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Quantifying the Relationship Between ENSO-Induced SST Anomalies and Rainfall Variability in East Java's Coastal Regions

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Abstrak

Fenomena El Nino and La Nina mempengaruhi kondisi musim hujan and musim kemarau terutama sebagai penyebab terjadinya banjir di wilayah pesisir. Pantai Utara Jawa merupakan wilayah pesisir dengan jumlah penduduk padat mengakibatkan rawan terhadap bencana akibat pengaruh anomali muka air laut yang disebabkan oleh interaksi antara laut and atmosfer. Salah satu wilayah yang sering terdampak adalah pantai utara Jawa Timur yang berbatasan langsung dengan pantai memiliki tingkat kerawanan yang tinggi terhadap bencana banjir rob. Penelitian ini bertujuan untuk mengkaji pengaruh indeks Nino 3.4 pada fase El Nino and La Nina dalam mempengaruhi curah hujan di pantai utara Jawa Timur khususnya di wilayah Tuban, Lamongan, Gresik, Kota Surabaya, Sidoarjo, Pasuruan, Probolinggo, and Situbondo. Korelasi antar parameter curah hujan dan indeks Nino3.4 digunakan mengetahui hubungan antar parameter. Hasil penelitian menunjukkan pada saat kondisi La Nina memiliki nilai korelasi negatif yang rendah sekitar -0.01 sampai -0.43 serta hanya di Sedayu, Ujung Pangkah and Stamet Perak II and Winangan Lor yang memiliki nilai korelasi positif dengan nilai korelasi 0.01 sampai 0.31. Sedangkan fase El Nino memiliki nilai korelasi negatif yang rendah sekitar -0.03 sampai -0.51 serta nilai korelasi positifnya antara 0.07 sampai 0.33. Pada kondisi Netral memiliki korelasi negatif di semua wilayah dengan nilai antara -0.04 sampai 0.17. Kesimpulannya adalah hampir semua wilayah penelitian memiliki nilai korelasi yang rendah dan negatif yang bermakna ketika curah hujan bernilai tinggi maka pada fase La Nino dan fase El Nino bernilai rendah.

Abstract

El Nino and La Nina phenomena affect the conditions of the rainy season and dry season, especially as a cause of flooding in coastal areas. The North Coast of Java is a coastal area with a dense population that is prone to disasters due to the influence of sea level anomalies caused by the interaction between the sea and the atmosphere. One of the areas that is often affected is the north coast of East Java which is directly adjacent to the coast has a high level of vulnerability to tidal floods. This study aims to examine the influence of the Nino 3.4 index in the El Nino and La Nina phases in influencing rainfall on the north coast of East Java, especially in the Tuban, Lamongan, Gresik, Surabaya City, Sidoarjo, Pasuruan, Probolinggo, and Situbondo areas. Correlation between rainfall parameters and Nino3.4 index is used to determine the relationship between parameters. The results showed that during La Nina conditions had a low negative correlation value of around -0.01 to -0.43 and only in Sedayu, Ujung Pangkah and Stamet Perak II and Winangan Lor which had a positive correlation value with a correlation value of 0.01 to 0.31. While the El Nino phase has a low negative correlation value of around -0.03 to -0.51 and a positive correlation value between 0.07 to 0.33. Neutral conditions have a negative correlation in all regions with values between -0.04 to 0.17. The conclusion is that almost all research areas have low and negative correlation values, which means that when rainfall is high, the La Nino phase and the El Nino phase are low.

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INTRODUCTION

Coastal areas, especially in Indonesia, have a significant economic role because they are the center of fisheries, transportation, and densely populated settlements. However, this area is very vulnerable to global climate change, especially in the form of changes in rainfall patterns that have an impact on coastal dynamics which will cause flooding (Asyam et al., 2024; Yustiana et al., 2023; Ainurrohmah and Sudarti, 2022; Irrgang et al., 2022; Toimil et al., 2020). Globally, the phenomena that influence rainfall in coastal areas of Indonesia include the Nino3.4 index which consists of El Nino and La Nina (Purnama et al., 2018), Dipole Mode and Madden Julian Oscillation (Giarno et al., 2020). Meanwhile, regional factors, Monsoon and Inter Tropical Convergence Zine (ITCZ) are indicators that influence the weather and climate in coastal areas of Indonesia (Du et al., 2023; Chand et al., 2023).

The Nino 3.4 index is a scale used to define El Nino and La Nina events (Norel et al., 2021). The threshold value of the Nino 3.4 index is categorized as weak with sea surface temperature anomalies in the range (0,5 – 0,9), moderate (1,0 – 1,4), strong (1,5 -1,9) and very strong (≥2,0). Different categories based on the Meteorology, Climatology and Geophysics Agency in the moderate category are in the range (1,0 – 2,0) and the strong category is in the range >2. El Nino Southern Oscillation is an oscillatory phenomenon between the El Nino phase and the La Nina phase (Timmermann et al., 2018). El Nino is a positive phase of ENSO that occurs when the sea surface temperature (SST) in the central and eastern tropical Pacific is warmer than normal (Haryanto et al., 2021). Meanwhile, La Nina is a negative phase of El Nino Southern Oscillation (ENSO) which occurs when the sea surface temperature (SST) in the central and eastern tropical Pacific Ocean is colder than normal conditions (Hidayat et al., 2021; Wang et al., 2017).

El Nino and La Nina events have a strong impact on the annual variation of rainfall (Deepa et al., 2018). When there is an interaction between the ocean and the atmosphere that produces El Nino, the Indonesian region will experience drought due to the movement of water mass in Indonesian waters to the West Indian Ocean and the East Pacific Ocean (Hasibuan et al., 2023). However, when the La Nina phenomenon occurs, it will cause a rainy season due to the increase in water mass moving from the West Indian Ocean and the East Pacific Ocean to Indonesian waters, especially in the northern and southern regions of Java (Karlina and Johan, 2020).

Research on the Nino3.4 index and its relationship to rainfall has been conducted Luluun et al., (2018) in his research stated that the El Nino Southern Oscillation phenomenon when in the La Nina phase causes increased rainfall in the Probolinggo area. In addition, the El Nino Southern Oscillation phenomenon also causes a longer dry season in the Bojonegoro area (Mulyanti, 2023). Bimaprawira and Rejeki (2021) found that the El Nino Southern Oscillation phenomenon affects rainfall in the coastal areas of Lamongan, East Java.

The North Coast of Java is a coastal area that is prone to disasters due to the influence of sea level anomalies caused by the interaction of the sea and atmosphere from the Pacific and Indian Oceans (Rahmawan, 2020). This is in accorandce with research conducted by Hidayat et al., (2018) stated that the El Nino Southern Oscillation phenomenon has a high impact and correlation on rainfall in the SON period (September-October-November) in the Semarang area. In addition, research by Santoso et al., (2017) explained that El Nino Southern Oscillation is dominant in the JJA (Juny-July-August) – SON (September-October-November) period with negative rainfall anomaly characteristics in most parts of Indonesia. However, in the DJF (December-January-February) – MAM (March-April-May) period, having a positive rainfall anomaly value does not have a significant effect on decreasing rainfall in Indonesia (Rodysill et al., 2019).

The northern coastal areas of East Java that directly border the coast such as Tuban, Lamongan, Gresik, Surabaya City, Sidoarjo, Pasuruan, Probolinggo, and Situbondo have a high level of vulnerability to tidal flooding or rob disasters. This is in line with research by Mulyana (2002), mentioned that during the La Nina phase, rainfall on Java Island increases, including at several points in East Java Province. In addition, based on a book issued by the National Disaster Management Agency (BNPB), the Probolinggo area has a high index in the disaster risk category. This is expected to be a concern for local governments in making policies in disaster management efforts at the regional level.

This study aims to examine the influence of the Nino 3.4 index on the El Nino and La Nina phases in influencing rainfall on the north coast of East Java, especially in the areas of Tuban,

Lamongan, Gresik, Surabaya City, Sidoarjo, Pasuruan, Probolinggo, and Situbondo.

Hopefully the results of this study can provide scientific contributions to the understanding of coastal dynamics in Indonesia, especially the north coast of East Java and be used as a consideration for making climate forecasts on the north coast of East Java.

METHODS

This study was conducted on the North coast of East Java, excluding Madura Island. The study was conducted in 8 districts or cities directly adjacent to the coastline, each with one rain post as a source of observation data, namely Tuban, Lamongan, Gresik, Surabaya, Sidoarjo, Pasuruan, Probolinggo, and Situbondo, as seen in Figure 1.

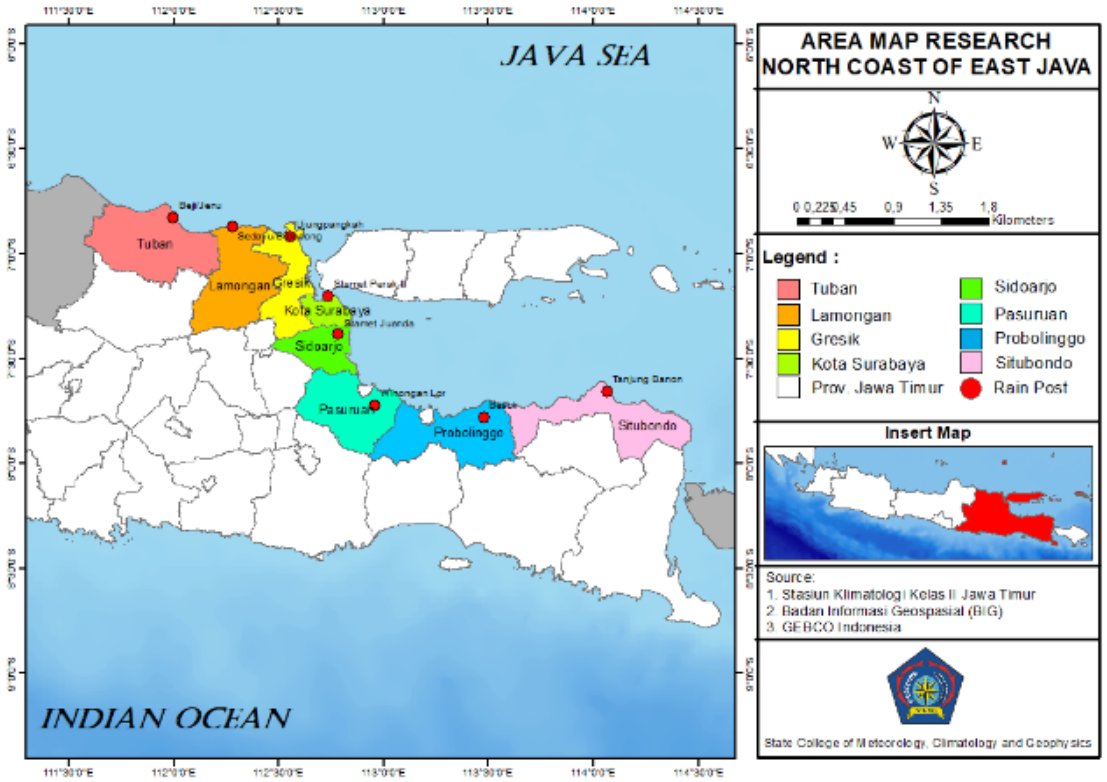


Figure 1. Map of observation locations

This study uses monthly rainfall data for the period 1991 - 2020 from 8 rain observation post locations in 8 districts or cities on the north coast of East Java, namely the Juanda Meteorological Station, Perak II Meteorological Station, Beji/Jenu Rain Post, Sedayu/Brondong Rain Post, Ujung Pangkah Rain Post, Winongan Lor Rain Post, Besuk Rain Post, and Tanjung Baron Rain Post. Next, the monthly Nino 3.4 sea surface temperature anomaly data (SST Index Nino 3.4) taken from the NOAA website (https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/nino34.long.anom.data) with a resolution of 1o x 1o. The use of this resolution aims to produce more accurate data because the smaller the resolution of the satellite used, the more it describes the conditions on the surface. Land use delineation uses ArcMap software. According to Wright et al. (1980), several aspects need to be assessed for determining land use classification: (i) the classification system can be applied to large areas; (ii) the classification system can be interpreted from land cover; and (iii) the classification system can be used with remote sensing data. This reference becomes the basis for determining land use classification using zone types from The East Sleman Detailed Spatial

From this analysis, a correlation coefficient of the relationship between rainfall and ENSO index. The correlation value between these two parameters can be calculated using the following formula:

$$r_{xy} = \frac{n\sum xiyi - (\sum xi)(\sum yi)}{\sqrt{(n\sum xi^2 - (\sum xi)^2) - ((n\sum yi^2 - (\sum yi)^2)}}$$

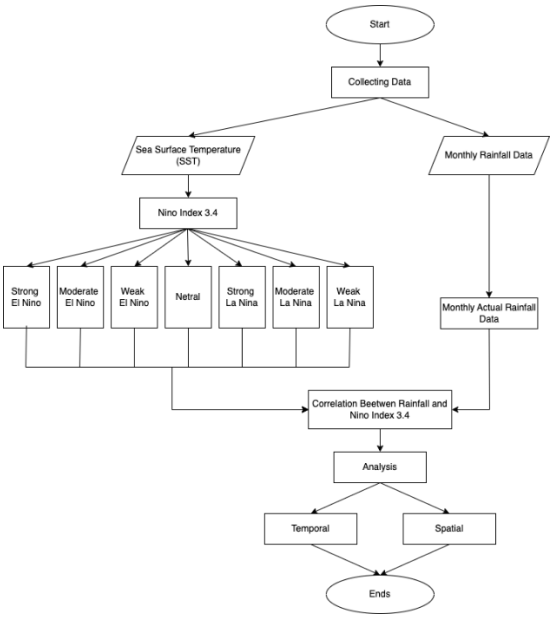
Information: r (pearson correlation coefficient), x (Nino 3.4 index), y (rainfall from 8 sites) and n (number of samples).

With the interpretation of the r value (correlation coefficient).

Table 1. *R value (correlation coefficient)*

R Value (Correlation)	Description
0,00 - 0,199	Very Weak
0,20 - 0,399	Weak
0,40 - 0,599	Moderate
0,60 - 0,799	Strong
0,80 - 1,000	Very strong

The flow diagram of this research is as follows:



The flowchart in this study illustrates the framework for analyzing the relationship between the Nino 3.4 index and monthly rainfall using temporal and spatial approaches. The process begins with the data collection stage, which includes sea surface temperature (SST) data and monthly rainfall data. SST data is used to calculate the Nino 3.4 index, which represents ocean temperature variability in the tropical Pacific region. Furthermore, the Nino 3.4 index is categorized into El Nino (strong, moderate and weak), Neutral, and La Nina (strong, moderate and weak). This categorization allows the identification of ENSO (El Nino-Southern Oscillation) phases that affect rainfall patterns.

Actual monthly rainfall data was then analyzed to evaluate the correlation with the Nino 3.4 index. The analysis includes both a temporal approach, which focuses on changes in the relationship over time, and a spatial one, which focuses on the geographical distribution of the correlation. The framework concludes with an interpretation of the results that is expected to provide a more comprehensive understanding of the impact of the ENSO phenomenon on rainfall variability.

RESULTS AND DISCUSSION

1. The relationship between La Nina events and rainfall

The occurrence of the Nino 3.4 index with the Strong La Nina category during the period 1991-2020 was recorded 14 times. The correlation between rainfall and the Nino 3.4 index during the Strong La Nina event on the north coast of East Java was predominantly negative, insignificant, and ranged from moderate to very low. This is indicating that the increase in the Nino 3.4 index was inversely proportional to the rainfall value.

The correlation value at the Stamet Perak II and Winongan Lor observation posts was less than 0.2, indicating a very low level of relationship. Meanwhile, in Tanjung Banon it was -0.43, indicating a negative value with a moderate correlation level and other areas had negative values with correlation levels between very low to low, including the Beji, Sedayu, Ujungpangkah, Stamet Juanda, and Besuk observation posts. The significance value indicates that the Strong La Nina event had no effect on rainfall variations on the North Coast of East Java.

In the Weak La Nina category, there were 59 recorded events. Generally, the correlation value of rainfall with the Nino 3.4 index during the Weak La Nina event on the north coast of East Java was negative and insignificant with a very low to low correlation level. Meanwhile, only at the Ujungpangkah observation post has a positive value of 0.05 and at the Stamet Juanda II observation post has a significant negative value. While at other posts there is a negative correlation with values between -0.1 and -0.23. This shows that the occurrence of Weak La Nina generally does not affect the variation of rainfall on the North Coast of East Java.

During the Moderate La Nina event, the correlation value between the Nino 3.4 index and rainfall on the North Coast of East Java is negatively correlated at the Beji, Ujungpangkah, Stamet Juanda, Winongan Lor, Besuk and Tanjung Banon observation posts and positively correlated at the Sedayu and Stamet Perak II observation posts.

During the Moderate La Nina event, the dominant correlation value is less than 0.2, which means that the relationship between the Nino 3.4 index and rainfall is very low. However, at the Tanjung Banon observation post it is -0.4 indicating an inverse relationship with a moderate relationship level and at the Sedayu

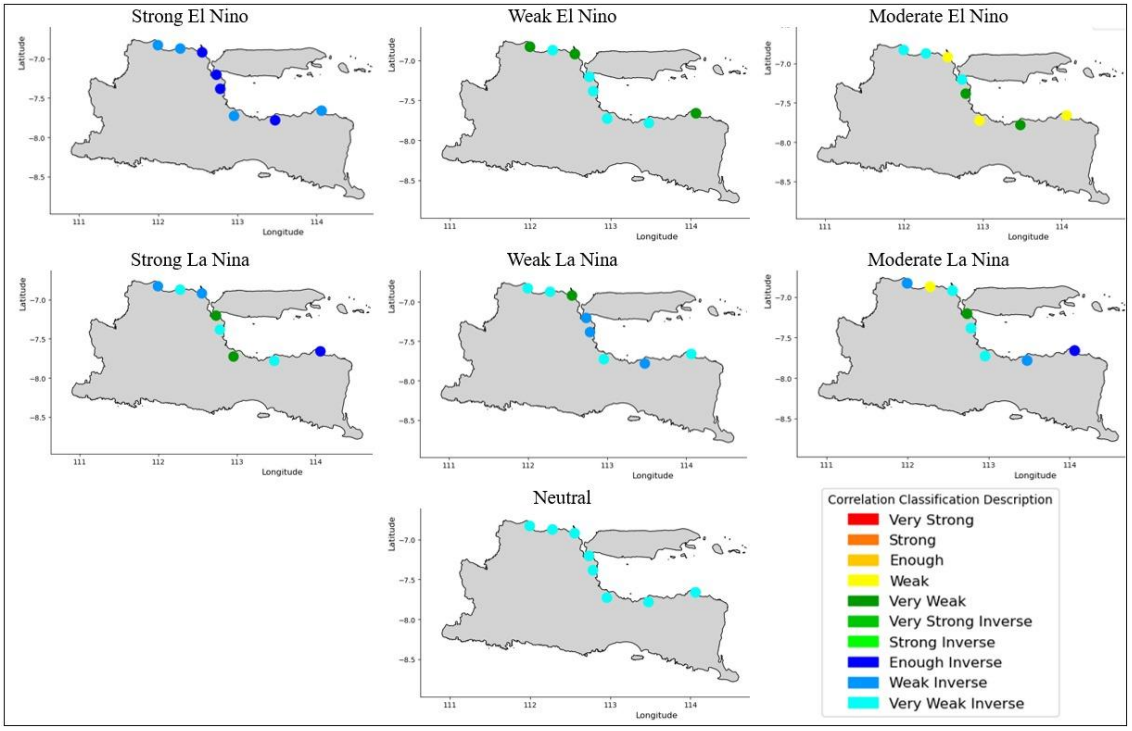


Figure 2. Figure Spatial map of El Nino, La Nina, and Neutral conditions in Strong, Weak and Moderate phase

Table 2. *Correlation values in the Strong El Nino, Weak El Nino, Moderate El Nino, Strong La Nina, Weak La Nina, Moderate La Nina, and Netral Phase*

Condition/ Observation Post	Beji	Sedayu	Ujung pangkah	Stamet Perak II	Stamet Juanda	Winongan Lor	Besuk	Tanjung Banon
Strong El Nino	-0.32	-0.39	-0.51	-0.46	-0.5	-0.32	-0.45	-0.38
Weak El Nino	0.1	-0.09	0.09	-0.12	-0.02	-0.13	-0.03	0.07
Moderate El Nino	-0.03	-0.05	0.23	-0.13	0.05	0.33	0.08	0.31
Strong La Nina	-0.36	-0.18	-0.24	0.08	-0.02	0.01	-0.19	-0.43
Weak La Nina	-0.1	-0.11	0.05	-0.22	-0.28	-0.18	-0.23	-0.15
Moderate La Nina	-0.03	0.31	-0.13	0.08	-0.01	-0.18	-0.2	-0.4
Neutral	-0.17	-0.11	-0.11	-0.09	-0.02	-0.04	-0.11	-0.13

observation post the correlation level is low with a value of 0.31 but not significant.

The results of the analysis show that during the La Nina event, both strong, weak and moderate categories generally do not have a significant effect on rainfall variations on the coast of East Java. Furthermore, the negative values indicate that an increase in the Nino 3.4 index is inversely correlation with rainfall values. Research by Simanjuntak, (2022) in Malang, East Java, revealed that rainfall patterns during La Nina events tend to be very fluctuating. Meanwhile, Renitasari et al., (2023) stated that the intensity of rainfall in Surabaya increased compared to the normal average during the La Nina phase. Correlation analysis by Sutikno and Anisa (2015), shows that most of the rainfall in East Java does not have a close relationship with the ENSO indicator, the rainfall pattern and ENSO indicator make it difficult to explain the significance of the relationship between the two. Research by Bimaprawira and Rejeki (2021) shows that rainfall in the East Java Coast is more influenced by the monsoon which has an annual periodicity and is more consistent than El Nino Southern Oscillation phenomenon.

2. The relationship between El Nino Events and Rainfall

The strong El Nino event seen through the Nino 3.4 index in the 30-year period from 1991 to 2020 was recorded 10 times. Based on previous research, the correlation value of rainfall with the Nino 3.4 index conducted in Central Java had a very low to low value with a positive relationship (Abdullah, 2021). Where these results are not in line with the results of the correlation of rainfall with the Nino 3.4 index on the North Coast of

East Java which has a negative value at all observation points. Where the negative value in this correlation states that when the Nino 3.4 index value increases, the rainfall value in the research area decreases. This is in line with research conducted by Hidayat et al., (2018) which states that negative values occur in the correlation between rainfall and the Nino 3.4 index in the coastal areas of Central Java.

Quite strong values were obtained from 4 out of 8 observation points in Ujungpangkah, Stamet Perak II, Stamet Juanda, and Besuk and 4 others in Beji, Sedayu, Winongan Lor, and Tanjung Banon had weak values. Indicates that the rainfall value in the northern coastal areas of East Java is quite affected by the Nino 3.4 index event during a strong El Nino. Weak El Nino events were recorded 53 times.

The correlation value between rainfall and the Nino 3.4 index during weak El Nino events had very weak values throughout. This shows that the impact of weak El Nino on rainfall is relatively small or inconsistent at each station.

During weak El Nino, the effect of reducing rainfall in Indonesia is not very significant, because the sea surface temperature anomaly in the Central Pacific is not strong enough to drastically affect wind patterns (Ashok et al., 2007).

The neutral phase occurs when the Nino3.4 index does not show significant anomalies towards either El Nino or La Nina. Overall, it has a negative correlation. This indicates a tendency for sea surface temperatures (SST) in the Central and Eastern Pacific regions to be slightly colder than average.

The overall correlation value in the neutral phase is in the very low category (0.02 - 0.17) as in the reference Table 1. Overall, for the correlation value in each phase, it can be seen in Table 2.

CONCLUSION

In determining the correlation between the Nino3.4 index and rainfall in the northern coastal area of East Java, a correlation test is used to analyze patterns between variables. The relationship between rainfall variations in the northern coastal area of East Java and the Nino3.4 index has varying levels of correlation consisting of moderate - very low for each location area. Overall, the correlation value of the Nino3.4 index with rainfall is a negative correlation which means that when the value of the Nino 3.4 index increases, rainfall decreases. The overall significance is not significant except in the area of Juanda Meteorological Station during weak La Nina and in the Beju area during neutral conditions. Future research should consider expanding the analysis to other coastal areas, using more observation points and investigating other weather or climate phenomena that affect rainfall variability. For overall significance, it is not significant except in the Juanda Meteorological Station area when La Nina is weak and in the Beju area when conditions are neutral.

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