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Climate Change Impact on Temperature, Rainfall, and Humidity in Batang Toru, South Tapanuli

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ABSTRACT

Batang Toru is a sub-district in South Tapanuli Regency that is vulnerable to climate change due to forest conversion to gold mining. This is thought to be the cause of climate change in Batang Toru. This study aims to determine climate variability due to the influence of gold mining in Batang Toru. This research can provide useful information for designing policies, reducing risks, and improving operational sustainability at the Batang Toru mine. The data used are monthly mean temperature, rainfall, and humidity data for 5 years before and after mining operations (1992-1996 and 2018-2022) obtained from BMKG FL Tobing Meteorological Station and NASA. The methods used are descriptive, quantitative, and correlation analysis of temperature, rainfall, and humidity data. Data processing uses Panoply software to create 2D distribution maps and Microsoft Excel to see the time series of each data. The results showed that temperature variability increased by 0.53°C. Batang Toru's rainfall variability is of the equatorial type, with peaks occurring in October and April. The average humidity value for the last 5 years was 84.88% and previously it was 82.88%. Based on the results of the study, it is known that the impact of gold mining operations has greatly affected climate variability in Batang Toru.

KEYWORDS: *Batang Toru, Air Temperature, Rainfall, Humidity, Climate Change.*

NOMENCLATURE

CO2	Carbon Dioxide
NASA	National Aeronautics and Space Administration
BMKG	Meteorological, Climatological and Geophysics Agency

1.0 INTRODUCTION

The Indonesian archipelago consists of large and small islands, highly vulnerable to the impacts of climate change. Indonesia has a tropical climate [1][2], dominantly influenced by two climates, namely wet and dry climates. The earth's climate is naturally regulated, but as more and more damage is done to the earth, climate change is difficult to predict. Sometimes there is a prolonged dry season, which causes the air temperature to rise, and the greenhouse effect increases, so the earth becomes hotter and hotter [3]. Climate change does not happen in a moment but occurs over a long period, usually more than ten years [4]. Greenhouse gases cause an increase in the amount of heat retained in the Earth's atmosphere, heat from the sun would normally be radiated back into space resulting in climate change [5].

Global warming is the increase in average temperatures in the Earth's atmosphere, oceans, and land due to human actions. Human activities involve burning fossil fuels, such as coal, oil, and natural gas, which release (CO2) and other gases into the atmosphere [6]. The impact of global warming is the increase in precipitation and actual conditions, rainfall worldwide has increased by 1% in the last hundred years, storms will become more frequent, groundwater will evaporate very quickly, areas will be drier than before, winds will blow faster with different patterns, hurricanes will also be more frequent [7].

Although rainfall is one of the most critical components of climate, its spatial and temporal existence is still challenging to predict because the physical processes involved are very complex and always changing [8][9]. Both terrestrial and coastal or marine conditions can be affected by climate change, which includes an increase in the intensity of extreme weather events in a given place, changes in rainfall patterns, and increases in temperature and sea level [10]. Changes in rainfall patterns will alter the onset of the wet and dry seasons, with longer dry seasons leading to droughts that threaten land productivity. Conversely, compared to customary conditions, the rainy season will be shorter but with higher intensity [11].

One area of Indonesia that is experiencing the effects of climate change is Sumatra Island. One of the regencies on Sumatra Island is South Tapanuli Regency, located in the North Sumatra region. South Tapanuli Regency has 14 sub-districts and an area of 4,335.35 km^2, and its altitude ranges from 0 to 1,985 m above sea level [12]. In Kabupaten Tapanuli Selatan,

rainfall tends to be irregular throughout the year. The highest rainfall occurs in December (2,583 mm), and the lowest occurs in June (560 mm) [13]. The Batangtoru Watershed has a variety of land uses, including plantations, mining, roads, commercial, offices, settlements, and the Batangtoru Hydroelectric Power Plant. This land use causes environmental changes that impact the climate in Batangtoru [14].

The Batang Toru landscape, located in the western Bukit Barisan Mountains of North Sumatra Province, is a wet tropical rainforest ecosystem that significantly maintains climate stability. Batang Toru has relatively stable climatic conditions despite the global increase in greenhouse gases. Temperatures in the region range from 20°C to 30°C with small annual amplitudes, but daily temperature variations tend to be larger, showing more pronounced differences between day and night temperatures.

Air humidity in the Batang Toru Landscape is also very high, generally above 80%, which is characteristic of primary tropical rainforest ecosystems. This high humidity plays an important role in maintaining the microclimate's balance and supporting the forest ecosystem's sustainability. Geographical factors and the presence of forests in the area strongly influence maintaining stable air temperature and humidity, making it more resilient to the effects of global climate change due to greenhouse gases. However, land cover change in the Batang Toru landscape and beyond is indicated by an increase in temperature through 2014 and a relatively small decrease in humidity in 2011.

The Batang Toru watershed has a high land degradation index, and the highest is found in the Batang Toru Hilir sub-watershed, which has 16.49% and 2.78%. Land degradation levels are very low (29.21%), low (21.35%), and medium (30.17%). Batang Toru has rainfall categorized as wet months with an average rainfall intensity of more than 100 mm/month. Wet months usually occur from September to May, and dry months usually occur from June to August. In the western part of South Tapanuli, high rainfall (300-500 mm/month) usually occurs from September to December and March to May. Primary and secondary natural forest ecosystems with relatively complete canopy structures are the cause. The cause of the canopy structure makes the Earth's surface cool, and the condensation occurs near the Earth's surface, which then falls as rain [15]. Batang Toru is experiencing climate change, with research showing that temperature changes can occur due to a decrease in greenery [16].

This study was conducted to assess how climate variability in Batang Toru, which consists of elements of air temperature, rainfall, and humidity, that was affected by gold mining in Batang Toru. This research is expected to be useful for the restoration of land functions that have been converted into gold mining areas in order to reduce the impact of climate change.

2.0 METHODS

2.1 Data Acquisition

The research site was located in Batang Toru, South Tapanuli Regency (Figure 1). The research data is secondary data from the Meteorology Climatology and Geophysics Agency, available online and the National Aeronautics and Space Administration (NASA). The data consists of monthly average temperature, rainfall, and humidity data. Data was for 5 years before mining operations, namely 1992-1996 and the last 5 years of data after operations from 2018-2022.

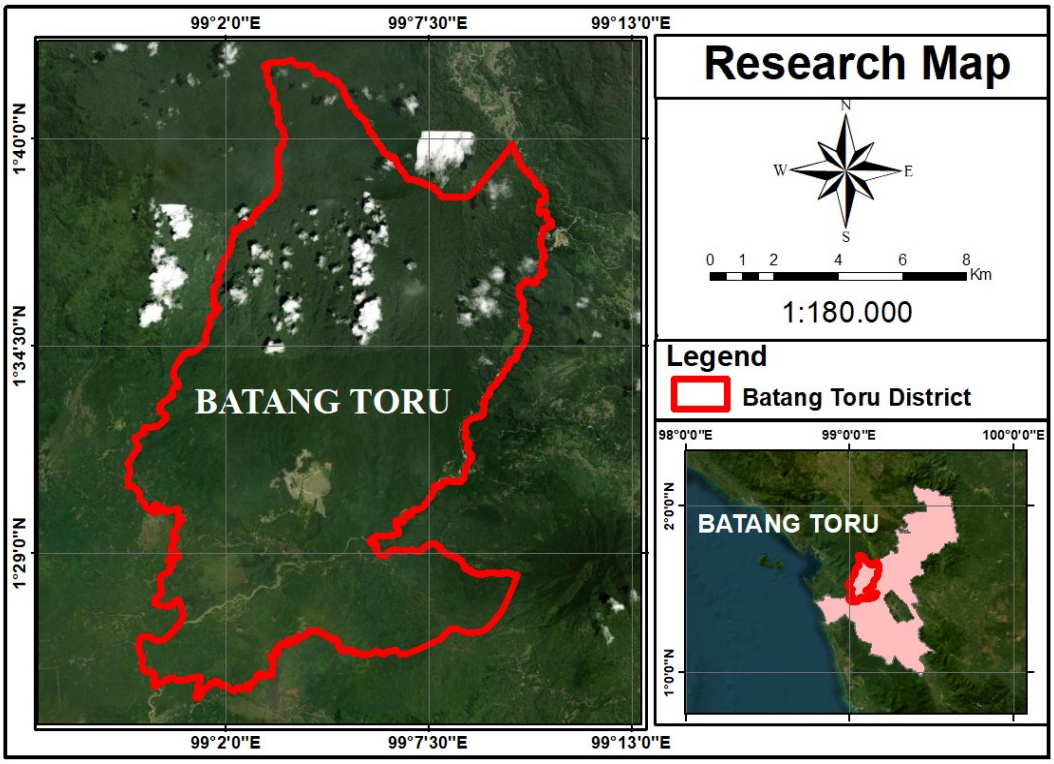

Figure 1: Research Location

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2.2 Data Processing

Data was processed using Panoply software and Microsoft Excel. Meanwhile, ArcGIS software was used to create research maps. Air temperature data was processed with Panoply to see a 2D distribution map. Hence, the data was processed in Microsoft Excel to see the time series of each data, namely temperature, rainfall, and humidity data.

2.3 Data Analysis

The analysis method was used in this research of descriptive and quantitative. The descriptive method was to describe all data or research objects [17], while the quantitative method aimed to measure and analyze data statistically [18]. Descriptive methods were presented in the form of 2D graphs, time series, and tables from the data that had been processed. The quantitative method was in the form of values of several parameters such as temperature, rainfall, and humidity that have been obtained. Correlation analysis between humidity and rainfall, air temperature, and rainfall and linear trends of each parameter was used in this study before and after the operation of the mine.

3.0 RESULTS AND DISCUSSION

3.1 Air Temperature Variability

The variability of monthly average air temperature between the two periods, 1992-1996, shows fluctuating values as shown in Figure 2. The air temperature in the period 2018-2022 tends to be higher than that in 1992-1996. This shows an upward trend in average temperature, indicating a global warming trend.

In addition, temperature variability in the 2018-2022 periods appears more fluctuating with a drastic drop in temperature in November 2019 of 2.95°C, which did not occur in the previous period. This more significant variation indicates changes in weather patterns that are increasingly unstable.

Air temperature variability shows that temperatures tend to be higher in the first transitional season (May). Meanwhile, in the period 1992-1996, air temperature tended to be more stable with smaller monthly fluctuations. This indicates that the air temperature in the period before the mine operated was relatively consistent with the season.

Overall, there was an increase in average temperature and temperature variability that is likely influenced by land use change due to mining operations.

3.2 Rainfall Variability

The graph in Figure 3 shows a comparison of rainfall between the periods 1992-1996 (red line) and 2018-2022 (blue line), which shows similar seasonal fluctuations, with months of high and low rainfall. However, there are significant differences in terms of rainfall intensity and variation.

In the period 1992-1996, rainfall tended to be more stable with less extreme fluctuations. In contrast, in the 2018-2022 periods, rainfall fluctuations were more variable. The peak rainfall in the 2018-2022 periods were also higher, reaching 25-30 mm, while in 1992-1996 the peak was around 15-20 mm. The 2018-2022 periods also experienced months with very low rainfall, indicating a more intense dry season. This difference indicates an increase in rainfall variability, which may be due to climate change.

The Batang Toru region has an equatorial rainfall type, which is typical of the wet tropics with significant rainfall throughout the year and peak rainfall in the wet season (October and April). The equatorial type is the movement of the convergence zone following the apparent movement of the sun to the north and south [19].

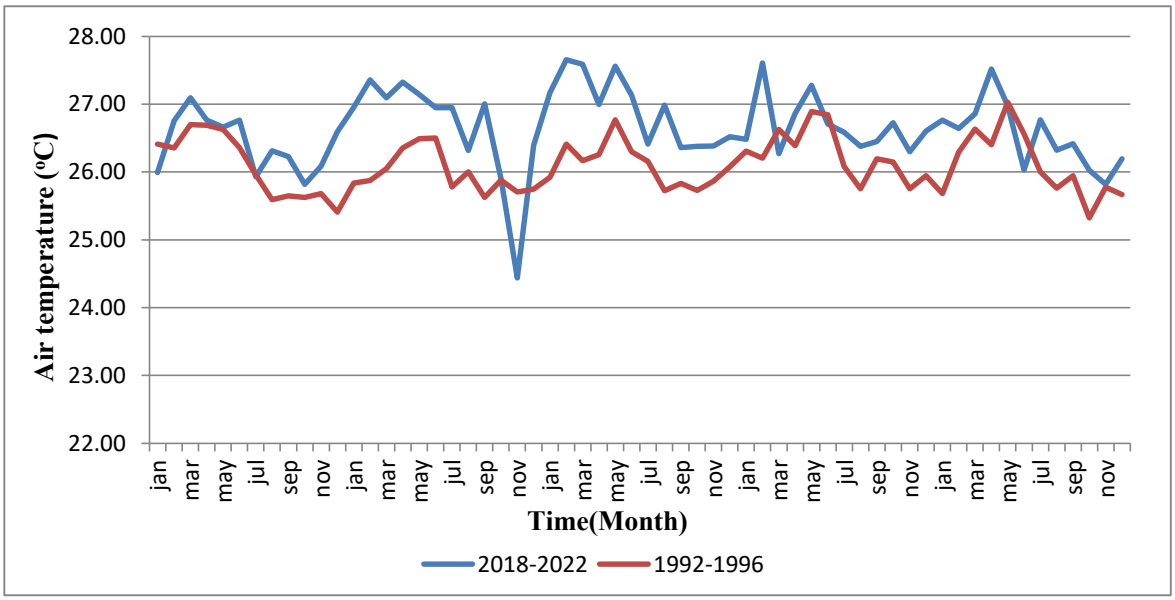

Figure 2: Air temperature variability in Batang Toru in 1992-1996 (red line) and 2018-2022 (blue line)

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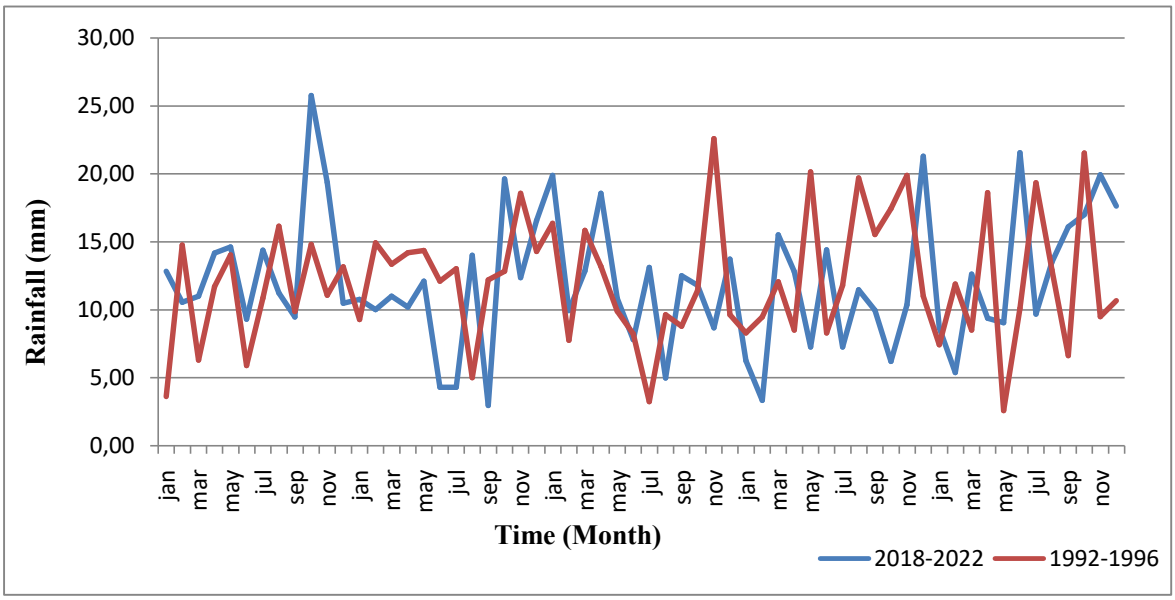

Figure 3: Variability of monthly average rainfall at Batang Toru in 1992-1996 (red line) and 2018-2022 (blue line)

Table 1 shows monthly rainfall data (mm) from 1992-1996 and 2018-2022. Based on the criteria, rainfall >100 mm is categorized as a wet month, then when rainfall is <60 mm, it is categorized as a dry month, and 60mm< rainfall <100 mm as a humid month, most months in the table fall into the wet month category [20]. Only a few months are classified as humid months, which are marked in yellow in the table, where humid months are seen in May 1996 with 80 mm rainfall, August 2020 with 89 mm rainfall, and February 2021 with 93 mm rainfall. In general, rainfall in most months is well above 100 mm, indicating a predominantly high or wet rainfall pattern, while humid months only appear in certain periods, especially in recent years.

3.3 Temperature Change

The temperature data shown in Figure 4 (blue line) appears stable, with very little fluctuation during this period. In contrast, rainfall (green line) has significant fluctuations and shows clear seasonal variations. Meanwhile, the air humidity (red line) shows a downward trend. Although the pattern is similar to that of rainfall, humidity tends to be higher when rainfall increases.

In general, fluctuations in rainfall and humidity are influenced more by seasonal factors or atmospheric conditions than by changes in temperature. Humidity often increases during times of high rainfall due to additional water vapor in the air, but this relationship is not always apparent in the short term. This indicates that while temperature, rainfall and humidity are interconnected, the influence of other factors, such as climate cycles and wind patterns, also play a role in determining the pattern of the data.

Table 1: Comparison of wet and dry months in 1992-1996 and 2018-2022

Months/Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1992	112	428	195	351	435	177	337	501	296	459	332	408
1993	288	418	414	426	445	363	404	155	366	398	557	443
1994	507	217	491	396	307	247	100	299	264	354	678	299
1995	257	265	374	255	625	249	245	611	466	541	597	341
1996	230	345	264	559	80	303	600	401	199	668	285	331
2018	411	306	352	440	453	279	460	348	294	799	581	336
2019	334	281	341	306	269	363	133	435	89	609	371	514
2020	617	289	399	557	336	234	407	154	375	366	260	425
2021	194	93	481	385	225	433	225	355	299	193	311	660
2022	269	150	392	281	280	647	300	419	483	527	598	547

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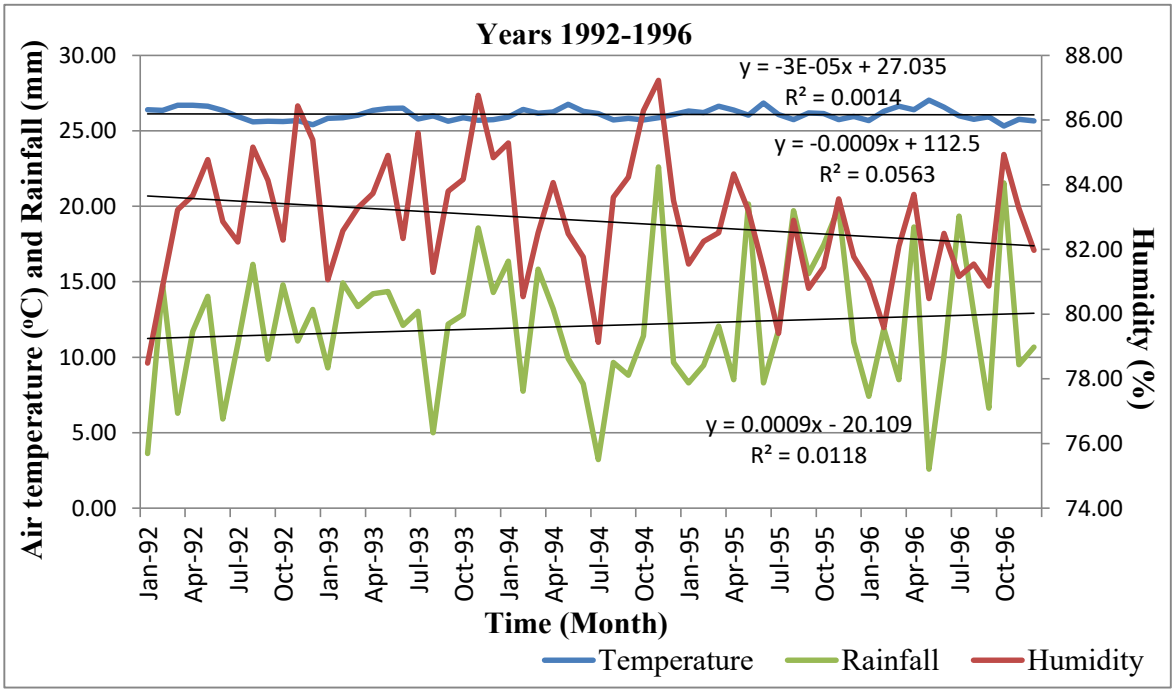

Figure 4: Temperature, precipitation and humidity patterns in 1992-1996

Based on Figure 4, the maximum temperature was recorded at 27.03°C in May 1996, the maximum rainfall was 22.60 mm in November 1994, and the maximum humidity was 87.23% in November 1994, for the minimum and average values can be seen in Table 2. Correlation analysis for 1994-1996 showed an r coefficient of 0.48 between humidity and rainfall, and -0.38 between air temperature and rainfall.

Figure 5 shows that the temperature tends to be stable over time, as shown by the almost flat blue line with minimal fluctuation. This temperature stability reflects no significant change in the average temperature over the period, as indicated by the minimal R^2 value (0.0023).

Table 2: Maximum, Minimum, Average values 1992-1996

	Air Temperature	Rainfall	Humidity
Maximum	27.03°C	22.60mm	87.23%
Minimum	25.32°C	2.58mm	78.48%
Average	26.09°C	12.08mm	82.88%

However, rainfall shows a larger fluctuation pattern with quite variable increases and decreases, reflecting seasonal variations or specific weather phenomena affecting the amount of rainfall. While there was a slight upward trend in rainfall overall, this trend is very weak (R^2 = 0.0015), so it cannot be considered significant, humidity tends to show a more regular pattern compared to rainfall, but there was a slight downward trend in humidity overall (R^2 = 0.0327). Moisture fluctuations seem to follow the rainfall pattern, with higher relative humidity when rainfall increases, although not necessarily directly related at all times.

The relationship between these three variables shows that a stable temperature does not significantly affect rainfall and humidity patterns, while rainfall affects humidity more as it adds water vapor to the atmosphere. However, the relationship between humidity and rainfall was also influenced by other factors, with constant temperature being the basis, while rainfall and humidity were fluctuating related.

Based on the climate in Figure 5, the air temperature has a maximum value of 27.66 °C in February 2022, the maximum value of rainfall was 25.77 mm in October 2018, and the maximum value of humidity of 89.71% in October 2019, for the minimum and average values can be seen in Table 3.

Table 3: Maximum, Minimum, Average values 2018-2022

	Air Temperature	Rainfall	Humidity
Maximum	27.66°C	25.77mm	89.71%
Minimum	25.32°C	2.96mm	78.79%
Average	26.64°C	12.05mm	84.88%

Before the operation of the mine (1992-1996), the average air temperature was 26.09°C, rainfall of 12.08 mm, and humidity of 82.88%. Whereas after the operation of the mine (2018-2022), the average air temperature increased to 26.64°C, rainfall to 12.05 mm, and humidity to 84.88%. Temperature experienced an upward trend, rainfall decreased, and humidity increased. The Correlation analysis (r) between humidity and rainfall, the r coefficient was 0.63 while the r value between air temperature and rainfall was -0.45.

Based on the results of 5 years of data before and after mine operations, it is known that there is an impact on climate change in Batang Toru.

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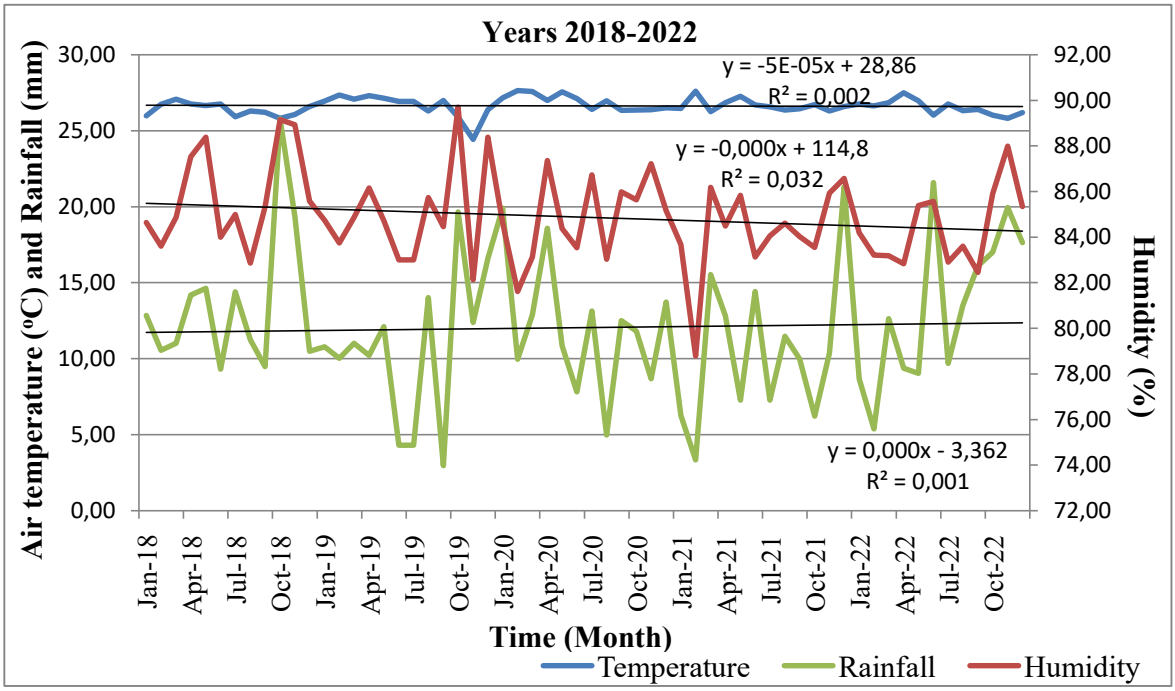

Figure 5: Temperature pattern against rainfall and humidity in 2018-2022

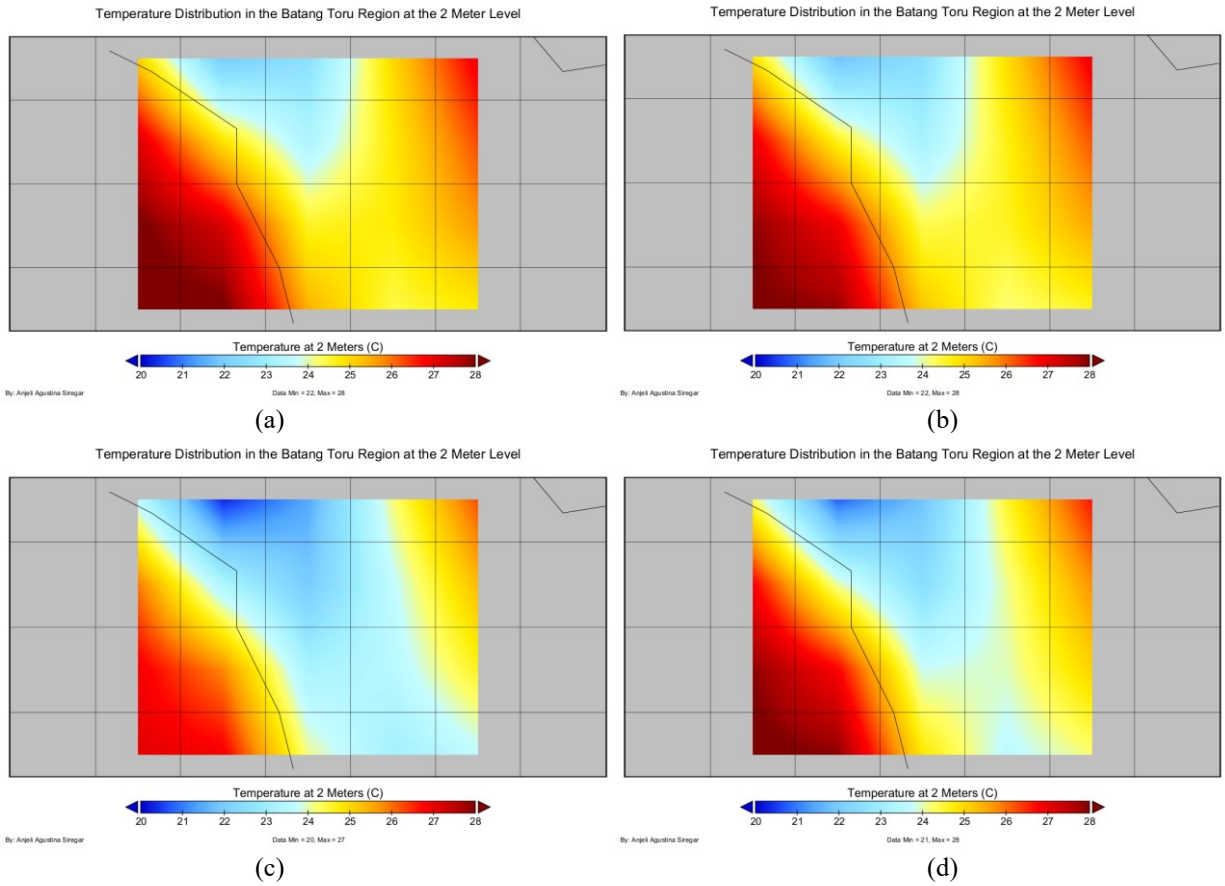

Figure 6: Temperature distribution map in Batang Toru, (a) March 1992, (b) March 2018, (c) August 1992 and (d) August 2018

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3.4 Climate Type Change

This temperature distribution map (Figure 6) shows a comparison of temperatures in the Batang Toru region at 2 meters for March and August in 1992 and 2022, respectively. The figure shows a significant change in temperature patterns over a 30-year period.

In the March 1992 and 2022 maps, the regions with higher temperatures marked in red and yellow, 27-28°C, appear larger in 2022 than in 1992. In contrast, the blue lower temperature region, 21-23°C was smaller, indicating an increase in the average temperature in the region. The same can be seen in the map for August. Compared to August 1992, the temperature in August 2022 tends to be higher, with a larger dominance of red color.

In addition, there were differences in temperature patterns between March and August. In March (1992 and 2022), the average temperature appears higher than in August, which may be related to seasonal differences, such as the influence of the dry season. Overall, this figure indicates an upward trend in temperature in the Batang Toru region from 1992.

4.0 CONCLUSION

The climate in Batang Toru has changed since the operation of the gold mine in Batang Toru due to land cover, and air temperature variability has increased by 0.53°C based on the last 5 years of data compared to data before mining operations. Rainfall variability in Batang Toru is of the equatorial type with peak rainfall in October and April. Humidity appears to follow the rainfall pattern, where relative humidity increases when rainfall increases. Based on the correlation, it can be seen that there is an increase in the correlation value of humidity with rainfall, as well as the correlation of air temperature with rainfall. The results of this study are recommended for restoring land functions that have been converted to gold mining areas in order to mitigate the impacts of climate change, provide useful information for policy design, reduce risks, and improve the sustainability of operations at the Batang Toru mine.

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