

# THERMAL STRESS PROJECTION BASED ON TEMPERATURE-HUMIDITY INDEX (THI) UNDER CLIMATE CHANGE SCENARIO

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## ABSTRACT

The degradation of green open spaces and the phenomenon of deforestation in Indonesia has increased discomfort in the region. Furthermore, if allowed to continue, the increase in temperature caused by greenhouse gases worsens the situation. Increased temperature and reduced air humidity are related to thermal stress, affecting human comfort and health. Thermal stress is measured based on the Temperature Humidity Index (THI), which calculates temperature and relative humidity variables. This study analyses THI projections under climate change scenarios RCP4.5 and RCP8.5. This study uses statistical downscaling and bias correction of Quantile Delta Mapping (QDM) to equalize the local climate. This study is divided into four 20-year periods from 2021 to 2100 to evaluate THI changes in future projections. Based on the study results, it is known that from 2041-2060, several big cities in Indonesia experienced an increase in THI and were included in the category of 50% of the population feeling uncomfortable. THI increased in the third and fourth periods. Areas that experienced a significant increase in THI were urban areas that lacked green open land and were densely populated. Surabaya City and Madura Island are the areas with the highest THI index.

**Keywords:** Bias Correction, Climate Change, Thermal Stress, Temperature-Humidity Index (THI)

## 1. Introduction

The largest deforestation in the country occurred in 2014-2015 at 1.092.181,5 Ha. Deforestation poses several threats, including floods, landslides, and droughts. The rate of deforestation and forest degradation globally has a significant impact on the increase in the accumulation of greenhouse gases (GHGs) [1]. Greenhouse gases are one factor in global warming. The Intergovernmental Panel on Climate Change (IPCC) in 2018 that the global temperature increase due to greenhouse gases was 1.5°C-2°C [2]. The increase in the extreme index in Indonesia in the annual average maximum daily temperature (TXmean) and minimum daily temperatures (TNmean) increased significantly by 0.18°C and 0.3°C [3].

Rising temperatures affect climate change as well as the level of comfort of human populations, especially in urban areas. Climate factors associated with the comfort level of the human population are temperature and humidity. Several indices measure the level of comfort of human populations, including the Temperature Humidity Index (THI) introduced by Thom [4] and updated by Nieuwolt [5] specifically for tropical regions.

Earth System Models (ESMs) are global climate models that have additional capabilities (improvements from the GCM model) by including biogeochemical processes that interact with physical climate [6]. ESMs, according to Anav et al. [7], are complex numerical models designed to simulate Earth's physical, chemical, and biological processes between the atmosphere, land, and oceans. Radiative Forcing (RF) data from greenhouse gas emissions will be used in future ESM simulations. Increased RF can cause warming effects, leading to an increase in global average temperatures.

In the AR5 report [8], the IPCC adopted four RF amplification hypotheses, known as the Representative Concentration Pathway (RCP). The four IPCC assumptions are RCP 8.5, RCP 6.0, RCP 4.5, and RCP 2.6. Marsitha and Suwandi [9] used the RCP scenario to project the agroclimate suitability of peanut crops in East Java. Lallo et al. [10] projected heat stress characteristics in cattle on the Caribbean island using the THI index, resulting in a few animals having experienced significant heat stress in the winter. Egypt experienced a change in the THI index from 2046 to 2060 [11].

ESM has a low resolution and does not represent the local climate. Statistical downscaling is a method of scaling down that uses statistical methods to generate

external ESMs on a local scale without requiring complicated computing. Here are some studies on statistical downscaling ([12], [13], and [14]).

However, some studies have found that statistical downscaling still has a significant bias, so in 2010, Piani et al. [15] symbolized the correction bias of quantile mapping to correct the bias caused by statistical downscaling—other research on statistical downscaling and correction bias ([16] and [17]). Although the quantile mapping bias correction algorithm is effective at eliminating bias, it has been found that quantile Mapping can artificially disrupt future model projection trends [18]. Therefore, [18] proposed the Quantile Delta Mapping (QDM) method, which explicitly keeps relative changes in rainfall. Based on this background, this study will calculate the forecast of the THI index in the future under the climate change scenarios RCP4.5 and RCP8.5 using already downscaled temperature and humidity and bias correction.

## 2. Methods

The study focuses on the future effects of climate change on the comfort level in Indonesia. The climate change scenarios used in the study are RCP4.5 [19] and RCP8.5 [20]. RCP4.5 is a scenario with a stable radiation pattern 2100 of  $4.5 \text{ Wm}^{-2}$  [19]. RCP8.5 has an increasing greenhouse gas construction year after year, with RF reaching  $8.5 \text{ Wm}^{-2}$  [20].

This research is based on secondary data. The data used in this study came from the Coupled Model Intercomparison Project (CMIP5). The model employed in this study is the Beijing Normal University Earth System Model (BNU-ESM). The BNU-ESM model was developed to study the mechanisms of ocean-atmosphere interaction by simulating climatological annual cycles and the Niño-Southern Oscillation (ENSO) [21]. The lower atmospheric upper limit for BNU-ESM is three hPa (approximately 30 km) [22]. The Modern-Era Retrospective Analysis for Research and Applications (MERRA) data reanalysis set developed by Rienecker et al. [23] serves as the basis for shrinking historical periods. The variables in this study are temperature and relative humidity. The data used is described on table 1.

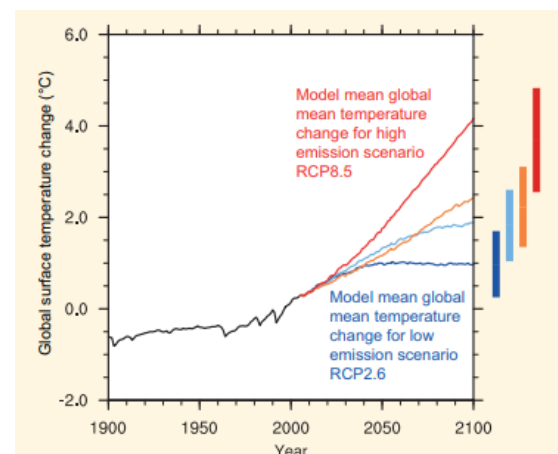
This QDM method, popularized by Canon et al. [24], is used in this study to increase the ESM resolution to match the local climate. Before performing the QDM bias correction, equalize the grid resolution between the ESM output and Reanalysis (MERRA 2) using the Climate Imprint (CI) method, also known as the delta method [25]. The QDM method retains the advantages of the Quantile Mapping (QM) method and accepts GCM trends and biases better than QM [24]. The QDM formulation is as follows:

$$\delta_f(t) = \frac{Q_{s,f}(t)}{F_{s,r}^{-1} [F_{s,f} [Q_{s,f}(t)]]} \quad (1)$$

$$Q_m(t) = F_o^{-1} [F_{s,f} [Q_{s,f}(t)]] + \delta_f(t) \quad (2)$$

Where  $\delta_f(t)$  and  $Q_m(t)$  are relative changes between historical data (ESM) and simulated data (ESM) in the t-quantile.  $F_{s,f}$  and  $F_{s,r}^{-1}$  are CDF of future ESM data and the inverse CDF of the historical period. The stages of QDM are as follows: (1) calculating relative and absolute changes according to equation (1) and applying equation (2) to obtain future projections that have been corrected for bias [26]. The bias correction results on the temperature and relative humidity variables will be used to calculate the Temperature Humidity Index (THI). The following is the THI formula according to Nieuwolt [5] in tropical climates:

$$THI = 0,8T + \left\{ \frac{RH \times T}{500} \right\} \quad (3)$$



**Figure 1.** Global average temperature changes of CMIP5 historical (1900-2005), RCP2.6 (old blue), RCP4.5 (yellow-blue), RCP6.0 (orange), and RCP8.5 (red) (Source: Moss et. Al. [8])

**Table 1. Summary Dataset**

Scenario	Model	Resolution	Variable
RCP 4.5	BNU-ESM	$2.8^{\circ} \times 2.8^{\circ}$	Temperature Relative Humidity
RCP 8.5	BNU-ESM	$2.8^{\circ} \times 2.8^{\circ}$	Temperature Relative Humidity
Reanalysis	MERRA 2	$0.625^{\circ} \times 0.625^{\circ}$	Temperature Relative Humidity
Historical	BNU-ESM	$2.8^{\circ} \times 2.8^{\circ}$	Temperature Relative Humidity

Where  $T$  is the temperature ( $^{\circ}\text{C}$ ),  $RH$  is the relative humidity, and  $THI$  is the temperature humidity index or comfort index ( $^{\circ}\text{C}$ ). According to Effendy [27], when the  $THI$  index is between  $21-24^{\circ}\text{C}$ , 100% of the population feels comfortable; when the  $THI$  is between  $25-26^{\circ}\text{C}$ , only 50% of the population feels comfortable; and when the  $THI > 26^{\circ}\text{C}$ , 100% of the population feels uncomfortable.

$THI$  analysis will be performed on RCP4.5 and RCP8.5 scenarios (as projections). The analysis focuses on changes over 20 years. Furthermore, the close relationship between geographical location (city or village) and the results obtained will be discussed.

### 3. Results and Discussion

Statistical downscaling and correction bias methods can be applied at micro and macro scales. We use statistical downscaling and correction bias for the macro-region by equating the resolution between the global climate owned by the RCP and the local climate (MERRA). The statistical downscaling method has been applied to macro cases by Fiseha et al. [28] to analyze the impact of climate change on the basin of the Tiber River. Kang et al. [29] did the same thing in 2021 to look at projected possible flooding in South Korean urban areas.

The first step in this analysis is to evaluate the results of statistical downscaling and bias correction on historical scenario data. The evaluation is carried out by looking at the pattern similarity between the BNU-ESM, which has been corrected for bias and MERRA 2. In addition, the bias value between the statistical downscaling results and the corrected bias with the MERRA 2 data is also a reference. The results show a similar pattern between the BNU-ESM maps resulting from downscaling and bias correction with MERRA (see Figure 2). In addition, a small absolute value of bias (below one) indicates that statistical downscaling and correction of bias are going well. In the absolute temperature variable, the bias is close to 0. Meanwhile, the relative humidity variable varies greatly. The highest absolute bias is on the islands of Sulawesi and Papua.

Based on Figure 3, the temperature in Indonesia is within the range of  $13-27^{\circ}\text{C}$  in the historical scenario, while relative humidity is within the range of 70-95%. The temperature in the ocean is higher than on land; for relative humidity, it is the opposite. Most highlands (mountains) have low temperatures and high relative humidity.

Microclimates, namely land cover areas, cause temperature and relative humidity differences based on geographical location. Areas with closed land cover have a high relative humidity level, while areas with industrial land cover have a low relative

humidity [30]. The northern part of Java Island has the highest temperature and lowest relative humidity. The northern part of Java Island is the industrial center and the main route connecting transportation between cities. In addition, in the northern part of Java Island, three big cities are center of economic activity (Semarang, Surabaya, and Jakarta).

In recent years, the issue of climate change has been much discussed. The IPCC provides an overview of climate change scenarios with different levels of radiative forcing scenarios. The IPCC designed four climate change scenarios, including RCP4.5 and RCP8.5 [31]. According to the RCP4.5 and RCP8.5 scenarios, the temperature in Indonesia tends to increase significantly. If the stable radiative forcing levels increase by  $4.5 \text{ Wm}^{-2}$  until 2100, the temperature in Indonesia will increase, as shown in Figure 4. a (blue line). If the radiative forcing level reaches  $8.5 \text{ Wm}^{-2}$ , the average temperature in Indonesia will rise, as shown in Figure 4. b (red line). The effect will be felt in Indonesia in the agricultural sector. Agriculture that utilizes rainfed land experienced a decrease in production of 14.4%/OC respectively [32]. Another effect is rising sea levels, which can cause flooding. The relationship between sea level rise and flooding is exponential [33].

Relative Humidity (RH) is one variable that describes rainfall at a time or season, where the highest RH is in the rainy season and the lowest is in the dry season. Changes in humidity also occur in the RCP4.5 and RCP8.5 scenarios but are more volatile every year. The RCP8.5 scenario is very volatile compared to RCP4.5, where the lowest RH is in the RCP8.5 scenario. This shows that the higher the radiative forcing, the more volatile the RH.

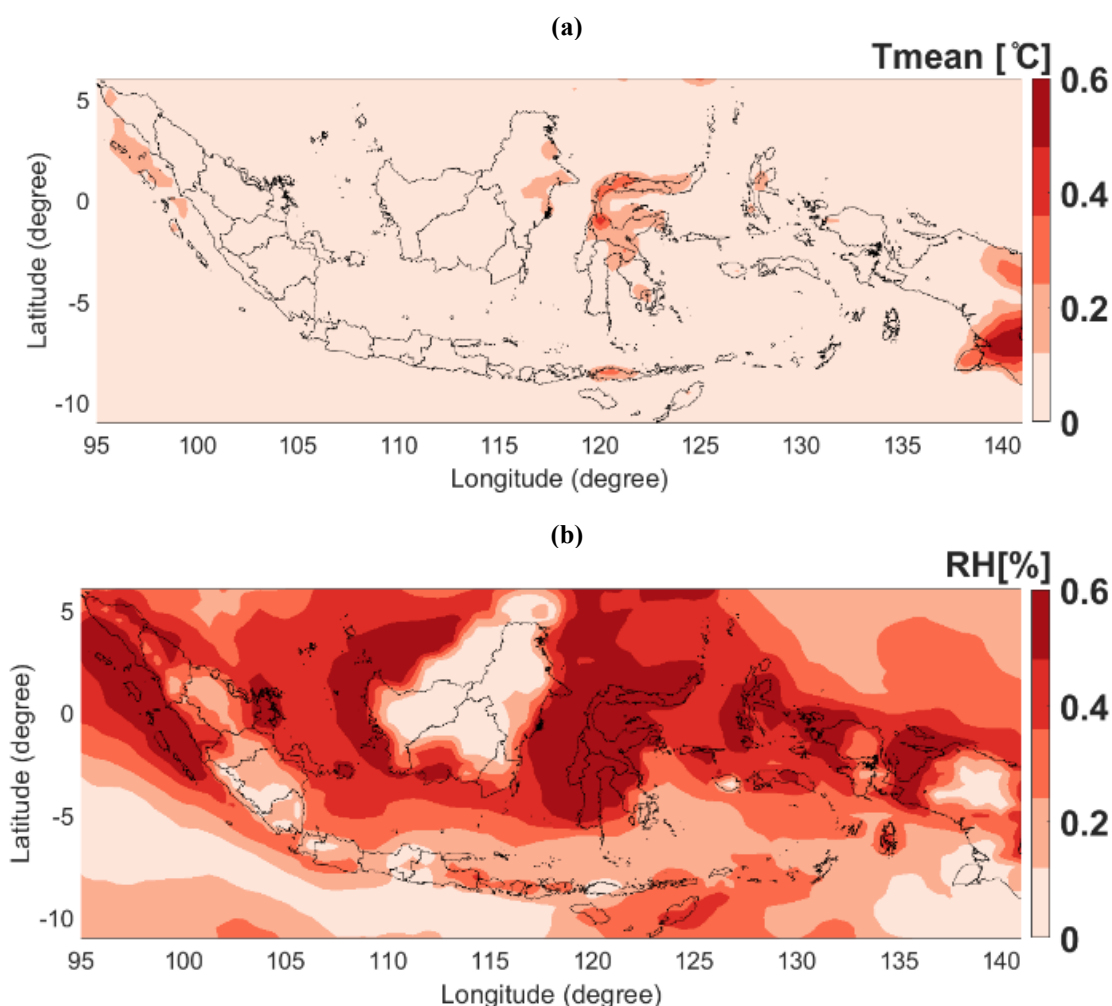
The comfort of an area can be seen based on the relative humidity and temperature variables. Temperature Humidity Index (THI) measures the level of heat stress, which is calculated based on temperature variables and relative humidity [34]. The THI formula is calculated based on formula (3), with a convenience limit modified by Effendy [27]. There are limitations:  $THI < 21^{\circ}\text{C}$  is cold; at  $21-24^{\circ}\text{C}$ , 100% of the population says they are comfortable; at  $THI$  between  $25-27^{\circ}\text{C}$ , only 50% of the population feels comfortable; and at  $THI > 27^{\circ}\text{C}$ , 100% of the population feels uncomfortable.

The results of downscaling and bias correction of RCP4.5 and RCP8.5 for each variable were then calculated by THI and mapped, as shown in Figure 5. We divided it into four periods to examine THI changes every 20 years. In the first period (2021 – 2040), there is no difference in the THI between the RCP4.5 and RCP8.5 scenarios. Most regions in Indonesia in the first period (2021 – 2040) tend to be

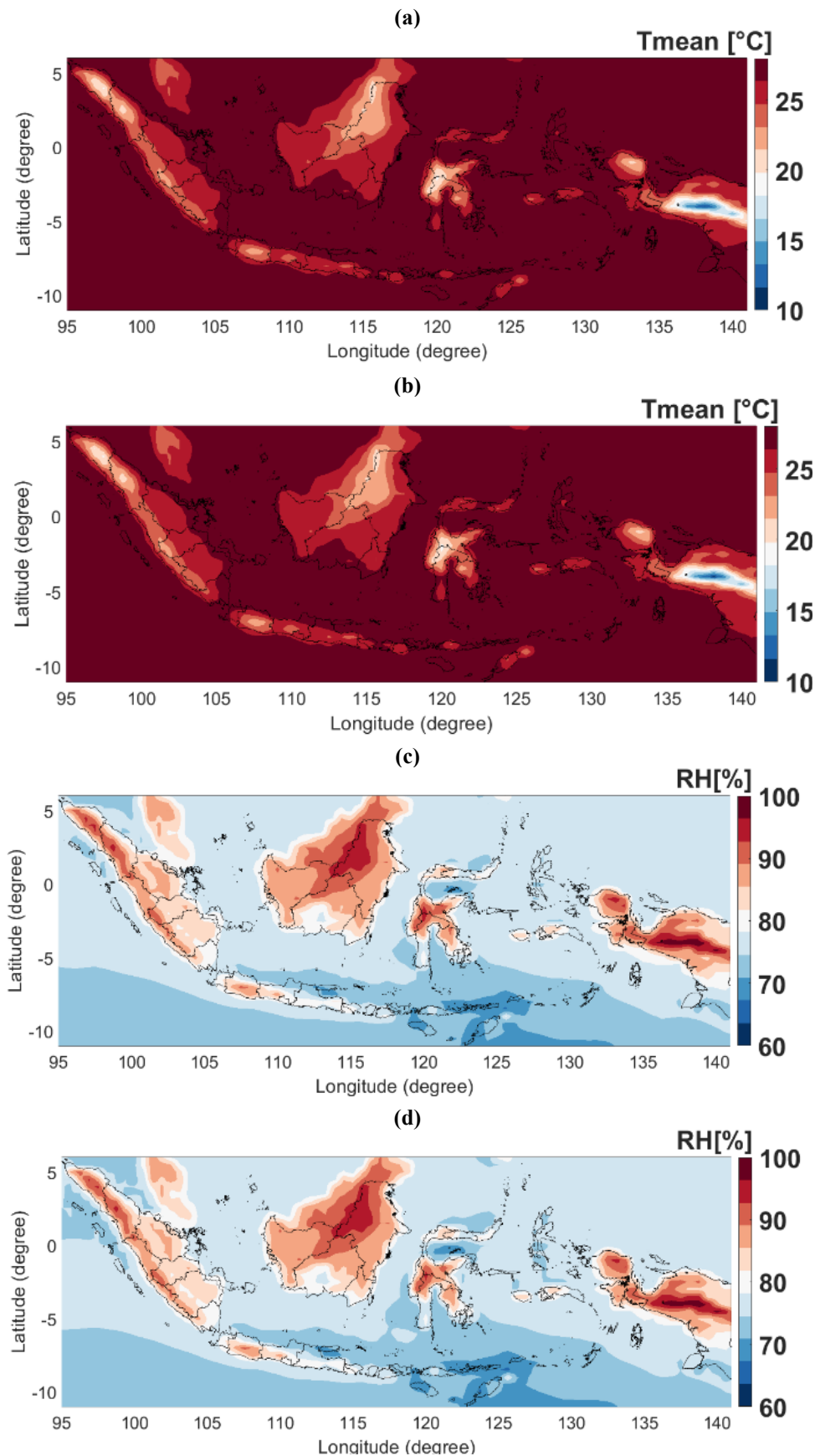
comfortable, even in most parts of the country, which are classified as a cold category. The difference is shown in the second period (2041-2060), where the RCP8.5 scenario tends to be higher than the RCP4.5 scenario. Madura Island and parts of Surabaya city are included in the less comfortable 50% population category. THI increased in several cities in the northern part of Java Island. Kartika et al. [35] found an increase in THI in northern Java as well. In the third period (2061 – 2080), the level of comfort based on THI is increasing, with most of the island of Java approaching 50% of the population feeling uncomfortable (see Figure 5g). The same thing also happened in Sumatra, Kalimantan (Borneo),

Sulawesi, and Papua. THI is increasing and becoming uncomfortable in the fourth period (2080 – 2100).

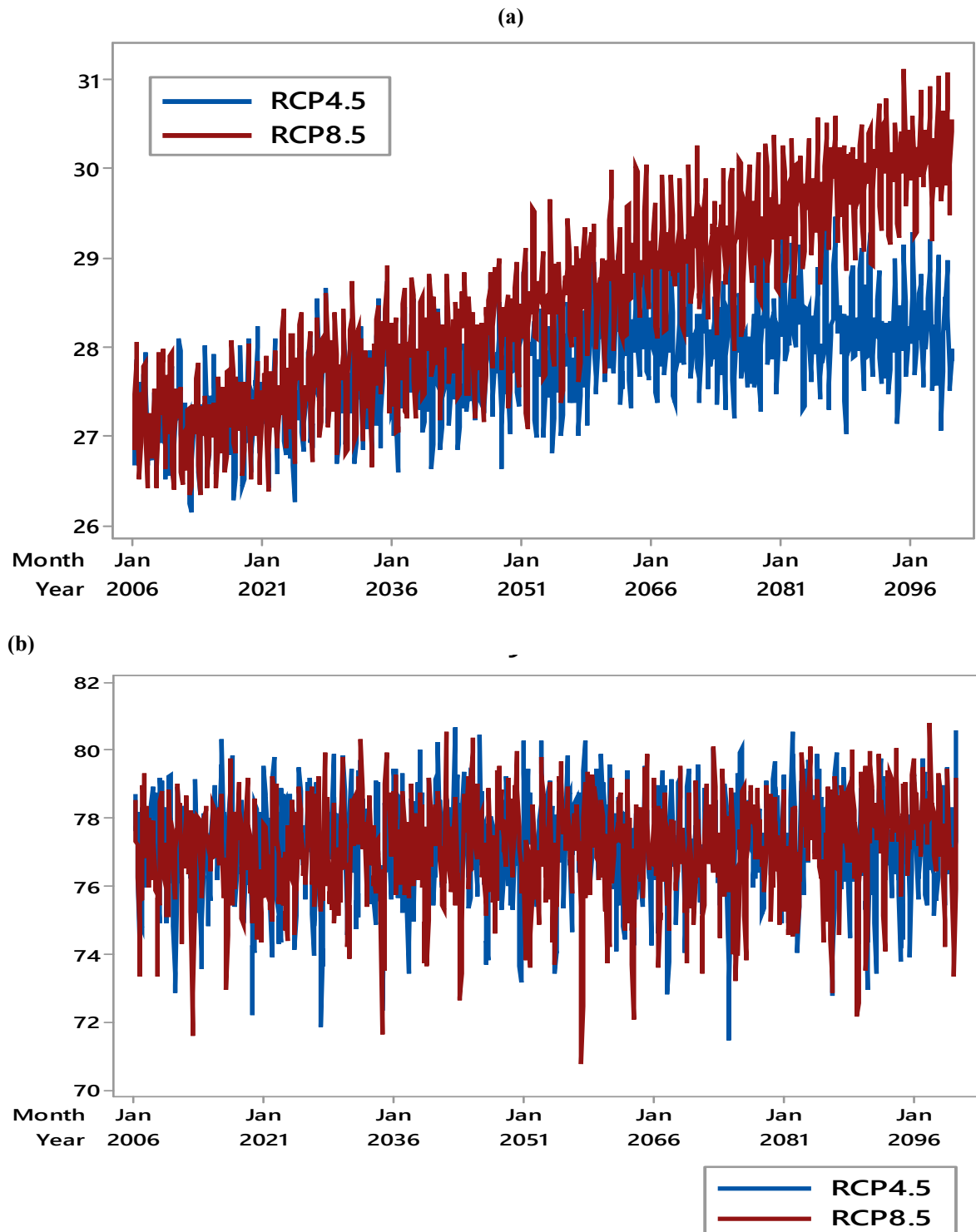
The increase in THI in big cities in Indonesia can only be separated from human activities in some fields. Reduced green space (open land) in urban areas is one of the triggers for increasing THI in Indonesia. Du et al. [36] proved that green open space significantly affects THI. Green open space in the capital city of Indonesia (Jakarta) experienced degradation from 2001-2014 by 5.1%, and built-up land increased by 13% [37]. In addition, forest fires that have occurred in recent years have exacerbated the situation.



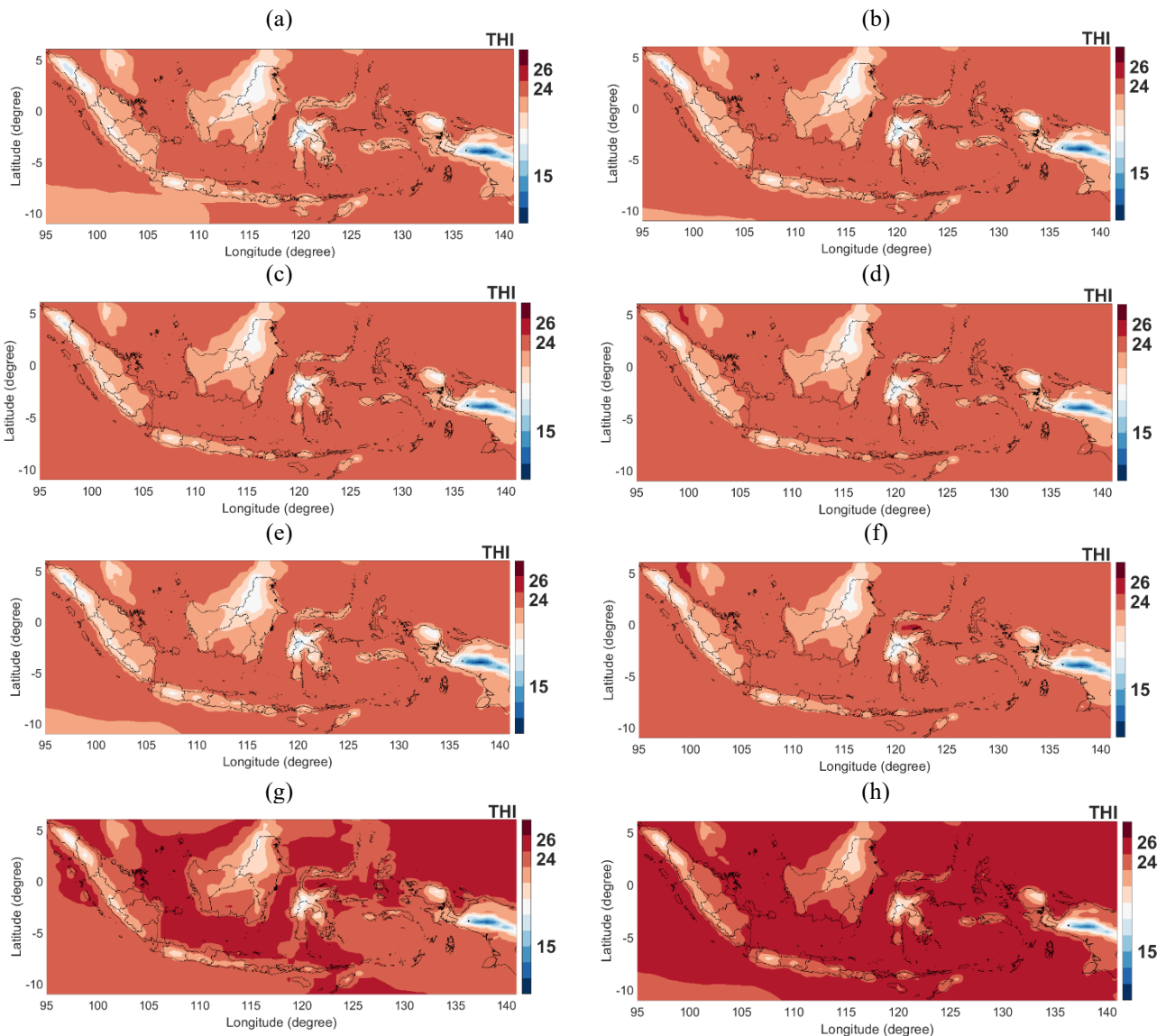
**Figure 2.** Bias Absolut antara data hasil *statistical downscaling*-bias koreksi dengan MERRA 2 (a) Variabel Temperatur (b) variabel *relative humidity*



**Figure 3.** Raw MERRA 2 and statistical results of downscaling bias correction (a) BNU-ESM temperature, (b) MERRA 2 temperature, (c) BNU-ESM relative humidity, and (d) MERRA 2 relative humidity



**Figure 4.** Raw data and results of Statistical downscaling can be corrected by (a) temperature and (b) relative humidity.



**Figure 5. Temperature-Humidity Index (THI) (a) RCP4.5 2021-2040, (b) RCP4.5 2041-2060, (c) RCP4.5 2061-2080, (d) RCP4.5 2081-2100, (e) RCP8.5 2021-2040, (f) RCP8.5 2041-2060, (g), RCP8.5 2061-2080, and (i) RCP8.5 2081-2100**

#### 4. Conclusion

Areas that have the highest temperature and low relative humidity are mostly in the northern part of Java Island. The area is mostly an industrial area and open land. Surabaya City and Madura Island have the highest temperature and lowest relative humidity in Indonesia compared to other major cities. The climate change scenarios RCP4.5 and RCP8.5 show that the temperature will be higher in the future if the stable radiative forcing increases by  $4.5 \text{ Wm}^{-2}$  for RCP4.5 and  $8.5 \text{ Wm}^{-2}$  for RCP8.5. In contrast, the relative humidity tends to fluctuate for the two scenarios. According to the four divisions of the THI period, some regions in Indonesia are still in the comfortable category for the first period (2021 – 2040). The second to fourth periods for both scenarios (RCP4.5 and RCP8.5) have experienced a significant increase. In most of Indonesia's major cities, 50% of the

population feels uncomfortable. The increase in THI is largely due to human activities and the lack of green open land.

**Suggestion.** This study only looked at the comfort index based on THI. Furthermore, this study uses only one ESM model, namely BNU-ESM. For future research, other comfort indices and other ESM models can be added to provide a more complete picture of the level of comfort in Indonesia.

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