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Analysis of Land and Sea Temperatures Trend During 1985-2021 Period to Understand Local or Global Warming Effect in Bengkulu City

Arya J Akbar, Ashar Muda Lubis*
Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Bengkulu, Indonesia
Email: asharml@unib.ac.id

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ABSTRACT

Global warming is a phenomenon where the earth's temperature rises drastically. The temperature increase causes negative impacts on the environment globally. Bengkulu City, Indonesia, is situated with a growing population and land-use change that may cause temperature rise. This research aimed to analyze the temperature change in the land and sea area of Bengkulu City. To understand the local or global factors influencing temperature changes in Bengkulu City, we also studied the correlation between land and sea temperatures. The temperature data were obtained from BMKG and NOAA PSL. Firstly, we analyzed the temperature trendlines for the last 36 years. Then we evaluated the coefficient determination (R^2) value to determine the correlation between sea and land temperatures. The results show that during the last 36 years, the sea temperature is increased by 0.40 °C, while the land temperature is increased by 1.07 °C. Moreover, we found a relatively weak correlation between sea and land temperature, with a 10.7% correlation. We argued that the increased temperature in Bengkulu City land is associated with land change use and rising population in the last few decades, which means the local factor affected the land temperature changes. On the other hand, global phenomena (IOD and ENSO) influenced sea temperature changes, which means the global factor affected the sea temperature changes. The rising land temperature is relatively high; hence it is necessary to understand better what parameters are causing temperature changes that may affect the physical environment in Bengkulu, Indonesia.

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I. Introduction

Land and ocean temperatures are critical factors in understanding the earth's weather behavior, such as the global warming phenomenon. Recent studies show that human activities can contribute significantly to CO_2 emissions that may impact global warming, causing likely harm to ecosystems and humans [1]. Moreover, rising temperatures may be associated with the occurrence of forest fires. For example, Indonesia experienced forest fires covering more than 3 million hectares of land in five years (2014-2019) [2], affecting our oxygen supply besides burning fossil fuels that release large amounts of CO_2.

Climate change can impact biological growth, such as the production and growth of animals and plants, as well as the diversity of biological, physical, and chemical that may affect the sustainability of life on the earth. Climate change also significantly impacts the growth of crops such as maize, wheat, and rice worldwide [3]–[5]. The temperature increase of the earth's surface temperature on a global scale augmented the indication of climate change due to global warming. The temperature and Diurnal Temperature Range (DTR) are essential indicators for detecting recent climate change [6]–[8]. Currently, the increase in temperature due to global warming is felt globally almost everywhere on the earth. The increase in temperature also becomes one of the indications of climate change where the earth's surface temperature increases on a global scale. The Intergovernmental Panel on Climate Change (IPCC) previously reported that the earth's

temperature rose 0.99 (0.84 to 1.10) °C higher during the first two decades of the 21st century (2001-2020) compared to the period 1850-1900 [9].

The increase in temperature will have various destructive impacts on the environment. High temperature melts ice in the polar. Melted ice causes sea-level rise, increasing the potential for flooding in coastal areas [10]. High temperatures cause extreme evaporation, resulting in high precipitation, which causes climate change and also increases the potential for flooding [11]. High temperatures can also cause droughts that trigger forest fires. Research shows that every 1 degree Celsius increase in temperature will increase the relative forest burned area by approximately 54.65% [12]. On the other hand, rising temperatures will indirectly affect the availability of food and clean water, settlements and public facilities, public health, and economic activities [13].

Since Indonesia is on and near the equator, monitoring the surface temperature is essential to detect global warming/global climate change exists or not. In addition, previous research has shown that Indonesia is one of the countries that will experience a high-temperature rise in this century [14]. Furthermore, on the west coast of Indonesia, Bengkulu Province, located in Sumatra near the equator, is also experiencing the impact of global warming. From satellite data, we know that Bengkulu experienced a fairly high-temperature increase at the beginning of the 21st century [15]. Temperature change in Bengkulu may be related to increased industrial, mining, and plantation activities. For example: currently, as we may know, Bengkulu is one of the palm oil producers in Indonesia [16]. At the same time, oil palm plantations are one of the causes of global warming because oil palm plantations are a massive source of nitrous oxide (greenhouse gas) [17]. In addition, Bengkulu is one of the largest coal mines in Sumatra, with 3.02 million tons of coal mined in 2017 [18]. A mining activity such as coal mining causes an increase in temperature in an area due to land-use change [19]. Furthermore, the use of coal as an energy source for the electric steam power plant (PLTU) in Bengkulu City since 2021 can produce greenhouse gases in the atmosphere.

Since the Bengkulu area is at risk of the global warming effect, it is necessary to analyze the present trend of temperature change in Bengkulu City. This study aimed to investigate temperature change on land and sea in Bengkulu City over the last several decades. We also studied the relationship between land and ocean temperatures to understand the change better. This study will be beneficial as one indicator and benchmark for how local or global warming exists in Indonesia, particularly Bengkulu City.

II. Theory

Global Warming

Global warming is an increase in the earth's temperature globally. Temperature increases in the atmosphere, sea, and land [20]. The presence of greenhouse gases causes global warming that retains heat from the sun's energy. The greenhouse gases include carbon dioxide (CO_2), Sulfur hexafluoride (SF_6), Methane (CH_4), Nitrous oxide (N_2O), and others [19]. Human activities are the main factor in greenhouse gases' high concentration nowadays [21].

Regression Analysis

Regression analysis is a method widely used in the world of science to determine the relationship between two or more variables [22]. Regression analysis is used to understand a dependent variable. Meanwhile, the independent variable is assumed to affect the dependent variable. Linear regression can be used to see the trendline of a dependent variable [23].

Data Preprocessing

Data pre-processing is a technique to improve raw data [24]. Raw data can be incomplete, contain outliers and have noise values [25]. Data outliers are strange or unexpected data; missing data are records containing missing fields or blank data, whereas noisy data contain irrelevant or unnecessary data [26]. Data pre-processing includes data cleaning and data reduction to reduce data errors in the data [27].

III. Method

The data used in this study were daily temperature data from the Bengkulu City area during the past 36 years (January 1985-August 2021) obtained from two sources. Firstly, we accessed land surface temperature data from the Bengkulu Province Meteorology, Climatology, and Geophysical Agency (BMKG). The temperature data were obtained through thermometer measurements in a weather cage at an altitude of 1.25 m above the ground surface. The NOAA SST V2 High-Resolution Dataset represented sea surface temperature data obtained from the NOAA Physical Sciences Laboratory page in *.nc format. The sea surface temperature data have a 0.25° latitude x 0.25° longitude resolution [28], [29]. Figure 1 shows the land and sea surface temperature locations used in this study.

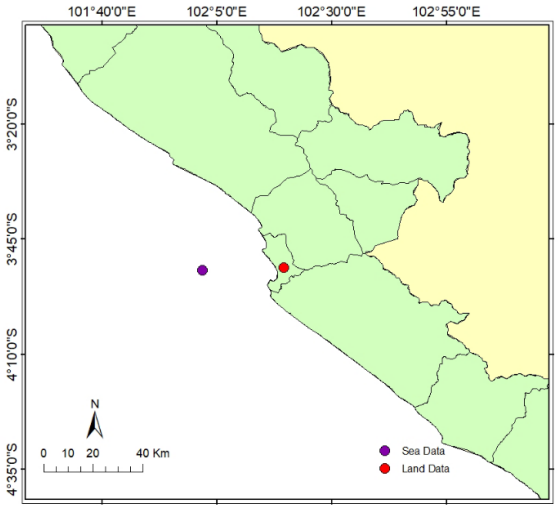

Figure 1. Map of station and data point in the research area.

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Next step, we applied data pre-processing for the temperature data obtained from BMKG and NOAA. Since the NOAA data is in *.nc format, it needs to be changed to match the BMKG data format (.txt format). This step also included data cleaning and data reduction. The noisy data can later affect our analysis. Hence it is necessary to pay attention to data quality, outliers, and missing data. Data cleaning also needs to be performed for some data.

We used linear trend analysis to investigate the trend temperature change in Bengkulu City [30]. The trendline of temperature changes can be used to determine how the average temperature increased during the last 36 years. We used the least-squares regression method to see the trendline of temperature changes. The formula for the trendline is given by

$$\hat{y}_i = a + bX_i, \tag{1}$$

Where Y_i is *i*th temperature data, $\hat{y}_i$ is predicted *i*th data value of temperature data, X_i is *i*th time in the day, a is the intercept value, and b is a coefficient representing temperature change (increase or decrease). n is the total data, and the value of b represents the changes rate of temperature data over time [31], estimated from

$$b = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sum_{i=1}^{n}(X_i - \bar{X})^2} \tag{2}$$

We gained the intercept value by putting the average data value as $\hat{y}_i$ and X_i to Equation (1). We obtained the average data with the formula

$$\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i. \tag{3}$$

Mean Square Error (MSE) and Root Mean Square Error (RMSE) are used to evaluate the accuracy of the data results. MSE and RMSE can be used to detect if any outlier data need to be clean in the data with the equations

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{y}_i)^2, \tag{4}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{y}_i)^2}, \tag{5}$$

In the next step, we calculated the temperature data anomaly $Y_{i\ anomaly}$. Data anomaly calculated by

$$Y_{i\ anomaly} = Y_i - \bar{Y}. \tag{6}$$

The daily land and sea temperature data distributions were analyzed using a normal distribution. We used the normal distribution to see the accuracy of the processed data [33], which can be identified from the normal distribution curve and estimated by

$$F(Y_i) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(Y_i-\bar{Y})^2/2\sigma^2} \tag{7}$$

We found the relationship between sea and land temperature rise by making a scatter plot of data anomaly. The value of R^2 (coefficient of determination) determines how strong the correlation between land and sea temperatures is. R^2 described by

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}. \tag{8}$$

The coefficient of determination value represents the variation of dependent variables explained by independent variables [34]. If the value is close to zero, the correlation is weak, whereas if the value is close to one, the correlation is strong [35].

IV. Results and Discussion

During 1985-2021, the city of Bengkulu experienced temperature changes, as illustrated in Figures 2A and 2B. The average temperatures for 36 years were 26.459 °C based on air temperature on land and 29.035 °C based on sea surface temperature on the sea. The straight lines in Figure 2 are the trendlines of daily temperature in Bengkulu City. The trendlines represent the temperature changes for 36 years.

The sea surface temperature changes show an increase in temperature in the sea around Bengkulu City. The rise in temperature in the sea is 0.401 °C. The land temperature change depicted in Figure 2B shows a significant boost for 36 years in the sea around Bengkulu City with a relatively stable graph compared to sea surface temperatures. The increase of temperature on land is 1.071 °C. The temperature increases in both places are quite significant, so it is necessary to pay attention and prepare how to deal with the adverse effects of this rising temperature on society in the future.

If we look at Figure 2D, land temperature data are well distributed. Most of the land temperature data are under the normal distribution bell. Figure 2C shows that the sea temperature data are not as well distributed as the land temperature data because many data are outside the curve. The data outside the normal distribution curve are possible outliers [36]. Although the data are conceivably outliers, we cannot remove the data because some conditions make outliers better not to remove. The requirements not to remove outliers are when there are many outliers, and the outliers are critical for analysis [37]. The values of the temperature data are still reasonable. In addition, the RMSE value of land and sea temperature data are 0.86 and 1.04. Due to these reasons, we kept the data outside the normal distribution curve for the following analysis.

In order to understand the relation between sea and land temperature, it is necessary to see the temperature increases in the range of minimum and maximum value. Figure 3 shows the sea and land temperature graph in monthly mean, maximum, and minimum temperature,

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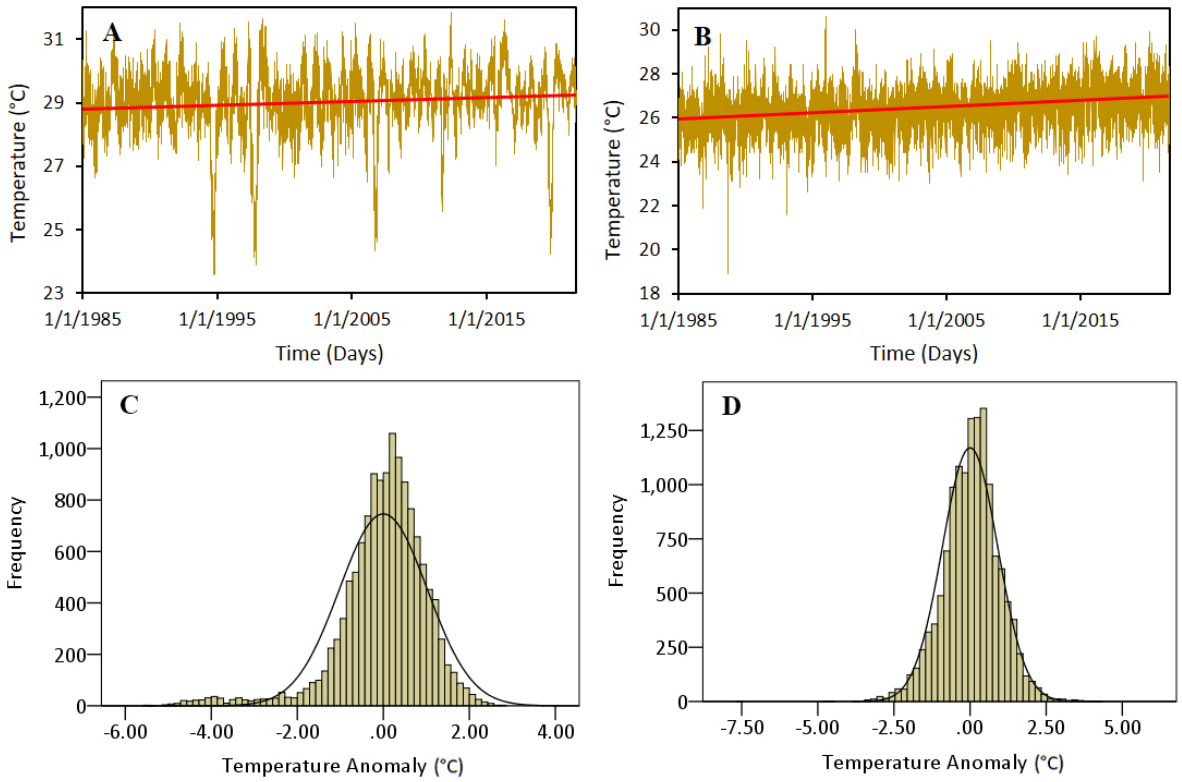

Figure 2. A Graph of sea temperature rise from BMKG station data, B Graph of the increase in land temperature from the NOAA SST V2 High-Resolution Dataset NOAA PSL data, C Normal distribution of sea temperature data, D Normal distribution of land temperature data.

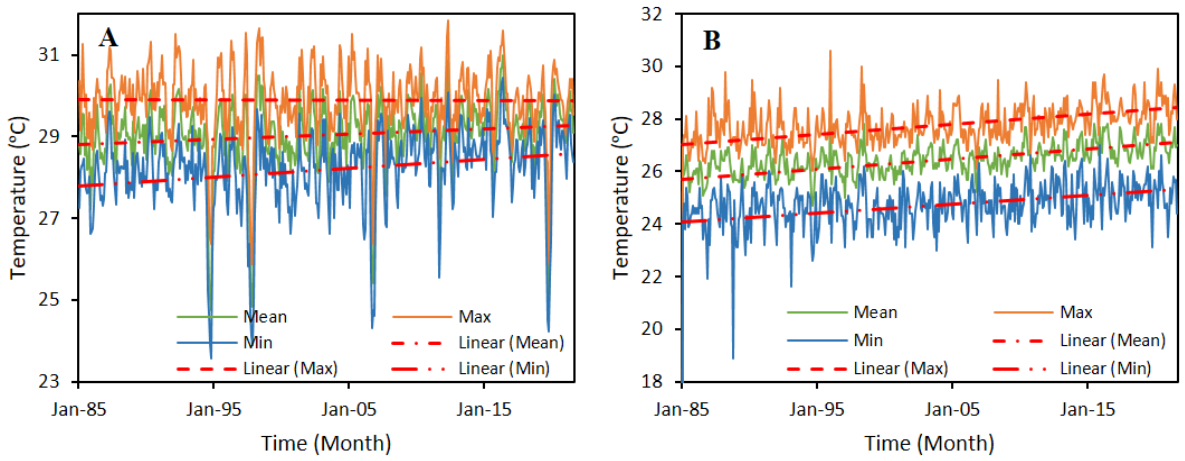

Figure 3. A Graph of sea temperature monthly (mean, maximum, and minimum temperature), B Graph of land temperature monthly (mean, maximum, and minimum temperature)

where the dash lines describe the trendline. From Figure 3A, it is observed for the last 36 years period that the monthly mean sea temperature increased by 0.401°C, the monthly maximum sea temperature fell by 0.005°C, and the monthly minimum sea temperature rose by 0.803°C. Whereas Figure 3B shows results for 36 years the monthly mean land temperature rose by 1.071°C, the monthly maximum land temperature rose by 1.071°C, and the monthly minimum land temperature rose by 0.937°C.

The scatter plot in Figure 4 shows the relationship between sea and land temperatures, where sea temperature is the fixed variable, and land temperature is the dependent variable. The linear regression lines show a correlation between both variables. From the coefficient determination (R^2) value, we know that the daily data

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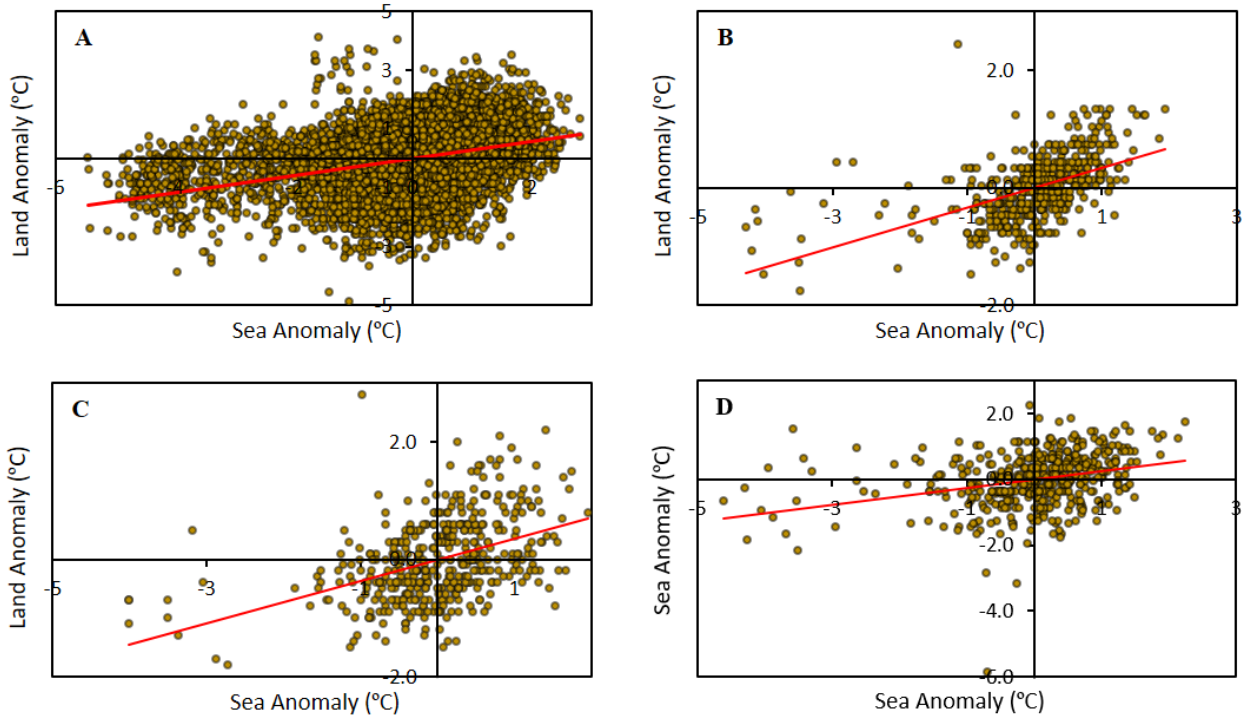

Figure 4. Relation between land and sea temperature rise anomaly (A. Daily data anomaly, B. Mean monthly data anomaly, C. Maximum monthly data anomaly, D. Minimum monthly data anomaly)

anomaly correlation is 10.7%, while the mean monthly data anomaly value correlation is 28.5%. The correlation of monthly data is higher because monthly total data is less than the total daily data; many data cause high variance and lower the correlation in this data. The maximum and minimum monthly data anomaly correlations in land and sea are 18.7% and 9.7%. The low correlation relates to the previous discussion, where different factors influence land and sea temperature.

Figures 2A and 2B show that land temperature increases much faster than the sea. The increase in land temperature is 2.5 times higher than the increase in sea temperature. The high increase in land temperature is due to the rapid development and population growth in Bengkulu City. Economy activities, land used for plantations and settlements, the high number of transportation, and a lack of awareness of the environment have certainly accelerated the increase in temperature on the land of Bengkulu City [19], [38]

Based on Statistics Indonesia (BPS) data, the population of Bengkulu City rose from 96,383 people in 1986 to 373,591 people in 2020 [39], [40]. Bengkulu City has the highest population growth rate in Bengkulu Province, with a 4.06% population increase yearly. Figure 5 shows the Bengkulu City population from 1986 to 2020 based on BPS data, where the trend is positive as the temperature changes in Bengkulu City [39]–[45]. The increase in population also affected the development of the residence and industry areas. Based on Landsat images from 2008 to 2018, the area built in Bengkulu City increased from 3,383.51 ha to 5,485.10 ha. Changes in the built area reached an increase of 5.0% per year [46]. Significant changes happened between 2011 to 2017, when 439.19 ha of agricultural land and non-agricultural land became build-up areas in Selebar Subdistrict, Bengkulu City [47]. High populations and the expansion of the area built increased the number of greenhouse gases in Bengkulu City.

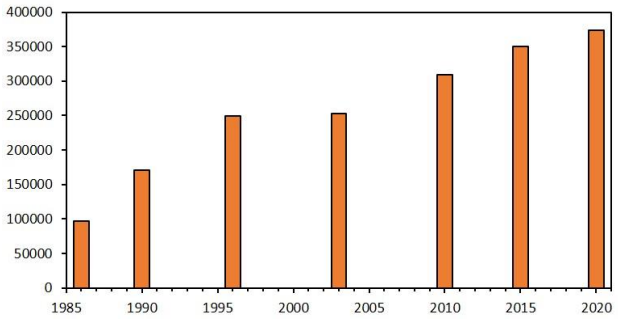

Figure 5. Bengkulu City population from BPS data (1986-2020)

The increased number of greenhouse gases accelerated the temperature increase in Bengkulu City [19]. The high greenhouse gas concentration on Bengkulu City land caused the increased temperature on the land to be higher than the increased temperature on the sea. Main human activities are on land and relatively far from the sea. Because of that, the increased sea temperature is lower than the increased land temperature. The temperature increase in Bengkulu City is similar to the global

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temperature increase, where land temperature increases higher than sea temperatures globally [9].

The fact that land temperature increased higher due to the accumulation of greenhouse gases on Bengkulu City land made the pattern of changes in sea temperature in Figure 2A seems quite different from changes in land temperature values in Figure 2B. At some points on the graph, the low point of sea temperature deviates very far from the trendline. Figure 2C also describes that sea temperature data is not well distributed. The variations in sea temperature happen due to the influence of the El-Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). It is known from previous research that ENSO and IOD correlate with sea temperature around the islands of the west part of Indonesia [48]–[50].

From Figure 6, low sea temperature occurred when IOD positive phase happened (1994, 1997, 2006, and 2019). A previous study found that the west coast of Sumatra Island (Bengkulu City) experienced a drastic temperature decrease when IOD positive phase happened [49]. ENSO's significant impact on low sea temperature occurred around 2011 in the La Nina phase [51]. The IOD phenomenon has more impact on the sea temperature around Bengkulu City than ENSO. The effect of IOD and ENSO felt strongly on sea temperature due to the water movement from the Indian and Pacific Oceans only touching seawater around Sumatra Island [48], [52].

From Figure 3, we can see a range of variations in sea temperature. The monthly maximum sea temperature tends to be stable with almost no changes for the last 36 years, and the monthly minimum sea temperature experiences drastic positive changes. This kind of increase in temperature also happens in other places on the earth. For example, some Nepal and Egypt cities experienced a rise in temperature where the minimum temperature rose faster than the maximum temperature [53], [54]. By previous studies, the maximum sea temperature change is smaller than the minimum sea temperature change, while the mean sea temperature increases significantly are signs of climate change [6], [55].

On the other side, changes in monthly mean, maximum, and minimum land temperatures are relatively similar to each other, where all of them rose positively. This increase in land temperature is different from the increase in sea temperature. The monthly maximum and minimum temperatures rose simultaneously, with the monthly maximum temperatures slightly higher than the others. This kind of increase in temperature also happened in Bangladesh [56]. The increase must be watched out for its future negative impact on the environment because the trendline and graph show that the temperature constantly changes in a positive trend.

From the previous discussion, we speculate that Bengkulu City's temperature rising on land affected by population growth and the expansion of area built that drive the greenhouse gases to high concentration. A previous study also shows that temperatures in Sumatra Island have high variation [15]. Temperature increase in land affected by local greenhouses concentration means that the land temperature in Bengkulu City is mainly affected by regional factors. On the other hand, global phenomena like IOD and ENSO influence sea temperature around Bengkulu City. Different factors that influence the temperature in the sea and land cause sea and land temperature to have a low correlation.

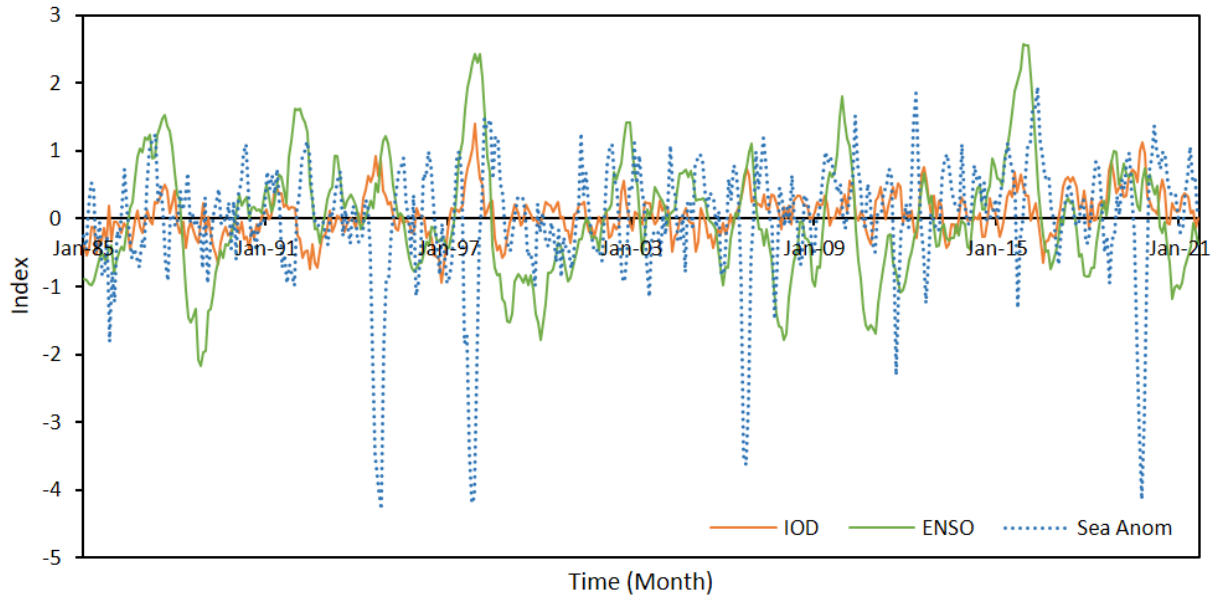

Figure 6. IOD and ENSO relation with temperature on Bengkulu Sea

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V. Conclusion

The increased temperatures in Bengkulu Province for the last 36 years are 1.071 °C for the land area and 0.401 °C for the sea area. Increased temperatures yearly are 0.030 °C for the land area and 0.011 °C for the sea area. The land temperature rose higher due to many activities that emit greenhouse gases, such as fast population growth and used land changes in Bengkulu City. ENSO and IOD highly influenced the sea temperature around Bengkulu City. From the analysis of the increase in monthly mean, maximum, and minimum temperatures, sea temperature showed signs of climate change where the maximum temperature rise lower than the minimum temperature, and the minimum temperature rose drastically. On the other hand, monthly mean, maximum, and minimum temperatures on land rose simultaneously.

The correlations between sea and land temperature are weak. The values are only 10.70% for daily temperature data and 28.52% for monthly temperature data. These low correlations are different due to the factors that influenced the temperature in both places. The land temperature is mainly affected by regional factors such as high population numbers and the used land changes leading to increased greenhouse gas concentration. At the same time, the sea temperature was not affected by the concentration of greenhouse gases as high as on land because of low human activity on the sea. Conversely, global phenomena like IOD and ENSO highly influenced the sea temperature changes in Bengkulu City. Since there are high-temperature rises and signs of climate change in Bengkulu City, all parties must make plans to protect the environment so that we can avoid the adverse effects of global warming.

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Declarations

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