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Spatio Temporal Modeling in Analyzing Temperature Humidity Index Using Google Earth Engine in South Sulawesi: Impact Analysis and Sustainable Mitigation Efforts

Susiyanti[1], Nasrul[1], Maddatuang[2], Ruliana[3], Rosmini Maru[1]

[1] *Geography Education Study Program, Universitas Negeri Makassar, Jl. A. P. Pettarani, Makassar, South Sulawesi, 90222, Indonesia*
[2] *Geography Department, Universitas Negeri Makassar, Jl. A. P. Pettarani, Makassar, South Sulawesi, 90222, Indonesia*
[3] *Statistics Study Program, Universitas Negeri Makassar, Jl. A. P. Pettarani, Makassar, South Sulawesi, 90222, Indonesia*

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Corresponding author:
Rosmini Maru
Email: rosminimaru@unm.ac.id

ABSTRACT

Climate change is one of the biggest challenges and threats to humanity today whose impact has very high dynamics. The high population density, population number, and population activity cause physical changes that affect the microclimate. Microclimate change can reduce people's thermal comfort/temperature humidity index (THI). The impact felt by the community is in the form of discomfort in outdoor activities, health risks such as heat stress, impact on agriculture and natural resource conservation, and animal health on farms to impact emergency response in disaster situations. Moreover, the summer of 2023, a record-breaking summer in 2023, continues the long-term warming trend, indicating the need for a study on the state of THI. This study aims to analyze THI trends and map the distribution of THI in South Sulawesi Province in 2013-2023. The method used in this study is a quantitative-descriptive method through a remote sensing approach using Google Earth Engine (GEE). The Temperature Humidity Index (THI) of South Sulawesi Province in the 2013-2023 time bracket with a cold category with a THI value of < 21 °C has an area of 994384.62 hectares, the comfortable category with a THI value of 21°C – 24°C has an area of 1190393.32 hectares, the fairly comfortable category with a THI value of 24 °C – 26°C has an area of 1810662.30 hectares and the uncomfortable category with a THI value of > 26°C has an area of 532780.13 hectares.

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1. INTRODUCTION

Climate change is one of the biggest challenges and threats to humans today, the impact of which is dynamic and has been identified as a major problem of the twenty-first century (Anandhi et al., 2011; Demasi et al., 2022; Hagemann et al., 2013; Huang et al., 2022). Climate is a natural factor that has a major influence on human life (Alizadeh, 2023). According to the Intergovernmental Panel on Climate Change (IPCC) Report (Fifth Assessment Report), global temperatures have increased rapidly since 1951 (Alexander, 2016). In 2014, Indonesia experienced an increase in air temperature of approximately 0.8 °C in the last 100 years, which triggered a hydrometeorological disaster (Malihah, 2022; Nasrul, et al., 2024).

High population density and activities cause physical changes in areas that affect the microclimate. Microclimate changes can reduce thermal comfort levels (Djelailia et al., 2023; Marciniak, 2014). Increasing temperatures will also have an impact on reducing people's thermal comfort levels which will be dangerous if no steps are taken to prevent it. The El Niño – Southern Oscillation (ENSO) factor is also considered to influence increasing temperatures (Agroho et al., 2021; Arfandi et al., 2024; Duan et al., 2021; Maru et al., 2024; Taufiq & Wulandari, 2022).

The observed climate change over a comparable period, both before and after, indicates a significant shift in climate patterns (Anggraini & Yuadi, 2023; Nasrul et al., 2024; Utami et al., 2024). Several studies, including that by Kustia and Sihombing (2022), have identified a trend of rising temperatures in Indonesia over the past few decades, which reflects the effects of ongoing climate change and global warming. The impact of global warming, primarily driven by increasing concentrations of carbon dioxide (CO2) in the atmosphere, has emerged as one of the most critical issues that must be addressed globally because of its widespread threat to ecosystems and human life (Eko et al., 2022; Ginting, 2017; Haris et al., 2023; Maru & Ahmad, 2014). Under various emission concentration scenarios, it is projected that temperatures in Indonesia will continue to rise in the future, exacerbating existing conditions and adding to the social, economic, and health burdens of the population. According to scientists at the Goddard Institute of Space Studies (GISS) at NASA in New York, the record-breaking heat of the summer of 2023 continues a long-term warming trend that has been observed over the past several decades, causing various tangible impacts on society, such as increased excessive energy use, physical discomfort, and heightened health issues (Utami et al., 2024). Therefore, urgent and coordinated measures are needed to address the negative impacts of rising temperatures and prevent further damage to the environment and quality of life of people worldwide (Nasrul, Nur, et al., 2024; Rahaman et al., 2023).

Based on this, researchers are interested in conducting in-depth research on the thermal comfort index or Temperature-Humidity Index (THI) with a special focus on the Sulawesi Province region, using remote sensing techniques via Google Earth Engine (GEE). GEE is a cloud-based platform, as described by Merchant et al. (2023), which offers environmental data analysis capabilities on a global scale, where users only need to access data from a repository on Google to obtain remote sensing imagery and other geospatial data in very large quantities, reaching petabytes. Additionally, Google Earth Engine has a variety of scientific algorithms already available on the platform, as described by Angkasa et al. (2023), providing a great opportunity for researchers to combine and develop existing algorithms and have broad and consistent data coverage with regular data updates. In addition, this platform enables a much faster computing process by utilising the computing energy available on Google servers, as explained by Lin et al. (2024), making it a very effective tool for conducting research involving the analysis of environmental data on a large scale.

The THI phenomenon is currently a national and international issue because of its huge impact (Rahaman et al., 2023). This is proven by the increase in air temperature of approximately 0.8 °C in the last 100 years (Alexander, 2016). The high population density, population, and population activities cause physical changes in the area which can increase the atmospheric temperature and impact the thermal comfort level of the community, especially in the South Sulawesi Province region. If no further treatment is carried out, this phenomenon will have negative effects on humans and the environment. The urgency of this research lies in the importance of knowing the condition of THI in South Sulawesi Province as an effort to mitigate microclimate change. South Sulawesi is one of the regions with increasing surface temperature intensity due to climate change which has an impact on greenhouse gas emissions.

2. METHOD

2.1. Type and Location of Research

This study employed quantitative-descriptive methods using remote sensing. The numerical data were systematically analysed to produce structured information (Kustia & Sihombing, 2022). Remote sensing techniques using the Google Earth Engine utilised Citra Land ERA 5 data from the ECMWF Reanalysis v5 for time series analysis from 2013 to 2023, enabling long-term environmental data processing with high accuracy (Hehanussa et al., 2023).

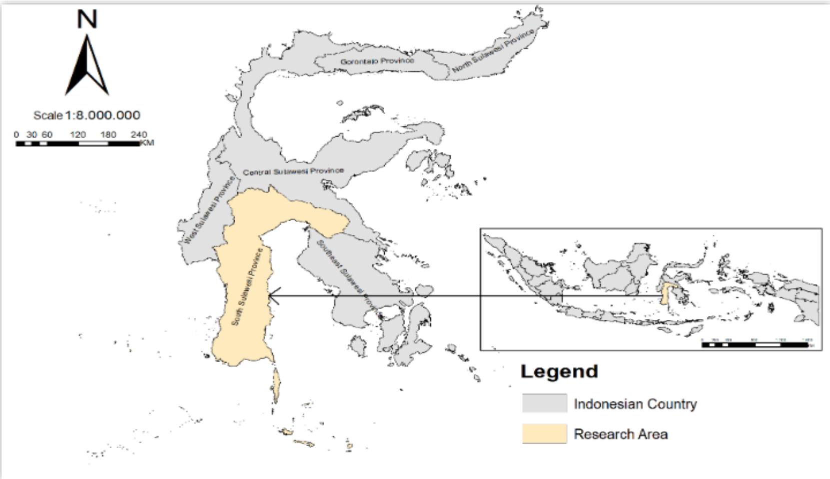


Figure 1. Map of the research location.

2.2. Data Collection

Data were collected using two main sources. First, water temperature and relative humidity data (2013–2023) were obtained from the ECMWF's ERA5-Land dataset via Google Earth Engine. Second, validation data were obtained from the South Sulawesi Climatology Station (BMKG). A correlation test was conducted to assess the consistency between the BMKG and ECMWF data.

2.3. Data Analysis

The data analysis technique used in this research is as follows: the air temperature was determined using ERA5-Land data by utilising the 2-meter temperature band. This band was then multiplied by the slope coefficient and converted to Celsius. The script code used for this process is shown in Figure 2.

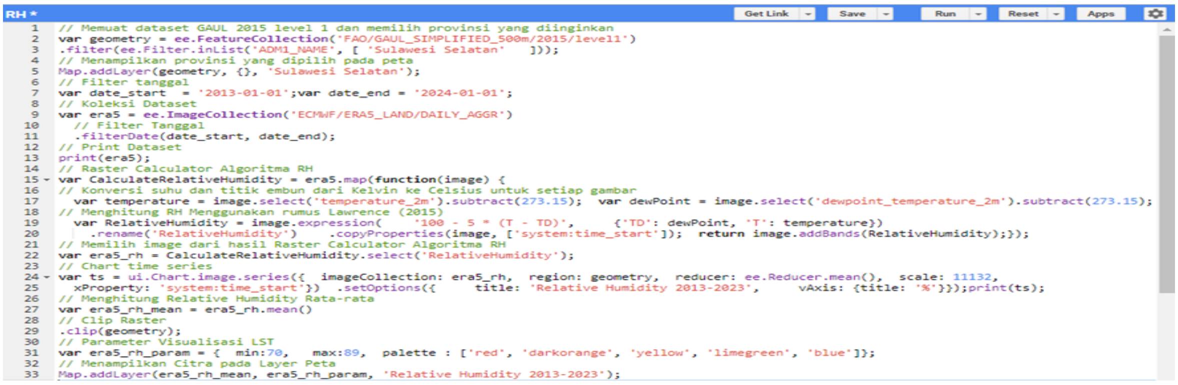
```
AT *                                   Get Link   Save   Run   Reset   Apps
// Memuat dataset GAUL 2015 level 1 dan memilih provinsi yang diinginkan
var geometry = ee.FeatureCollection('FAO/GAUL_SIMPLIFIED_500m/2015/level1')
    .filter(ee.Filter.inList('ADM1_NAME', [ 'Sulawesi Selatan'     ]));
// Menampilkan provinsi yang dipilih pada peta
Map.addLayer(geometry, {}, 'Sulawesi Selatan');
// Filter tanggal
var date_start  = '2013-01-01';
var date_end  = '2024-01-01';
//Koleksi Dataset
var era5 = ee.ImageCollection('ECMWF/ERA5_LAND/DAILY_AGGR')
//Filter Tanggal Dataset
.filterDate(date_start, date_end)
//Memilih Band Dataset
.select('temperature_2m');
//Print Dataset
print(era5);
//Multiply with slope coefficient and Conversion to Celcius
var era5_at = era5.map(function(image) {
  return image    .add(-273.15)    .copyProperties(image, ['system:time_start']);});
//Chart time series
var ts = ui.Chart.image.series({  imageCollection: era5_at,  region: geometry,
  reducer: ee.Reducer.mean(),  scale: 11132,  xProperty: 'system:time_start'})
  .setOptions({     title: 'Air Temperature 2023',     vAxis: {title: '°C'}});print(ts);
// Rata-rata ERA5 AT
var era5_at_mean = era5_at.mean()
//Clip ERA5 AT
.clip(geometry);
//Parameter Visualisasi
var era5_at_param = { min: 16,
max: 27,
  palette: ['blue', 'limegreen', 'yellow', 'darkorange', 'red']};
//Menampilkan ERA5 AT pada Layer Peta
Map.addLayer (era5_at_mean, era5_at_param, 'AT_AVE_2023');
```

Figure 2. Script for converting ERA5-Land 2m temperature to Celsius.

The next step was to determine the Relative Humidity (RH) value, which is the percentage of moisture in the air relative to the maximum amount of moisture that the air can hold at a given temperature. This value was obtained using ERA5-Land imagery by utilizing the 2-meter dew point temperature band and converting the temperature from Kelvin to Celsius. The relative Humidity is calculated using the following formula:

$$RH = 100 - 5(T - TD) \tag{1}$$

where RH is Relative Humidity; T is Air Temperature; and TD are Dew Point Temperature. The script code used for this calculation is shown in Figure 3.



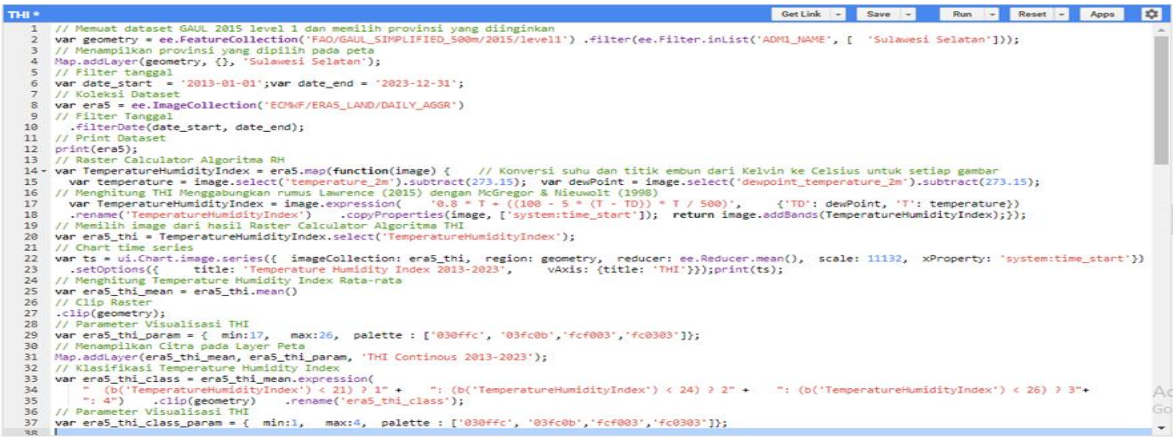
```
RH *
// Memuat dataset GAUL 2015 level 1 dan memilih provinsi yang diinginkan
var geometry = ee.FeatureCollection('FAO/GAUL_SIMPLIFIED_500m/2015/level1')
.filter(ee.Filter.inList('ADM1_NAME', [ 'Sulawesi Selatan'   ]));
// Menampilkan provinsi yang dipilih pada peta
Map.addLayer(geometry, {}, 'Sulawesi Selatan');
// Filter tanggal
var date_start  = '2013-01-01';var date_end = '2024-01-01';
// Koleksi Dataset
var era5 = ee.ImageCollection('ECMWF/ERA5_LAND/DAILY_AGGR')
  // Filter Tanggal
  .filterDate(date_start, date_end);
// Print Dataset
print(era5);
// Raster Calculator Algoritma RH
var CalculateRelativeHumidity = era5.map(function(image) {
// Konversi suhu dan titik embun dari Kelvin ke Celsius untuk setiap gambar
  var temperature = image.select('temperature_2m').subtract(273.15);  var dewPoint = image.select('dewpoint_temperature_2m').subtract(273.15);
// Menghitung RH Menggunakan rumus Lawrence (2015)
  var RelativeHumidity = image.expression(    '100 - 5 * (T - TD)',     {'TD': dewPoint, 'T': temperature})
    .rename('RelativeHumidity')    .copyProperties(image, ['system:time_start']);  return image.addBands(RelativeHumidity);});
// Memilih image dari hasil Raster Calculator Algoritma RH
var era5_rh = CalculateRelativeHumidity.select('RelativeHumidity');
// Chart time series
var ts = ui.Chart.image.series({  imageCollection: era5_rh,  region: geometry,  reducer: ee.Reducer.mean(),  scale: 11132,
  xProperty: 'system:time_start'})  .setOptions({     title: 'Relative Humidity 2013-2023',     vAxis: {title: '%'}});print(ts);
// Menghitung Relative Humidity Rata-rata
var era5_rh_mean = era5_rh.mean()
// Clip Raster
.clip(geometry);
// Parameter Visualisasi LST
var era5_rh_param = {  min:70,   max:89,  palette : ['red', 'darkorange', 'yellow', 'limegreen', 'blue']};
// Menampilkan Citra pada Layer Peta
Map.addLayer(era5_rh_mean, era5_rh_param, 'Relative Humidity 2013-2023');
```

Figure 3. Script for Relative Humidity calculation using ERA5-Land data.

The next step was to determine the thermal comfort index using formula modelling according to McGregor and Nieuwolt (1998).

$$\text{THI} = (0{,}8 \text{ x } T) + \left[\frac{RH + T}{500}\right] \tag{2}$$

where THI is the temperature–humidity index, T is the air temperature, and RD is the relative humidity. The results of the relative humidity and air temperature analyses were categorised based on thermal comfort levels. Specifically, temperatures below 21°C are classified as cold, temperatures between 21°C and 24°C are considered comfortable, temperatures ranging from 24°C to 26°C are considered moderately comfortable, and temperatures exceeding 26°C fall into the discomfort category. The THI formula was applied to the RH value using a script to generate the THI output. The script code used is shown in Figure 4.



```
THI *
// Memuat dataset GAUL 2015 level 1 dan memilih provinsi yang diinginkan
var geometry = ee.FeatureCollection('FAO/GAUL_SIMPLIFIED_500m/2015/level1') .filter(ee.Filter.inList('ADM1_NAME', [  'Sulawesi Selatan']));
// Menampilkan provinsi yang dipilih pada peta
Map.addLayer(geometry, {}, 'Sulawesi Selatan');
// Filter tanggal
var date_start  = '2013-01-01';var date_end = '2023-12-31';
// Koleksi Dataset
var era5 = ee.ImageCollection('ECMWF/ERA5_LAND/DAILY_AGGR')
// Filter Tanggal
  .filterDate(date_start, date_end);
// Print Dataset
print(era5);
// Raster Calculator Algoritma RH
var TemperatureHumidityIndex = era5.map(function(image) {    // Konversi suhu dan titik embun dari Kelvin ke Celsius untuk setiap gambar
  var temperature = image.select('temperature_2m').subtract(273.15);  var dewPoint = image.select('dewpoint_temperature_2m').subtract(273.15);
// Menghitung THI Menggabungkan rumus Lawrence (2015) dengan McGregor & Nieuwolt (1998)
  var TemperatureHumidityIndex = image.expression(    '0.8 * T + ((100 - 5 * (T - TD)) * T / 500)',     {'TD': dewPoint, 'T': temperature})
  .rename('TemperatureHumidityIndex')    .copyProperties(image, ['system:time_start']);  return image.addBands(TemperatureHumidityIndex);});
// Memilih image dari hasil Raster Calculator Algoritma THI
var era5_thi = TemperatureHumidityIndex.select('TemperatureHumidityIndex');
// Chart time series
var ts = ui.Chart.image.series({  imageCollection: era5_thi,  region: geometry,  reducer: ee.Reducer.mean(),  scale: 11132,  xProperty: 'system:time_start'})
  .setOptions({     title: 'Temperature Humidity Index 2013-2023',     vAxis: {title: 'THI'}});print(ts);
// Menghitung Temperature Humidity Index Rata-rata
var era5_thi_mean = era5_thi.mean()
// Clip Raster
.clip(geometry);
// Parameter Visualisasi THI
var era5_thi_param = {  min:17,   max:26,  palette : ['030ffc', '03fc0b','fcf003','fc0303']};
// Menampilkan Citra pada Layer Peta
Map.addLayer(era5_thi_mean, era5_thi_param, 'THI Continous 2013-2023');
// Klasifikasi Temperature Humidity Index
var era5_thi_class = era5_thi_mean.expression(
    "  (b('TemperatureHumidityIndex') < 21) ? 1" +    ": (b('TemperatureHumidityIndex') < 24) ? 2" +    ": (b('TemperatureHumidityIndex') < 26) ? 3"+
    ": 4")    .clip(geometry)    .rename('era5_thi_class');
// Parameter Visualisasi THI
var era5_thi_class_param = {  min:1,   max:4,  palette : ['030ffc', '03fc0b','fcf003','fc0303']};
```

Figure 4. Script for calculating THI from Relative Humidity data.

Data validation was performed to determine the level of correlation between the relative humidity and water temperature data of the South Sulawesi Climatology Station with five land era data using the correlation test using the Pearson correlation formula.

$$r_{xy} = \frac{n\sum x_i y_i \; - (\sum x_i)\,(\sum y_i)}{\sqrt{(n\sum x_i^2 - (\sum x_i)^2)(n\sum y_i^2 - (\sum y_i)^2)}} \tag{3}$$

where r_{xy} is the correlation between x and y, n is the number of samples, x_i is the i-th x value, and y_i is the i-th y value. Correlation calculations were performed using SPSS to determine the value of air temperature and relative humidity data obtained from the South Sulawesi Climatology Station and five Land Era data. The level of closeness can be described as follows.

Table 1. Interval Coefficient of Pearson correlation values

Coefficient Interval	Correlation Closeness
0,00-0,20	Very weak
0,21-0,40	Weak
0,41-0,70	Moderate
0,71-0,90	Strong
0,91-0,99	Very Strong
1	Perfect Correlation

Source: (Nugroho et al., 2008)

The distribution of THI values was represented using a script code in conjunction with ArcMap, culminating in the generation of the distribution map output. The research methodology is illustrated in Figure 5.

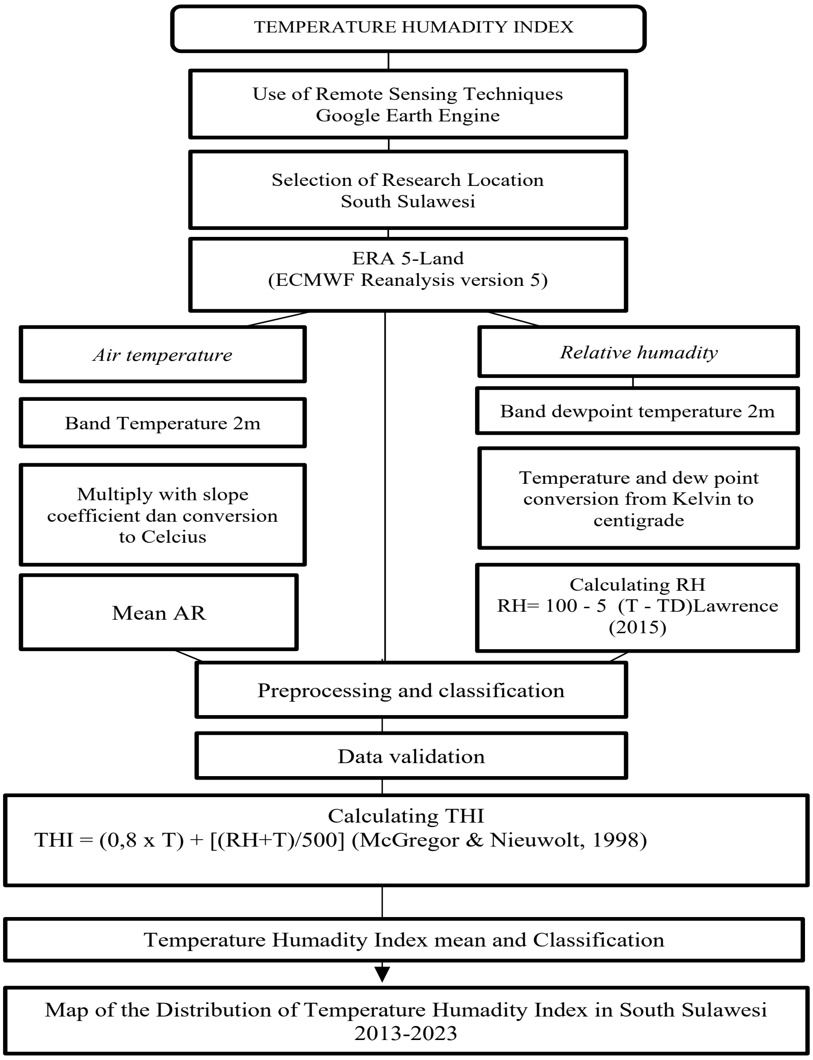


Figure 5. Flowchart of Recearch.

3. RESULTS AND DISCUSSION

3.1. Result

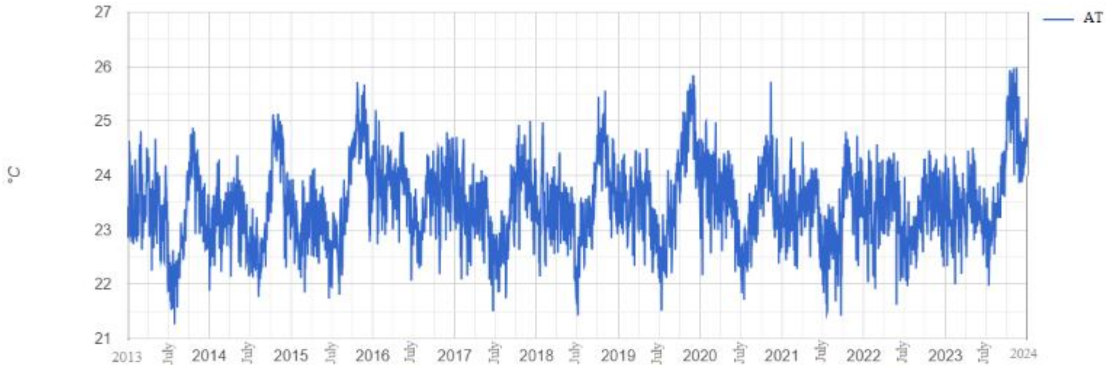


Figure 6. Air Temperature in South Sulawesi Province 2013-2023.

Based on Figure 6, the lowest air temperatures (AT) in South Sulawesi from 2013 to 2023 generally occurred between June and September, ranging from 21.4°C to 22.1°C. The highest ATs were recorded between October and December, reaching up to 26.0°C. The hottest year was 2023, with a peak temperature of 26°C occurring in November.

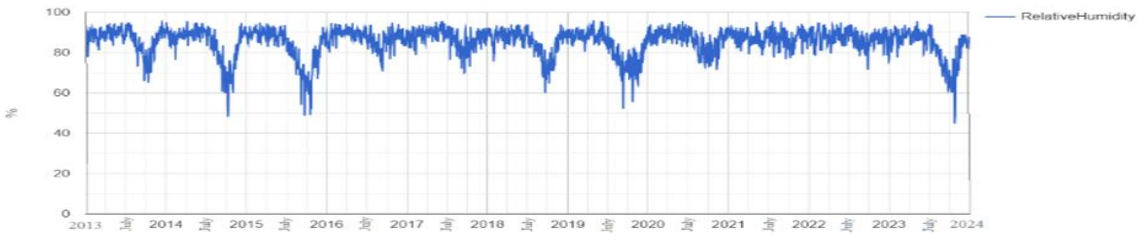


Figure 7. Relative Humadity In South Sulawesi 2013-2023.

Based on Figure 7, the lowest relative humidity (RH) in South Sulawesi from 2013 to 2023 typically occurred between September and October, whereas the highest RH was mostly recorded between March and July, ranging from 94% to 96%. The year 2023 recorded the lowest RH of the period, with October recording the lowest monthly RH at 44.7%.

Tables 2 and 3 present the results of the Pearson correlation test used to validate the ERA5-Land dataset with the BMKG station data. RH showed a very strong correlation (r = 0.987), and AT showed a strong correlation (r = 0.888), confirming ERA5's reliability for climatological spatial analysis in South Sulawesi.

Table 2. Correlation Test of RH and AT (BMKG vs. ERA5-Land)

Variable	Pearson Correlation	Sig. (2-tailed)	Interpretation
RH	0,987	0,000	Very Strong
AT	0,888	0,000	Strong

Based on Figure 8, the average THI value reached a peak of 24.46 °C on 15 November 2023 indicating a transition into the "fairly comfortable" category. Over the 2013–2023 period, THI values showed an increasing trend with seasonal fluctuations, with the hottest years being 2020 and 2023.

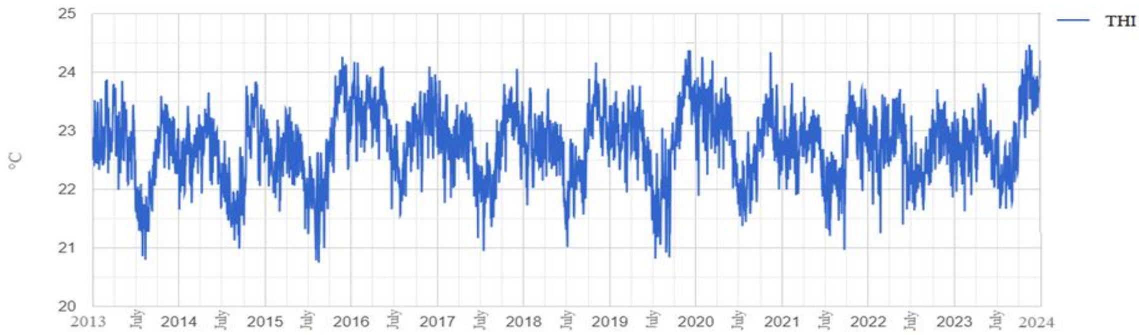


Figure 8. Average THI in South Sulawesi 2013–2023.

The categorisation of the Temperature-Humidity Index (THI) over the 2013–2023 period in South Sulawesi is summarised in Table 3. This classification highlights the distribution of land areas affected by varying degrees of thermal discomfort.

Table 3. Mean THI Distribution Categories (2013–2023)

THI Category	Range (°C)	Area (hectares)
Cold	< 21	994.384,62
Comfortable	21–24	1.190.393,32
Fairly Comfortable	24–26	1.810.662,30
Uncomfortable	> 26	532.780,13

Based on Figure 9, which presents annual THI distribution maps, the areas categorised as "fairly comfortable" and "uncomfortable" increased progressively. The red areas indicating discomfort expanded noticeably in 2019, 2020, and 2023.

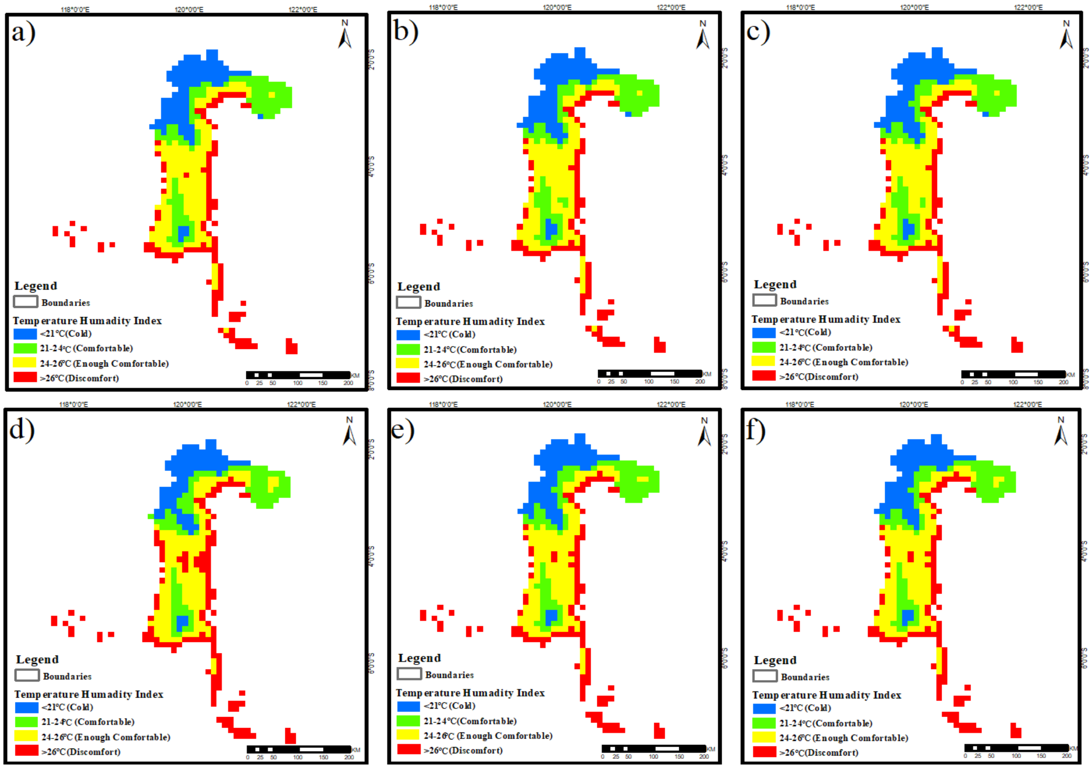


Figure 9. Map of Temperature Humidity Index (THI) Distribution for South Sulawesi Province. a) THI 2013; b) THI 2014; c) THI 2015; d) THI 2016; e) THI 2017; f) THI 2018.

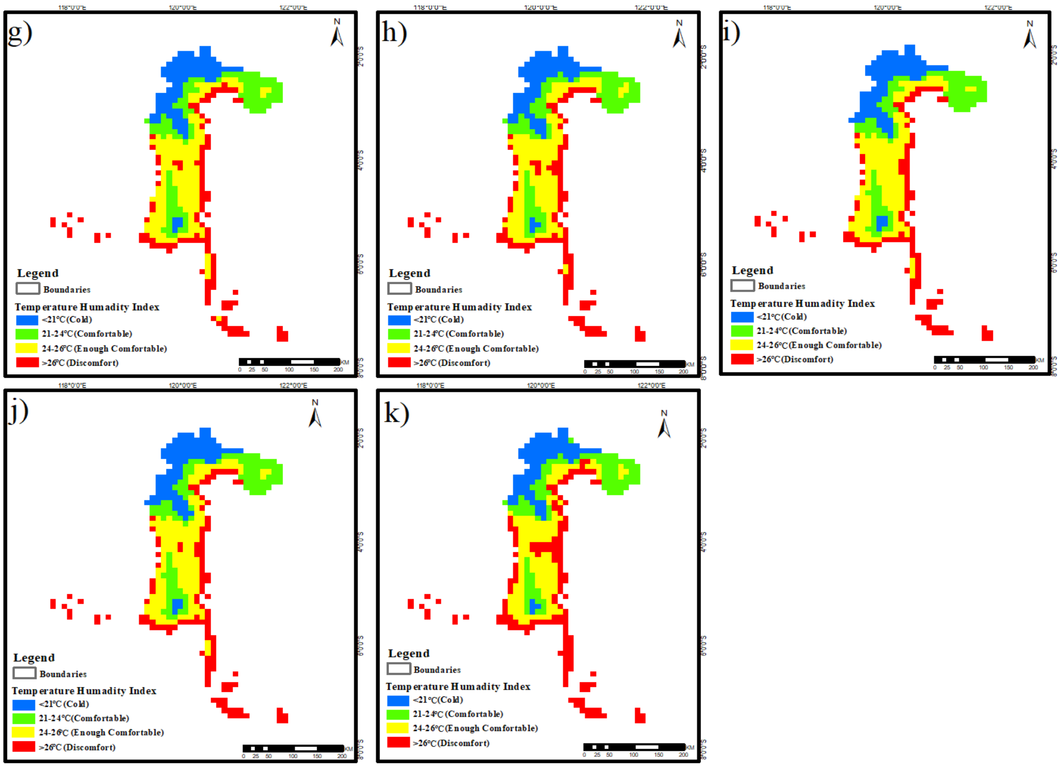


Figure 9. Map of Temperature Humidity Index (THI) Distribution for South Sulawesi Province. g) THI 2019; h) THI 2020; i) THI 2021; j) THI 2022; k) THI 2023.

Figure 6 confirms that the spatial extent of THI over the ten-year period shows 40% of South Sulawesi in the fairly comfortable category, 26% in comfortable, 22% in cold, and 12% in the uncomfortable category.

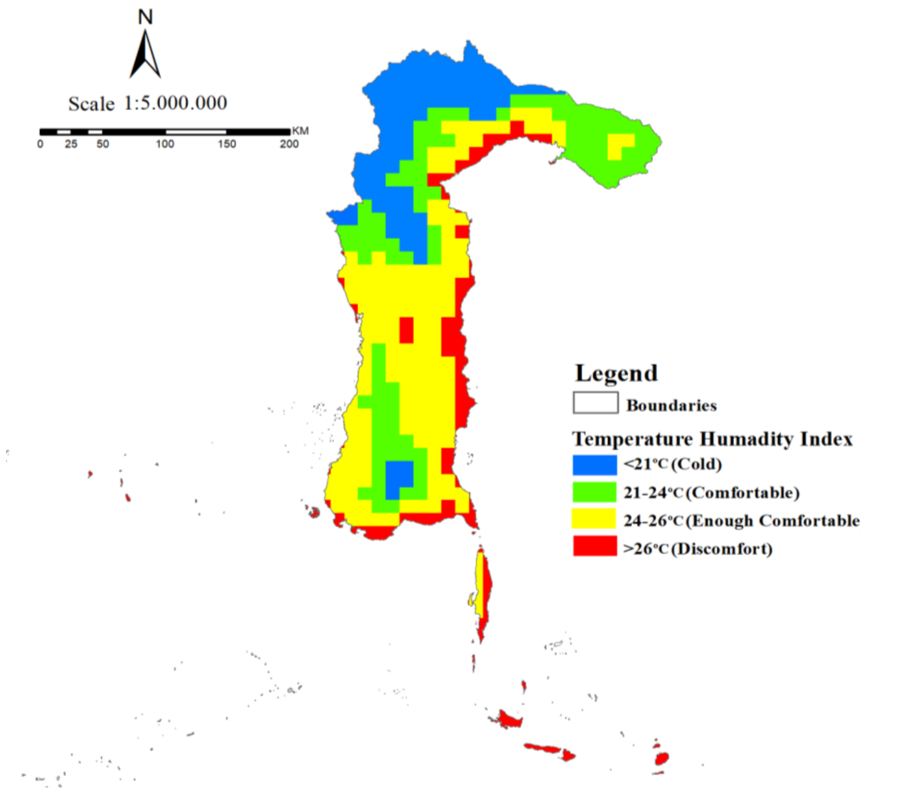


Figure 10. THI Mean distribution map for South Sulawesi 2013-2023.

3.2. Discussion

The mean water temperature value in the 2013-2023 period in South Sulawesi Province increased yearly. The highest average temperature (water temperature) will occur in 2023, namely, 26 °C in November. The increase in water temperature every year causes the temperature to feel hotter than it did in previous years. Scientists at NASA's Goddard Institute of Space Studies (GISS) in New York have proven this temperature increase through research. The summer of 2023 was record-breaking and continued the long-term warming trend. This increase in temperature is due to the increase in population and population activities which cause physical changes in the area that affect the microclimate (Utami et al., 2024). The El Niño–Southern Oscillation (ENSO) also influences increasing temperatures (Duan et al., 2021).

The relative humidity in the 2013-2023 period in South Sulawesi Province and Indonesia was high on average. ideal air humidity ranges from (45-65%) while in Indonesia, including South Sulawesi, the average is above 65% and continues to increase (Rudin et al., 2020). This high humidity is the result of Indonesia being located on the equator, which makes the climate warm throughout the year, and the majority of Indonesia's territory is water or sea. The flow of warm water from the Pacific to the Indian Ocean also contributes to increased evaporation and air humidity. As a country with a tropical climate, Indonesia receives large amounts of sunlight throughout the year, which causes a lot of evaporation and high air humidity levels, and the large number of tropical forests in Indonesia also contributes to this. high air humidity. During the dry season, air temperatures rise, and humidity often remains high, creating a sultry atmosphere. This is a common phenomenon in Indonesia, where hot temperatures accompanied by high humidity can make people feel uncomfortable. When the relative humidity in the air is high, the body's ability to cool itself through the evaporation of sweat is reduced. This makes the perceived temperature (heat index) higher than the actual air temperature. For example, a maximum temperature of 35°C can feel like 43°C under high humidity conditions. High humidity can increase the risk of health problems such as dehydration and heat exhaustion because the body cannot cool itself effectively. Excessive humidity can also trigger the growth of fungi and bacteria and worsen respiratory conditions. In 2023, the relative air humidity will decrease to 44.7%, which is in the dry humidity category. Dry humidity causes the temperature to increase and feel more intense (Rahayuningtyas & Kuala, 2016). Low humidity can cause a dry environment which has a negative impact on ecosystems, agriculture, and human health.

The temperature humidity index in South Sulawesi province during the 2013-2023 period was in the comfortable category of 21°C – 24°C. Comfort can still be felt. However, the THI values continue to increase annually. This is proven by the highest THI in 2023, an average of 24.46 o C, indicating that South Sulawesi is in the quite comfortable category. This is a threat to the province of South Sulawesi, which must pay more attention to aspects of environmental management and development. This is also closely related to high air temperatures and non-ideal relative humidity.

During the 2013–2023 period, the spatial distribution of the Temperature-Humidity Index (THI) in South Sulawesi showed that 994,384.62 ha were categorised as cold (THI < 21°C), 1,190,393.32 ha as comfortable (THI 21–24°C), 1,810,662.30 ha as fairly comfortable (THI 24–26°C), and 532,780.13 ha as uncomfortable (THI > 26°C). On average, 40% of the region experienced fairly comfortable conditions, 26% comfortable, 22% cold, and 12% uncomfortable, illustrating the thermal comfort distribution pattern across the province.

The increase in the Temperature Humidity Index (THI) in South Sulawesi Province during the 2013-2023 period has significantly impacted climate change and various aspects of life. The increase in average temperature, which peaked in 2023 at a water temperature of 26°C, indicates a continuing warming trend, as confirmed by a NASA study (Wang et al., 2022). Factors such as the increasing population and human activities that influence the microclimate, as well as the influence of the El Niño–Southern Oscillation (ENSO), also worsen these conditions (Duan et al., 2021). This increase in temperature exacerbates the phenomenon of high air humidity which exceeds the ideal limits (45–65%) in most areas, giving rise to thermal discomfort which can increase health risks such as heat exhaustion and dehydration (Rudin et al., 2020).

Spatially, the distribution of THI shows that the majority of areas are in the comfortable to quite comfortable category, but the annual increase in THI indicates a shift towards a hotter and more uncomfortable category. With significant areas in the moderately comfortable (24–26°C) and uncomfortable (>26°C) categories, threats to ecosystems, agriculture, and public health become real (Rahayuningtyas & Kuala, 2016). For example, drought due to low humidity in 2023 will disrupt plant productivity and the sustainability of local ecosystems.

Strategic steps are needed to reduce this impact in sustainable mitigation efforts. Reforestation and sustainable forest management can stabilise microclimates and reduce the effects of warming (Maru & Ahmad, 2014). At the local level, increasing green open spaces and using environmentally friendly technologies, such as low-thermal building materials, are practical solutions. In addition, the implementation of a real-time THI monitoring system will help the government and society to respond adaptively to climate change (Utami et al., 2024). Collaboration between the government, academia, and society is needed to ensure that development in South Sulawesi remains environmentally friendly and sustainable.

4. CONCLUSIONS

The temperature–humidity index (THI) of South Sulawesi Province from 2013 to 2023 shows that the "cold" category, with a THI value of less than 21°C, covers an area of 994,384.62 ha. The "comfortable" category, with a THI value ranging from 21°C to 24°C, covered an area of 1,190,393.32 hectares. The "fairly comfortable" category, with a THI value between 24°C and 26°C, spans an area of 1,810,662.30 hectares, while the "uncomfortable" category, with a THI value greater than 26°C, covered 532,780.13 ha. Additionally, over the same period, 40% of the population in South Sulawesi Province reported experiencing "fairly comfortable" conditions, 26% felt "comfortable", 22% felt "cold", and 12% reported feeling "uncomfortable".

The increase in the Temperature Humidity Index (THI) in South Sulawesi from 2013 to 2023 indicates a continuous warming trend, exacerbated by population growth, human activities, and the ENSO phenomenon, which raises air humidity beyond ideal limits and triggers health risks and thermal discomfort. Spatially, although most areas are still categorised as comfortable, annual trends show a shift toward hotter conditions, threatening ecosystems, agriculture, and public health in the future. For example, the drought in 2023 disrupted crop productivity and ecosystem balance. For mitigation, reforestation, expansion of green spaces, eco-friendly technologies, and a real-time THI monitoring system are needed to support adaptive responses to climate change through collaboration between the government, academia, and society.

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6. REFERENCES

Agroho, F. L., Syahreza, S., & Sugiyanto, D. (2021). Analysis of the rainfall event in 2018-2019 using the air stability index method at the Meteorological Station of Sultan Iskandar Muda Banda Aceh. *Journal of Physics: Conference Series, 1882*(1). https://doi.org/10.1088/1742-6596/1882/1/012023

Alexander, L. V. (2016). Global observed long-term changes in temperature and precipitation extremes: A review of progress and limitations in IPCC assessments and beyond. *Weather and Climate Extremes, 11*, 4–16. https://doi.org/10.1016/j.wace.2015.10.007

Alizadeh, O. (2023). Changes in the mean and variability of temperature and precipitation over global land areas. *Environmental Research: Climate, 2*(3), 035006. https://doi.org/10.1088/2752-5295/ace279

Anandhi, A., Frei, A., Pierson, D. C., Schneiderman, E. M., Zion, M. S., Lounsbury, D., & Matonse, A. H. (2011). Examination of change factor methodologies for climate change impact assessment. *Water Resources Research, 47*(3), 1–10. https://doi.org/10.1029/2010WR-009104

Anggraini, P. G. S., & Yuadi, I. (2023). Tren Publikasi Climate Change (Perubahan Iklim) Tahun 2020-2023 Pada Scopus. *JIPI (Jurnal Ilmu Perpustakaan Dan Informasi), 8*(2), 213. https://doi.org/10.30829/jipi.v8i2.15917

Angkasa, Z., Angrini, S. N., Febrina, S. E., & Iskandar, I. (2023). The Use of Passive Cooling Techniques in Urban Heat Island (UHI) Mitigation: Literature Review. *Jurnal Arsitektur, 7*(1), 130–142. https://doi.org/https://doi.org/10.32502/arsir.v7i1.6212

Arfandi, A., Yusuf, M., Nasrul, N., Amdah, M., Hasja, A. D., & Maru, R. (2024). The Ability of Green Open Space in Reducing Green House Gas (GHG) Emissions on Jalan Hertasning, Makassar Citu. *SAINSMAT: Jurnal Ilmiah Ilmu Pengetahuan Alam, 13*(2), 154–161. https://doi.org/10.35580/sainsmat132515432024

Demasi, M., Chekuri, B., Paladine, H., & Kenyon, T. (2022). Climate Change: A Crisis for Family Medicine Educators. *Family Medicine, 54*(9), 683–687. https://doi.org/10.22454/FamMed.-2022.827476

Djelailia, H., M'hamdi, N., Jemmali, B., Bouraoui, R., & Najar, T. (2023). Temperature-Humidity Index Values and Their Significance on the Daily Production of Dairy Cattle in the North African Arid Region. *Al-Qadisiyah Journal For Agriculture Sciences, 13*(1), 147–154. https://doi.org/10.33794/qjas.2023.137406.1114

Duan, X., Xue, F., & Zheng, F. (2021). Sea surface temperature anomaly in the tropical North Atlantic during El Niño decaying years. *Atmospheric and Oceanic Science Letters, 14*(6), 100077. https://doi.org/10.1016/j.aosl.2021.100077

Eko, W., Parikesit, Joy, B., Setyawati, W., & Mahdi, R. (2022). Projection of CO2 emissions in Indonesia. *Materials Today: Proceedings, 63*, S438–S444. https://doi.org/10.1016/j.matpr.2022.04.091

Ginting, N. (2017). Benefits of using biogas technology in rural area: Karo district on supporting local action plan for greenhouse gas emission reduction of north sumatera province 2010-2020. *IOP Conference Series: Earth and Environmental Science, 65*(1). https://doi.org/10.1088/1755-1315/65/1/012007

Hagemann, S., Chen, C., Clark, D. B., Folwell, S., Gosling, S. N., Haddeland, I., Hanasaki, N., Heinke, J., Ludwig, F., Voss, F., & Wiltshire, A. J. (2013). Climate change impact on available water resources obtained using multiple global climate and hydrology models. *Earth System Dynamics, 4*(1), 129–144. https://doi.org/10.5194/esd-4-129-2013

Haris, H., Nasrul, N., Amalul, M. A. M., Ziddiq, S., Amdah, M., Nur, M. M., & Maru, R. (2023). Sebaran Jaringan Penakar Hujan di DAS Jeneberang Menggunakan Metode Polygon Thiessen. *Jurnal Sainsmat, 12*(2), 192–199. https://doi.org/10.35580/sainsmat-122523242023

Hehanussa, F. S., Sumunar, D. R. S., & Rakuasa, H. (2023). Pemanfaatan Google Earth Engine Untuk Identifikasi Perubahan Suhu Permukaan Daratan Kabupaten Buru Selatan Berbasis Cloud Computing. *Gudang Jurnal Multidisiplin Ilmu, 1*(1), 37–45. https://doi.org/10.59435-/gjmi.v1i1.27

Huang, G., Xu, Z., Qu, X., Cao, J., Long, S., Yang, K., Hou, H., Wang, Y., & Ma, X. (2022). Critical climate issues toward carbon neutrality targets. *Fundamental Research, 2*(3), 396–400. https://doi.org/10.1016/j.fmre.2022.02.011

Kustia, T., & Sihombing, T. B. A. (2022). Kenyamanan Termal Klimatologis di Provinsi Riau berdasarkan Temperature Humidity Index (THI). *Buletin GAW Bariri, 3*(2), 41–46. https://doi.org/10.31172/bgb.v3i2.78

Lin, X., Chen, J., Wu, T., Yi, S., Chen, J., & Han, X. (2024). Time-series simulation of alpine grassland cover using transferable stacking deep learning and multisource remote sensing data in the Google Earth Engine. *International Journal of Applied Earth Observation and Geoinformation, 131*(May), 103964. https://doi.org/10.1016/j.jag.2024.103964

Malihah, L. (2022). Tantangan Dalam Upaya Mengatasi Dampak Perubahan Iklim Dan Mendukung Pembangunan Ekonomi Berkelanjutan: Sebuah Tinjauan. *Jurnal Kebijakan Pembangunan, 17*(2), 219–232. https://doi.org/10.47441/jkp.v17i2.272

Marciniak, A. M. (2014). The use of temperature-humidity index (thi) to evaluate temperature-humidity conditions in free- stall barns. *Journal of Central European Agriculture, 15*(2), 73–83. https://doi.org/10.5513/JCEA01/15.2.1455

Maru, R., & Ahmad, S. (2014). Daytime Temperature Trend Analysis in the City of Jakarta, Indonesia. *World Applied Sciences Journal, 32*(9), 1808–1813. https://doi.org/10.5829/idosi.wasj.2014.32.09.1021

Maru, R., Alimato, A., Nyompa, S., Nasrul, N., Arfandi, A., & Amda, M. (2023). Strategi Adaptasi Petani Sawah dalam Menghadapi Perubahan Iklim di Kabupaten Maros. *Jurnal Environmental Science, 6*(1). https://doi.org/https://doi.org/10.35580/jes.v6i1.52038

Maru, R., Baharuddin, I. I., Umar, R., Rasyid, R., Uca, Sanusi, W., & Bayudin. (2015). Analysis of the heat island phenomenon in Makassar, South Sulawesi, Indonesia. *American Journal of Applied Sciences, 12*(9), 616–626. https://doi.org/10.3844/ajassp.2015.616.626

Maru, R., Nasrul, N., Nuryadin, M. T., Nur, M. M., Amdah, M., Hasja, A. D., Musyawarah, R., Mulianti, M., & Tripaldi, A. (2024). Spatial Analysis of Flood Vulnerability Levels in Makassar City Using Geographic Information Systems. *Jurnal Ilmu Alam Dan Lingkungan, 15*(2), 87–97. https://doi.org/https://doi.org/10.20956/jal.v15i2.36931

Maru, R., Nasrul, N., Rasul, M., Rivaldi.R, R. ., Wahyuni, R. S., Faizin, S. A., & Nuryadi, N. (2025). Impact of Land Use on Urban Heat Island Phenomenon: A Spatial Analysis of Pare-pare City, South Sulawesi. *Jambura Geoscience Review, 7*(1), 13–24. https://doi.org/10.37905/jgeosrev.v7i1.27362

Merchant, M., Brisco, B., Mahdianpari, M., Bourgeau-Chavez, L., Murnaghan, K., DeVries, B., & Berg, A. (2023). Leveraging google earth engine cloud computing for large-scale arctic wetland mapping. *International Journal of Applied Earth Observation and Geoinformation, 125*, 1–13. https://doi.org/10.1016/j.jag.2023.103589

Nasrul, N., Amdah, M., & Maru, R. (2024). Impact of Climate Change on Water Availability: Systematic Literature Review. *Journal of Geographical Sciences and Education, 2*(4), 183–192. https://doi.org/10.69606/geography.v2i4.139

Nasrul, N., Nur, D. E., Kausarani, R., Amdah, M., Arfandi, A., Musyawarah, R., Nur, M. M., Hasja, A. D., & Maru, R. (2024). Studi Analisis Hubungan Iklim Mikro Terhadap Kondisi Kenyamanan Termal Ruang Kuliah Jurusan Geografi FMIPA Universitas Negeri Makassar. Indonesian Journal of Fundamental and Applied Geography, 1(2), 31–36. https://journal.lontaradigitech.com/IJFAG/article/view/500

Nugroho, S., Akbar, S., & Vusvitasari, R. (2008). Kajian Hubungan Koefisien Korelasi Pearson, Spearman-rho, Kendall-Tau, Gamma, dan Somers. *Jurnal Ilmiah MIPA, 4*(2), 372–381. https://ejournal.unib.ac.id/index.php/gradien/article/view/279

Rahaman, S. N., Ahmed, S. M. M., Zeyad, M., & Zim, A. H. (2023). Effect of vegetation and land surface temperature on NO2 concentration: A Google Earth Engine-based remote sensing approach. *Urban Climate, 47*(2), 101336. https://doi.org/10.1016/j.uclim.2022.101336

Rahayuningtyas, A., & Kuala, S. I. (2016). Pengaruh Suhu Dan Kelembaban Udara Pada Proses Pengeringan Singkong (Studi Kasus : Pengering Tipe Rak). *ETHOS (Jurnal Penelitian Dan Pengabdian), 4*(1), 99–104. https://doi.org/10.29313/ethos.v0i0.1663

Rudin, N. A., Damayanti, F. N., Sawajir, M. U., Zacharias, D. K. N., Tasik, M. S., & Donuisang, R. D. (2020). Potensi Keanekaragaman Vegetasi Pohon untuk Konservasi Air di Desa Kolobolon, Kecamatan Lobalain, Rote Ndao, Nusa Tenggara Timur. *Prosiding Seminar Nasional Biologi, 6*(1), 191–198. https://doi.org/https://doi.org/10.24252/psb.v6i1.15731

Taufiq, A., & Wulandari, C. (2022). Comfort Level of Green Open Space in Bandar Lampung Based on Climate and Humidity. *Jurnal Belantara, 5*(1), 01–13. https://doi.org/10.29303/jbl.v5i1.847

Utami, R. D., Sideng, U., Yusuf, M., Nasrul, N., Nur, M. M., Hasja, A. D., & Maru, R. (2024). Characteristics of Urban Heat Island in Pare-Pare City: Insights From Spatial Analysis. *Jurnal Ilmu Alam Dan Lingkungan, 15*(2), 43–52. https://doi.org/https://doi.org/10.20956/jal.v15i2.36779

Wang, Y., Ye, A., Peng, D., Miao, C., Di, Z., & Gong, W. (2022). Spatiotemporal variations in water conservation function of the Tibetan Plateau under climate change based on InVEST model. *Journal of Hydrology: Regional Studies, 41*, 1–17. https://doi.org/10.1016/j.ejrh.2022.-101064.