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STATISTICAL DOWNSCALING USING REGRESSION NONPARAMETRIC OF FOURIER SERIES-POLYNOMIAL LOCAL OF CLIMATE CHANGE

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ABSTRACT

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Indonesia is a tropical country that is vulnerable to the impacts of climate change. Climate change causes an effect on the level of comfort (heat stress) that can affect the level of human immunity, one of the indices to calculate the level of human comfort (heat stress) is the Thermal Humidity Index (THI). Climate change scenarios modeled in Earth System Models (ESMs). ESM has a coarse resolution and is subject to considerable bias. This research is using secondary data. The data source used in this study comes from the Coupled Model Intercomparison Project (CMIP5). This research will focus on projected heat stress which is calculated based on THI with the temperature and humidity variables. Therefore, in this research to reduce the bias correction method used Statistical Downscaling (SD) and nonparametric regression. The results of the bias correction using the Statistical Downscaling (SD) method and Nonparametric Regression Fourier-Polynomial Local Series in this study the R-square value for Relative Humidity yields 95% and for Temperature yields 94%. The projection of climate change based on the value of the Temperature Humidity Index (THI) in Indonesia in the category of 50% of the population of Indonesians feeling comfortable conditions occurred in 2006-2059. Then the population of citizens in Indonesia felt uncomfortable conditions occurred in 2060 to 2100 with a THI value of 27.0730°C - 27.7800°C.

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1. INTRODUCTION

The world is experiencing two major disruptions, namely climate change and the industrial revolution 4.0. The temperature on earth has increased significantly, and Indonesia is no exception. One of the causes of rising temperatures in Indonesia is deforestation. Global rates of deforestation and forest degradation have a significant impact on increasing the accumulation of greenhouse gases (GHGs) [1]. In addition, Indonesia has a tropical climate which is vulnerable to being affected by climate change (for example: drought). The Intergovernmental Panel on Climate Change (IPCC) in 2018 reported that the increase in global temperature due to greenhouse gases was 1.5˚C-2˚C [2]. Meanwhile, the increase in the extreme index in Indonesia increased significantly by 0.18˚C (maximum temperature) and 0.3˚C (minimum temperature) [3].

Climate change causes heat stress effects that can affect human psychology. Heat stress can be measured by the Thermal Humidity Index (THI) which was introduced by [4] and updated by [5] specifically for the tropics. According to [6] mild heat stress classification occurs at THI 68 to 75. The IPCC climate change scenarios are modeled in Earth System Models (ESMs). ESM has a rough resolution and does not represent the local (regional) climate and has a large bias. Therefore, in this study, to equate the local (regional) climate and correct bias, the Statistical Downscaling (SD) and nonparametric regression methods were used. The following are several studies regarding SD and correction bias including: [7], [8], [9] and [10]. This research will focus on projected heat stress which is calculated based on THI with the temperature and humidity variables in the RCP4.5 and RCP8.5 scenarios. In this model, to equalize the local climate and correct for bias in the ESM output, the SD method and nonparametric regression are used.

One of the goals of the statistical downscaling method is to obtain appropriate statistical data for the atmospheric scale. Downscaling has been implemented by [11], this study statistical downscaling of earth system models using quantile delta mapping (QDM). Previous research on the THI index was conducted by [12] projected the characteristics of heat stress in livestock using the THI index in the Caribbean islands, the result is that there are several animals that have experienced considerable heat stress in winter. The nonparametric regression method is used in this study because the data used is nonlinear data, the approach used is a fourier series and a local polynomial. Both of these methods have been studied a lot including research on nonparametric regression including: [13], [14], [15] and [16]. This study will conclude the results of climate change projections in Indonesia, through the Statistical Downscaling method which then reduces bias correction with Nonparametric Regression. THI is measured from the variable temperature and humidity. The temperature is estimated using the Local Polynomial method, while the humidity variable is estimated using the Fourier Series.

Regression analysis is an analysis to determine the effect between the dependent variable and the independent variable. If you want to find a pattern of relationship between the independent variable and the dependent variable (y), where the shape of the regression curve is unknown, the method used is a nonparametric regression approach [13]. The function $f(t_i)$ is a regression curve of unknown shape. The $f(t_i)$ curve is assumed to be smooth in a given function space. The Fourier series is a trigonometric polynomial function that has a degree of flexibility. This is because the Fourier series is a curve that shows the cosine function [17]. In local polynomial regression, the level of smoothness of the function is determined by the bandwidth. Research on local polynomials has been extensively developed by [16] who examined the estimation of local polynomial regression curves.

Heat stress is one of several effects of climate change/weather. Several variables that cause heat stress are air, temperature, humidity, air movement and radiant heat. Heat stress in moderate, mild, and severe conditions results in discomfort at work, work safety, and health. There are several indices to calculate the level of heat stress, one of which is the Thermal Humidity Index (THI). According to [18], THI index value between 21-24 °C means that 100% of the population feels comfortable, while THI index value between 25-27 °C means that only 50% of the population feels comfortable, and THI> 27°C it states as much as 100%. the population feels uncomfortable.

2. RESEARCH METHODS

2.1 Subsection of Material

This research is using secondary data. The data source used in this study comes from the Coupled Model Intercomparison Project with the website address: https://esgf-node.ipsl.upmc.fr/search/cmip5-ipsl/. The second data source is the MERRA 2 data reanalysis developed by NASA, with the website address:

https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/data_access/. The variables used in this study are temperature and relative humidity.

2.2 Method

The stages of conducting research in the form of data analysis are as follows:

1. Perform data preprocessing by cutting data according to Indonesian territory based on latitude and longitude
2. Prepare the computer for downscaling
3. Perform downscaling and correction bias using a nonparametric regression method, namely the local polynomial approach and fourier series in the MIROC-ESM model for RCP4.5 and RCP8.5 scenarios.
   a. Given n observation data $\{(t_i, y_i)\}_{i=1}^{n}$ which satisfies the equation above. If $T_i \epsilon [-L, L]$ and $Y_i \epsilon R$ it is assumed that the period $f(t)$ can be approximated by a Fourier series which is defined as follows:

$$f(t) = \frac{1}{2} a_0 + \gamma t + \sum_{k=1}^{K} a_k \cos\left(\frac{2\pi k t}{2L}\right) \quad (1)$$

   b. The population mean nonparametric regression model with the estimation of local polynomial is:

$$y_i = \eta(t_i) + e_i \quad ; \quad i = 1,2, \dots, n \quad (2)$$

   with $e_i \sim N(0, \sigma^2)$ is the measurement error. Suppose t is a predictor variable where the function η will be estimated with the Local Polynomial estimator. The function $\eta(t_i)$ can be approximated by degree polynomials p and h (bandwidth).

$$\eta(t_i) \approx \eta(t) + (t_i - t)\eta^{(1)}(t) + \cdots + (t_i - t)^p \eta^{(p)}(t)/p! \quad (3)$$

$$t_i \in [t - h, t + h].$$

   Suppose $\beta_r(t) = \eta^{(r)}(t)/r!; r = 0,1,2, \dots, p$, then:

$$\eta(t_i) \approx \beta_0(t) + (t_i - t)\beta_1(t) + \cdots + (t_i - t)^p \beta_p(t) \quad (4)$$

4. Calculate the THI index. The comfort index is calculated using the formula [5]:

$$THI = 0{,}8T + \left\{\frac{RH \times T}{500}\right\} \quad (5)$$

   with: T = Temperature ($°C$), RH = Relative Humidity, and THI = Thermal Humidity Index ($°C$).
5. Analyzing the results of calculating the THI index

3. RESULTS AND DISCUSSION

3.1 Statistical Downscaling on Earth System Models (ESM) data

ESM data still has low resolution, so the general picture of the impact of climate change in Indonesia is still very inaccurate. The downscaling and bias correction methods enhance the resolution of the ESM data. The resolution obtained from the results of downscaling and correction bias equals the local climate. This study uses ESM data from the RCP4.5 scenario, the CSIRO-Mk3.6.0 model. The comfort level can be identified using the Temperature Humidity Index (THI) method. Comfort is basically not only influenced by temperature but also influenced by another climate parameter, namely relative humidity.

First, a comparison will be made between the RCP4.5, MERRA-2 data and the downscaling results using the Time Series Plot to find out the comparison in 2 different data and the data that has been downscaled. The data that will be compared has previously been calculated on an annual average from daily data to annual data using the annual average to calculate the annual average.

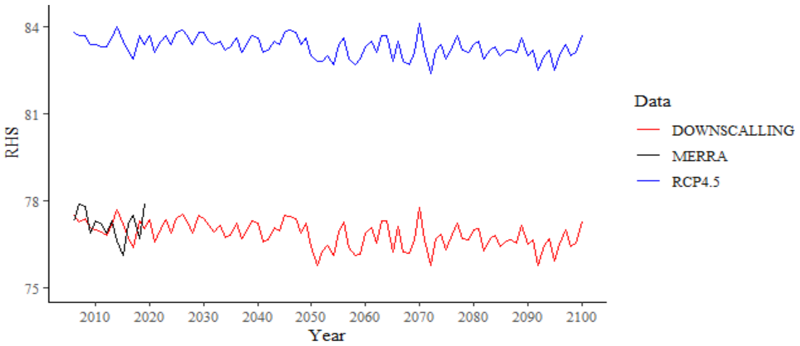

Figure 1. Time series plot of RH RCP4.5 and MERRA-2

Based on the time series plot shown in **Figure 1**, it can be seen that the Relative Humidity (RH) variable from the three RCP4.5, MERRA and downscaling data in Indonesia has a nonlinear pattern and appears to fluctuative over a period of years so that it can be approached with a fourier series nonparametric regression.

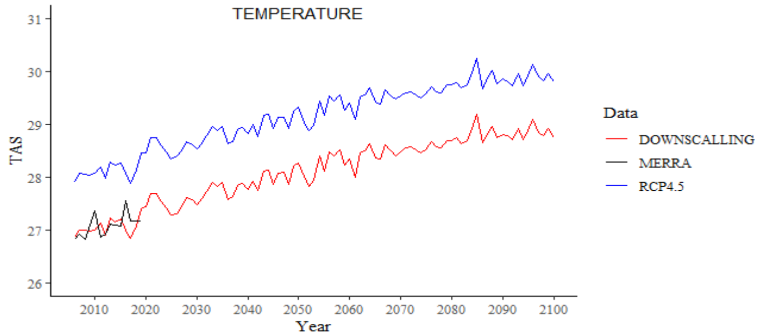

Figure 2. Time series plot of temperature RCP4.5 and MERRA-2

Based on the time series plot in **Figure 2**, it can be seen that the Temperature variable for the three data RCP4.5, MERRA and downscaling in Indonesia is nonlinear so that it can be approximated by local polynomial nonparametric regression.

3.2 Statistical Downscaling with Nonparametric Regression

Statistical downscaling modeling can be approached with a nonparametric regression model. The temperature and relative humidity data are nonlinear so that they can be approximated by a nonparametric regression model. Several nonparametric regression approaches that can be used are Fourier series and local polynomials. The following is the modeling of Temperature and Relative Humidity using a nonparametric regression approach:

a) Variable Temperature with Local Polynomial

Variable Temperature with a local polynomial nonparametric regression model approach, before creating the model first determine the optimal bandwidth and polynomial order using the GCV method. Determination of the optimal bandwidth and polynomial order using the Generalized Cross Validation (GCV) method. The application of the GCV method is to take the minimum value. Algorithms and computational programs to determine optimal bandwidth and polynomial order are executed so that the results are as shown in **Table 1**:

Table 1. GCV value results for each bandwidth value and polynomial order

Polynomial Orde (p)	H	GCV
1	24.4	0.0241
2	**11.4**	**0.0233**
3	15	0.0237
4	12.2	0.0242

In the temperature data based on **Table 1** the minimum GCV value is 0.0233, with a bandwidth (h) value of 11.6. Thus, the nonparametric regression model for temperature data is approximated by a local polynomial with an optimum bandwidth value of 11.6 and a polynomial order of p = 2. After these values are obtained, then determine the estimation of each parameter using the local polynomial approach. The following are the estimation results for each local polynomial nonparametric regression parameter:

Table 2. The result of estimation of kernel local polynomial nonparametric regression

Parameter	Value
$\hat{\beta}_0$	28.2263
$\hat{\beta}_1$	0.0219
$\hat{\beta}_2$	-0.0001

After obtaining the results of parameter estimation, a local polynomial nonparametric regression model can be formed:

$$\hat{\eta}(t_i) \approx 28.2263 + (t_i - 50)0.0219\text{-}(t_i - 50)^2 0.0001$$

The next step is to compare the results of estimation of temperature data based on the results of the local kernel polynomial nonparametric regression modeling with the downscaling results. The graph shown in red is the result of estimation of the local polynomial approach, while the graph in blue is the result of downscaling. The following is a graph of downscaling data with local polynomial approximation data:

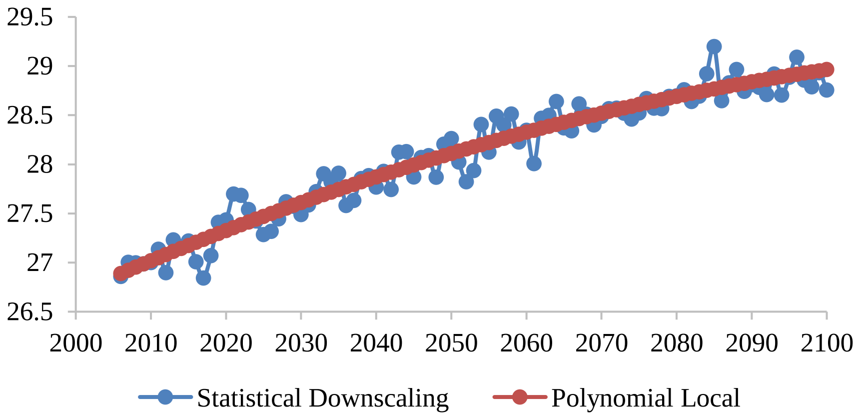

Figure 3. Graph of Temperature Data with Downscaling and Kernel Polynomial Local

Based on **Figure 3**, it can be obtained that the results of approximations with local polynomials are suitable for projecting temperature data. The ability to evaluate the accuracy of the model approach can be shown in the value of the coefficient of determination (R^2) and the Mean Square Error (MSE) value. The results of the local polynomial approach are said to be better if the coefficient of determination is close to 100% and the MSE value is getting smaller. Based on the results using the polynomial kernel nonparametric regression approach applied to temperature data, it shows a coefficient of determination of 0.94 and an MSE of 0.0219. The coefficient of determination is 94%, meaning that the projection time can explain the temperature data in Indonesia by 94%, while 6% is explained by other variables not used in this study.

b) Variable of Relative Humidity (RH) with Fourier Series

In the fourier series nonparametric approach, the first thing to do is to determine the optimal K value. The optimal K value is a positive integer. Determination of optimal K using the GCV method. The method used to obtain optimal parameters in Relative Humidity (RH) is Generalized Cross Validation (GCV). The method used to obtain optimal parameters in Relative Humidity (RH) is Generalized Cross Validation (GCV). The minimum GCV value is the criterion for the optimal K value to be selected. The following are the GCV results for each K value.

Table 3. GCV, *MSE* and R^2 values for each *K*

Nilai *K*	GCV	MSE	R^2
60	0.0858	0.0354	82%
67	0.0608	0.0312	84%
78	**0.0134**	**0.0092**	**95%**
88	0.0013	0.0011	99%

Based on Table 3, it shows that the value of K=78 has produced a fairly high R^2 value, while for the value of K=88 it produces an R^2 of 99%. If the value of K = 88 is chosen, then the estimation results of the regression parameters that must be searched for are 90 parameters. Therefore, the model chosen is a model with a fairly high R^2 and also a parsimony (simple) model. Therefore, the model chosen is K=78 with 80 parameters and R^2 of 95%, so the model obtained for Relative Humidity (RH) is as follows:

$$\hat{y} = 25.732 + 0.0357\, t + 0.00776 \cos t - 0.0174 \cos 2t - 0.0178 \cos 3t + \ldots - 0.0306 \cos 70\, t$$

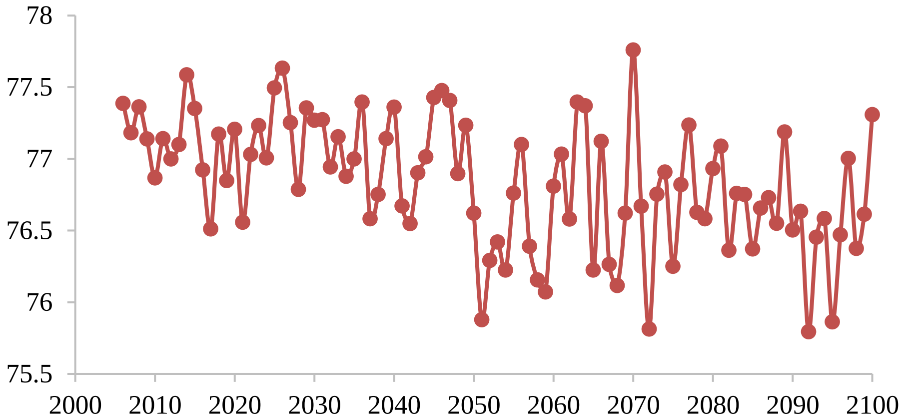

Figure 4. Graph of Relative Humidity (RH) data with Downscaling - Fourier Series

Figure 4 shows that the highest Relative Humidity for Indonesia occurred in 2070 which was 77.75° C while for the lowest Relative Humidity occurred in 2072 at 75.77° C. Fourier because it was chosen with a fairly high R^2 value of 95%.

3.3 Temperature Humidity Index (THI) Value

Determination of the comfort index based on the THI method relates temperature and relative humidity which is formulated in the calculation:

$$THI = 0.8T + \left\{\frac{RH \times T}{500}\right\}.$$

The following is the Indonesian THI data plot using the Downscaling Local Polynomial-Fourier Series approach:

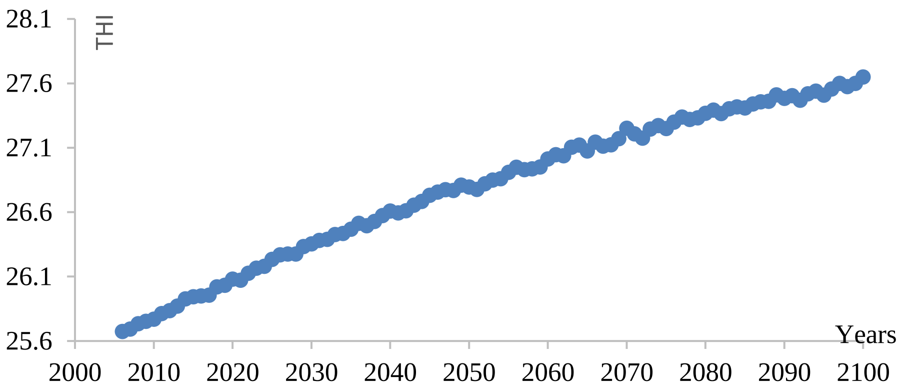

Figure 5. Indonesian THI data plot with Downscaling-Local Polynomial Fourier Series

Based on Figure 5, it shows that THI in Indonesia has increased every year with an average increase of around 0.03°C. In 2006 to 2059 it is projected that the THI value will be between 25.6728° C to 26.9516°

C, meaning that the territory of Indonesia is in a fairly comfortable condition, namely only 50% of the Indonesian population feels comfortable. Then the population of citizens in Indonesia felt uncomfortable conditions occurred in 2060 to 2100 with THI values between 27.0730° C to 27.7800° C, meaning that as much as 100% of the population in Indonesia felt uncomfortable. The high increase in the value of THI in Indonesia is increasing over time, so that within 30 years it can be used as one of the guidelines in preparing regional spatial plans which always prioritize green open space (Ruang Terbuka Hijau = RTH) programs as a form of mitigation of the rate of change in temperature and humidity. air so that environmental conditions remain comfortable.

4. CONCLUSIONS

Statistical Downscaling using the nonparametric regression method Fourier Series - Local Polynomial is applied to Climate Change data in Indonesia which is calculated based on the THI value resulting that in 2006-2059 the projected THI value is between 25.6728° C - 26.9516° C meaning only 50% of the population Indonesia feels comfortable. In 2060-2100 with a THI value between 27.0730° C-27.7800° C, it means that as much as 100% of the entire population in Indonesia feel uncomfortable. The high increase in the value of THI in Indonesia has been increasing over a period of 30 years, so that within 30 years it can be used as one of the guidelines in preparing regional spatial planning which always prioritizes green open space (Ruang Terbuka Hijau = RTH) programs as a form of mitigation of the rate of change in temperature and humidity so that conditions the environment remains comfortable

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