 houses were moderately damaged, 17 houses were swept away, 60 houses were submerged, 743 houses were affected, 40 access roads were covered by fallen trees, 5 bridges were broken, 1 public facility was affected, and 1 ship sank.

Figure 6 shows the spatial distribution of rainfall around East Nusa Tenggara at the time of TC Seroja. Very heavy rainfall distribution on 4 April, 2021 occurred in a small part of East Manggarai Regency, part of Ngada Regency, part of East Flores Regency, part of Lembata Regency, a small part of Alor Regency, part of Rote Ndao Regency, a small part of Kupang City, a small part of Malacca Regency, and most of Belu Regency; while on 5 April, 2021 it occurred in a small part of Ngada Regency, part of Sabu Raijua Regency, part of Rote Ndao Regency and a small part of Kupang Regency; and for 6 April, 2021 it will occur in parts of Sabu Raijua Regency, a small part of Rote Ndao Regency and a small part of East Sumba Regency.

The distribution of extreme rainfall on 4 April, 2021 occurred in a small part of Ngada Regency, a small part of Alor Regency, a small part of Belu Regency, most of Kupang City, most of Kupang Regency, a small part of Rote Ndao Regency, and a small part of East Sumba Regency; while on April 5 it occurred in most areas of Kupang City, Kupang Regency, and a small part of East Sumba Regency; and on 6 April, 2021 it occurred in some East Sumba Regency. The distribution of this extreme rainfall is also in line with the Seroja Tropical Cyclone track.

Figure 7 shows the comparison of the total rainfall on 4 and 5 April 2021 and the normal monthly rainfall in April.
Figure 7 shows that the occurrence of TC Seroja, causing a very significant increase in the accumulation of the first 10-days rainfall in April, 2021 in almost all areas of NTT by more than 500% compared to the 10-days normal in April in the region. If looking at the comparison between the first 10-days of rainfall in April 2021 and the total normal rainfall in April, it can be seen that the average limit has been exceeded by more than 100% at several observation posts. Furthermore, figure 7 shows that the total rain on April 4 and 5 has exceeded its normal baseline, supporting the hypothesis that TC Seroja causes extreme rain in the NTT region.

Table 1 expos the impact of TC Seroja on the increase in rainfall compared to normal conditions 10-days I on April, 2021 and normal monthly rainfall in April. It can be seen that during the peak of the TC Seroja on 4-5 April 2021, several areas experienced an increase in rainfall far above a-ten days averages and monthly averages. Especially in Kalabahi, the rainfall during TC Seroja accumulated rainfall equivalent to 228.67% compared to normal rain in April, which means that rainfall for two days is equal to 2 times the normal rainfall in April there is an increase in very extreme rainfall. The agreeing case also happened in Aimere (148.59%), Waigete (162.61%), Larantuka (191.94%), Tanarara (124.57%) and Weluli (114.59%).

Table 1. The Comparison of the rainfall average 10-daily I in April, 2021 with the normal rainfall in April in the NTT region.

| No | Name Pos          | Day 1 | Limitang | 4 April 2021 | 5 April 2021 | Normal Days | Normal April | Dasi 1 vs Norm Days | Dasi 1 vs Norm April | Dasi 5 vs Norm Days | Dasi 5 vs Norm April | Variance (%) |
|----|-------------------|-------|----------|--------------|--------------|-------------|--------------|----------------------|---------------------|---------------------|---------------------|---------------|
| 1  | Sawanima Bajo     | 119.9 | -8.49    | 19.7         | 5.4          | 114         | 61           | 100                  | 724                 | 108                 | 24                  | 47            |
| 2  | Weleng            | 119.95| -8.86    | 14           | 19           | 151         | 88           | 254                  | 178                 | 60                  | 30                  | 35            |
| 3  | Sawanima Rantung  | 120.54| -8.6     | 12.5         | 7.4          | 148         | 101          | 437                  | 78                  | 34                  | 20                  | 10            |
| 4  | Tengkaitanic      | 120.54| -8.34    | 30.6         | 12.5         | 172         | 54           | 134                  | 218                 | 126                 | 63                  | 117           |
| 5  | Gapong Sabu      | 120.53| -8.53    | 10.5         | 9.5          | 194         | 99           | 309                  | 387                 | 124                 | 26                  | 26            |
| 6  | Bitungkisa       | 120.54| -8.32    | 7.5          | 3.5          | 211         | 73           | 253                  | 282                 | 99                  | 11                  | 15            |
| 7  | Dusukpulembako   | 120.52| -8.0     | 2            | 6            | 305         | 48           | 170                  | 650                 | 182                 | 9                   | 19            |
| 8  | Mano              | 120.55| -8.55    | 0.2          | 2            | 206         | 192          | 389                  | 135                 | 60                  | 11                  | 7             |
| 9  | Karamesor        | 121    | -8.56    | 107          | 97           | 475         | 127          | 354                  | 371                 | 120                 | 224                 | 136           |
| 10 | Aimere           | 120.85| -8.63    | 42           | 29           | 117         | 23           | 48                   | 518                 | 245                 | 71                  | 314           |
| 11 | Malagogiu         | 121.1 | -8.8     | 14           | 9            | 91          | 90           | 203                  | 101                 | 45                  | 26                  | 29            |
| 12 | Pus Met Ende     | 121.2 | -9.1    | 10.2         | 42.3         | 102         | 44           | 131                  | 231                 | 78                  | 58                  | 130           |
| 13 | Wutubuku         | 121.94| -8.76    | 10           | 22           | 114         | 26           | 97                   | 318                 | 117                 | 42                  | 117           |
| 14 | Latimaukara      | 122.2 | -8.65    | 4.9          | 32           | 94          | 63           | 166                  | 175                 | 89                  | 37                  | 69            |
| 15 | Waigete           | 122.43| -8.65    | 0.9          | 59           | 380         | 51           | 97                   | 757                 | 394                 | 158                 | 312           |
| 16 | Sitarimara Larantuka | 122.97| -8.33   | 14.8         | 14.8         | 241         | 43           | 446                  | 800                 | 399                 | 164                 | 385           |
| 17 | Kalabahi          | 124.53| -8.22    | 12.7         | 83           | 490         | 39           | 126                  | 1279                | 438                 | 243                 | 668           |
| 18 | Pus Met Tambolako | 119.21| -9.41    | 23           | 123          | 54           | 160          | 228                  | 277                 | 77                  | 19                  | 35            |
| 19 | Waisirirupu       | 119.45| -9.54    | 73           | 23           | 106         | 118          | 203                  | 165                 | 65                  | 96                  | 81            |
| 20 | Temu/Mantrang    | 120.13| -9.5     | 5            | 3            | 154         | 37           | 86                   | 413                 | 160                 | 8                   | 21            |
| 21 | Tanarara          | 120.3 | -10.02   | 74           | 83.5         | 387         | 66           | 129                  | 587                 | 306                 | 158                 | 239           |
| 22 | Lambangapu       | 120.28| -9.71    | 44           | 44           | 148         | 52           | 99                   | 283                 | 149                 | 87                  | 167           |
| 23 | Labangrapu       | 120.02| -9.44    | 0.2          | 39           | 254         | 96           | 141                  | 467                 | 187                 | 92                  | 163           |
| 24 | Oilisal           | 124.58| -9.85    | 7            | 19           | 230         | 42           | 152                  | 600                 | 167                 | 88                  | 209           |
| 25 | Noreanmu         | 124.5 | -9.59    | 0.1          | 26.3         | 132         | 38           | 150                  | 507                 | 128                 | 115                 | 303           |
| 26 | Budadakfio       | 124.69| -9.6     | 0.3           | 46           | 256         | 69           | 153                  | 318                 | 156                 | 139                 | 173           |
| 27 | Weluli           | 125.05| -9.34    | 103           | 41.5         | 350         | 52           | 137                  | 392                 | 149                 | 138                 | 301           |
| 28 | Keleksa          | 125.11| -9.63    | 112           | 47           | 216         | 108          | 309                  | 200                 | 70                  | 39                  | 147           |
| 29 | Ranggup          | 120.08| -8.56    | 0            | 27           | 279         | 106          | 362                  | 176                 | 76                  | 32                  | 20            |
Figure 8. Daily rainfall accumulation on 1 to 10 April, 2021 in NTT region.

Figure 8 shows the daily rainfall accumulation before (1 April, 2021), during TC Seroja (2 to 5 April, 2021), and after the TC Seroja moved towards NTT and its surroundings (6 April, 2021). The data displayed in the figure were obtained from several BMKG observation stations in the province of NTT. The TC Seroja caused a significant increase of rainfall accumulation on 1 April in almost all areas of NTT by more than 500% compared to that of the average in April. Some affected areas were East Manggarai, Ngada, Sikka, East Flores, Lembata, Alor, East Sumba, Sabu Raijua, Rote Ndao Regency, Kupang City, Kupang and South of Central Timor Regency. The highest increase in rainfall occurred in Kupang City and Lembata Regency.

The BMKG regional office in NTT reported that these hydrometeorological disasters caused by TC Seroja, i.e., floods, flash floods and landslides, strong winds, affected following regions:
1. Alor Regency (floods, landslides and strong winds)
2. East Flores Regency (flash floods, landslides and strong winds)
3. Lembata Regency (flash floods and strong winds)
4. Sabu Raijua Regency (strong winds, fallen trees, damage to buildings, waves crashing)
5. Kupang City (floods, flash floods, waves crashing, strong winds, landslides, fallen trees, damage to buildings at almost every point in Kupang City)
6. Rote Ndao Regency (strong winds, fallen trees, waves crashing, damage to buildings)
7. Manggarai Regency (Strong Wind)
8. Ende Regency
9. East Sumba Regency (flash floods and strong winds)
10. West Manggarai Regency (Strong Wind)
11. Kupang Regency (flood + flash floods, landslides, strong winds, many access roads to Trans Timor are cut off)
12. Malacca Regency (flood + flash floods, strong winds, bridges collapsed due to floods, landslides)
13. South Central Timor Regency (landslides and strong winds)
14. Belu Regency (floods, tidal floods, flash floods, strong winds, landslides, waves crashing on the north coast)
15. North Central Timor Regency (strong winds, landslides, fallen trees, floods)
16. Sikka Regency (tidal flood).

3.3. The Impact of TC Seroja to Sea Wave Heights.
Figure 9, indicates the maximum sea wave height on 1 to 9 April, 2021 in southern of NTT waters.

Figure 9. Maximum Sea Wave Height on 1st – 9th April, 2021 in southern of NTT
On 1 April, 2021, before TC Seroja occurred, the impact of sea wave heights has been seen in the south of NTT waters, the maximum wave height in the southern waters of NTT reached 4 meters, and the maximum wave height increased on 3 April, 2021 more than 6 meters. During the TC Seroja phenomenon, on 4 to 6 April, 2021 there was an increase in extreme wave heights in the Sawu Sea and in the south of NTT waters. On 7 to 9 April, 2021, after TC Seroja moved away to the South, and the wave heights in the Sawu sea and south of NTT decreased (Figure 9).

The impact of the tropical cyclone can reach thousands of kilometers in the ocean. On 6 April, 2021, a wave height of up to 7 meters occurred around the center of a tropical cyclone with a fairly large area, although the cyclone category has the same value, the wave height caused by the circulation of the tropical cyclone varies according to each growth phase of tropical cyclone.

4. Conclusions
The impact of the TC Seroja phenomenon has affected the intensity of extreme rainfall in the NTT region that occurred on 4 April, 2021, covering the Ngada, Alor, Belu, Kupang, Rote Ndao, and East Sumba regions. Meanwhile, on 5 April, 2021, extreme rainfall occurred in Kupang and East Sumba. On 6 April, 2021, extreme rainfall still occurred in East Sumba Regency. This extreme rainfall triggered flooding in several areas, including Alor, East Flores, Lembata, Kupang, East Sumba, Malacca, Belu, and North Central Timor.

The activity of the TC Seroja also has an impact on wave heights in the southern waters of NTT. On 1 April, 2021 the height of the waves reached 4 meters, On 3 April, 2021 the height of the sea waves increased and reached up to 6 meters. On 4-6 April, 2021 the sea wave height reaches 7 meters, and potentially more than 7 meters. Meanwhile, on 7-9 April, 2021, the wave height in the waters of NTT has begun to decay as the TC Seroja moves away from the NTT area to the southwest.

Reflecting on the occurrence of tropical cyclones that have a negative impact on people’s lives, it is necessary to increase the dissemination of an early warning system that is fast and affordable to the public.

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