# Urban Climate Mitigation through NDVI and Albedo Monitoring: A Case Study in Kendari, Indonesia

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## ABSTRACT

The objective of this research is to apply spatial analysis of the Normalized Difference Vegetation Index (NDVI), albedo, and air temperature in Kendari City to identify the types of land use change resulting from changes in the vegetation of the Nipa-Nipa-forest area, the air temperature trend over the last 10 years, and to map areas with high mitigation needs. The method used is the spatial analysis of Landsat satellite imagery through supervised classification supported by ground check points to test the accuracy of 10 land use types. Air temperature analysis, and NDVI and albedo analysis are extracted from surface reflectance data to evaluate vegetation conditions and surface energy changes. The results show that air temperature variability is influenced by the duration of sun exposure and altitude. The diurnal pattern indicates that the temperature peaks at two in the afternoon and decreases again toward evening. At an altitude of 21.7 meters, the temperature is relatively lower during the day and higher at night compared to other layers. The Nipa-Nipa Grand Forest still dominates with the highest NDVI values, but has decreased in some zones due to forest fragmentation. Meanwhile, built-up areas and open land have experienced a significant increase with low NDVI values and high albedo, which indicates a reduction in vegetation quality and an increased potential for the urban heat island effect. Albedo values in vegetated areas, such as forests and mangroves, decreased between 2017 and 2022, indicating ecosystem degradation. The classification accuracy test yielded an overall accuracy of 94% and a Kappa value of 0.92, which shows a very high level of reliability and consistency with international research standards. The contribution of this research is to provide a spatial data-based scientific foundation regarding ecological dynamics in tropical urban areas, especially the role of the Nipa-Nipa Grand Forest as a climate buffer. These findings can support sustainable spatial planning, conservation strategies, and climate change mitigation efforts in Kendari City and similar regions.

**Keywords:** spatial analysis, land use, NDVI, forest, Kendari.

## INTRODUCTION

Kendari City, like many other urban centers worldwide, faces increasingly complex and intense climate change challenges [1], [9]. Rapid urbanization, along with the accompanying land use and land cover change, is a significant contributor to local climate dynamics, exacerbating extreme weather events and strengthening the warming effect in urban areas challenges challenges [2]. In this context, a deep understanding of key spatial environmental variables such as the Normalized Difference Vegetation Index (NDVI), Air Temperature, and albedo (surface reflectance) is crucial for formulating effective urban climate mitigation strategies challenges [7], [8], [24].

Land use change, especially the conversion of natural vegetation (including forests) to built-up land, contributes to increased greenhouse gas emissions and reinforces the intensity of local warming [4], [23]. Global urbanization also shows that more than half of the world's population now lives in urban areas, and urban population growth reaches about 67 million people per year [18]. The complex interaction between urbanization, land cover change, and climate variability demands a comprehensive study so that city policies and plans can be more adaptive to climate change [11].

Data from the Meteorology, Climatology, and Geophysics Agency (BMKG) shows that Kendari City has a high flood potential, especially during the May to June period, as a result of high rainfall. For instance, on March 6, 2024, extreme rainfall of 170 mm occurred within six hours, approaching

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the monthly average of 200 mm, which caused flooding in several city areas [6]. The topography of Kendari City, which is on the edge of the bay and surrounded by mountains, along with rapid urbanization without an adequate drainage system, exacerbates the risk of flooding and inundation. Furthermore, extreme temperature fluctuations are also a chronic problem: the El Nino–La Nina phenomenon, which previously appeared every 5–7 years, can now occur more frequently, triggering extreme weather and worsening the urban heat island effect. Between 1998 and 2020, the average maximum temperature increased to 32 °C, with the highest surge in 2018 reaching 33.3 °C [12].

The overview of various global problems and activities occurring in the Kendari city forest area impacts land use change, such as forest area conversion that affects global climate change [21], [26], making the utilization of remote sensing data necessary to determine air temperature changes and land use conditions [20], [22]. In facing this challenge, a remote sensing approach is highly important [28]. This method enables the spatial and temporal monitoring of land use/land cover change, surface temperature, vegetation density (NDVI), and albedo [15]. The use of Landsat imagery in this research allows for application at various scales, and this imagery is widely used in studies of surface temperature change and ecoregion identification [29], [36].

In global literature, the relationship between albedo, vegetation, and surface temperature has been widely studied. For example, [35], showed a correlation between albedo and 2m air temperature, vegetation fraction, and urbanization factor (built-up fraction). Another study by [16], observed long-term albedo changes due to urban expansion, finding that increased built-up land often increases regional surface albedo, although with complex effects on local climate. [31], also highlighted the importance of monitoring albedo along with NDVI in assessing the impact of reflective surfaces on local climate. [37], discussed the heterogeneity of urban albedo and how city structure, building density, and vegetation change affect spatial albedo. Meanwhile, [39], described surface albedo in the Boston metropolitan area using 30m imagery, finding that summer albedo contributes to surface temperature variability.

These studies reinforce the premise that albedo and vegetation (NDVI representation) play a key role in regulating the urban surface energy balance. Urbanization and the conversion of vegetation to impervious surfaces (asphalt, concrete, roofs) create surfaces with high albedo but without absorption or evapotranspiration capacity, contributing to higher surface temperatures and local heating effects [9]. Spatial analysis can identify areas with a high risk of heating effects and mitigation potential through increased vegetation cover [3], [4], [24]. In the context of Kendari City, spatial understanding of fluctuations (NDVI), Air Temperature, and albedo over the last decade allows for the identification of priority mitigation areas, for instance, areas experiencing vegetation degradation or significant increases in impervious surfaces. This spatial analysis can help policymakers strategically place "cooling green zones," regulate building surface materials, and strengthen drainage systems and city vegetation. Studies such as [17], show that increasing vegetation and increasing albedo in open areas can minimize the Surface Urban Heat Island (SUHI) effect more effectively than in densely closed areas. Therefore, this research aims to apply spatial analysis of NDVI, albedo, and air temperature in Kendari City to identify the types of vegetation in the Nipa-Nipa forest area, the trend of air temperature and rainfall change over the last 10 years, and to map areas with high mitigation needs. The results are expected to make a significant contribution to climate-adaptive spatial planning, strengthen the city's resilience to environmental risks, and support data-based policies to dampen the impact of local heating and climate extremes in the future.

## RESEARCH METHODS

### Study Area

This research was conducted in and around the Nipa-Nipa Grand Forest and the Kendari City Forest, which are administratively located in Kendari City, Southeast Sulawesi Province. Geographically and astronomically, the area is located between 3°54'40" - 4°5'5" S and 122°26'33" - 122°39'14" E. The research location is presented in Figure 1 below.

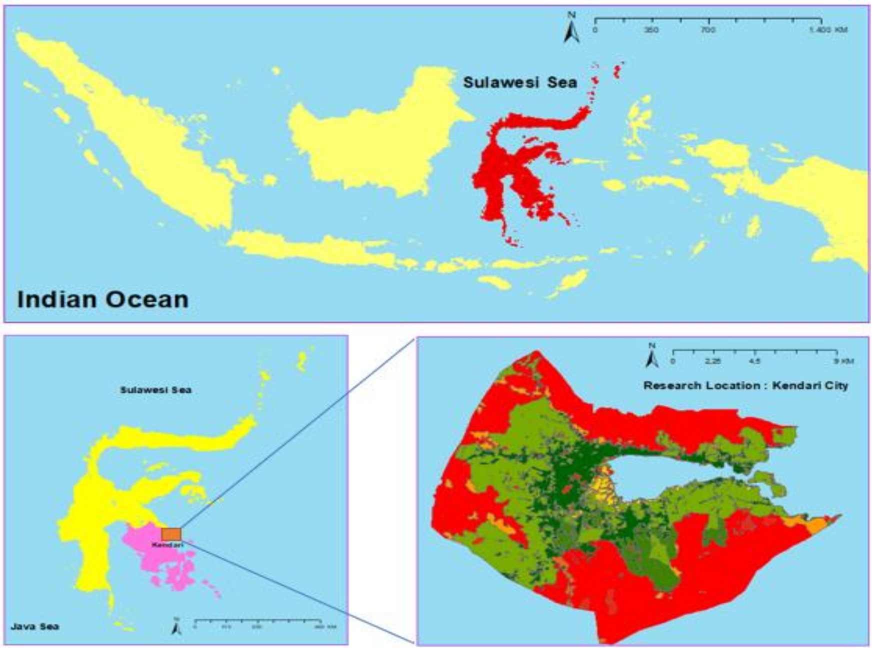


**Figure 1**. Research Location

**Analytcal Method**

The main data used in this study are satellite images obtained during the Landsat 8 OLI/TIRS recording period in 2017 and 2022 (path/row 112/63 with <10% cloud cover obtained from http://earthexplorer.usgs.gov/). Radiometric correction is the process of making improvements to pixel values distorted by atmospheric factors. This is necessary to obtain the actual pixel values in the correct position, as atmospheric effects cause reflections of objects on the Earth's surface to have different DN values from the actual values. The atmospheric factors to be corrected are errors in reflecting the surface or the curvature of the earth, the direction of sunlight, weather conditions, atmospheric conditions, and other factors so that the information provided is more accurate [40]. Remote sensing analysis data is further classified and the change in each land cover is calculated using spatial analysis techniques. The spatial analysis referred to in this research involves presenting the results of the NDVI and Albedo analyses [7].

**Albedo Analysis**

All solar radiation reaching the Earth's surface is modified through reflection, scattering, and absorption in the atmosphere. The ratio of shortwave radiation reflected back to the atmosphere to the incoming shortwave radiation is albedo [41]. The energy reflected by a surface is shortwave, so the sensor used to calculate albedo is a sensor that receives short wavelengths [24]. Solar radiation that reaches the surface will be reflected and absorbed by the surface [42]. The higher the radiation reflected back to the atmosphere, the higher the albedo value. The higher the radiation reflected back to the atmosphere, the smaller the absorption of radiation by the surface. The surface response to high or low radiation absorption varies according to the type of surface characteristics. Non-vegetated surfaces cause higher radiation to be reflected back to the atmosphere, higher albedo values, and less radiation absorbed. Based on [32] research, improvements in surface albedo values can directly result in precipitation simulation. The albedo estimation process uses geometrically and radiometrically corrected Landsat-8 satellite image data, processed using ArcGIS 10.6 software.

The equation used to calculate albedo with the raster calculator feature in ArcGIS 10.6 is based on the formulation for Landsat-7 that has been adjusted and can be applied to Landsat-8 [44], which has been normalized by [45]:

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$$\alpha = \frac{0.356\rho 2 + 0.130\rho 4 + 0.373\rho 5 + 0.085\rho 6 + 0.072\rho 7 - 0.0018}{0.356 + 0.130 + 0.373 + 0.085 + 0.072}$$

with ρ being the ToA reflectance of each band used.

**NDVI Analysis**

The NDVI estimation process uses Landsat-8 satellite image data. NDVI is a method used to show the difference in land use density classes and compare the level of greenness of vegetation [23]. The bands needed for NDVI calculation are band 5 and 4. The following is the NDVI equation [32] [3]:

$$\textbf{NDVI} : \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

with band 5 being the NIR (Near Infrared) channel and band 4 being the Red channel.

**RESULT AND DISCUSSION**

**Analysis of the Nipa-Nipa Grand Forest Area, Albedo, NDVI, and Air Quality**

Grand Forest areas, which are conservation areas with very high ecological roles for the surrounding regions and serve as a balancing area in the face of increasing global climate change, the main impacts of which are increased air temperature resulting in albedo changes and increased rainfall leading to erosion and floods. The forest and plants of the Nipa-Nipa Grand Forest in Kendari City, Southeast Sulawesi, are important ecosystems that support biodiversity and function as an ecological buffer and natural tourist destination. The condition of this forest is generally Nipa forest and swamp areas, which are the natural habitat of various typical coastal flora and fauna species. The illustration of the research area for data measurement is presented in Figure 2 below.

**Figure 2**. Location of the Kendari City Forest Area

In general, this forest condition faces several challenges, such as pressure from human activities in the form of illegal logging, land conversion for settlements and agriculture, and the impact of climate change that accelerates coastal ecosystem damage. Conservation and sustainable management efforts are highly necessary to maintain the sustainability of the Nipa-Nipa ecosystem in Kendari. The vegetation in the Nipa-Nipa Grand Forest varies in height. Sampling included around 100 vegetation samples of various heights, which were then averaged according to the classes in the image results of the Kendari City Area albedo calculation, as shown below.


**Figure 3.** Distribution of Albedo values for various land uses in 2017 and 2022

Based on Figure 3 A and B, it is known that the albedo for various land use classes in the Tahura Nipa-Nipa area, Kendari City, for the years 2017 and 2022, shows characteristic differences that reflect changes in land use and vegetation conditions. In 2017, the land classes with the highest albedo values were built-up land and open land, with albedo values approaching or exceeding 0.6, indicating surfaces that reflect solar radiation relatively highly. This may be due to hard surface materials such as building domes, roofs, roads, and areas without dense vegetation cover. Other classes such as shrub, plantation, and moor showed medium albedo values (around 0.2-0.4), while forest showed lower albedo values (perhaps around 0.1-0.2), consistent with the fact that dense vegetation absorbs more light than it reflects. Water-covered areas (pond/water) appeared with low to very low albedo values, because water absorbs a lot of energy and reflects little at relevant wavelengths.

In 2022, the general pattern remained the same, but there was a slight decrease in albedo in some vegetative classes (forest, shrub, plantation), while built-up land and open land maintained or slightly increased their albedo values, due to the intensification of development and the reduction of surface vegetation cover. The decrease in albedo in the vegetation class can be interpreted as a decrease in density, due to fragmentation, degradation, or land conversion. This result is consistent with several international studies. For example, the study "Assessing the Impacts of Urbanization on Albedo in Jing-Jin-Ji Region of China" reported that with increasing urbanization, built-up surface classes experienced a relative increase in albedo, while vegetation and natural classes like forests showed lower albedo values and decreased sensitivity over time [32]. This is reinforced by the research results of [33] that urbanization causes the average albedo value in urban areas to increase while vegetation cannot maintain the albedo as before.

In the Samara Karoo Reserve (SKR), South Africa, a study found that vegetation restoration and grassland growth caused a significant decrease in albedo during the peak season, because the new vegetation absorbed more radiation than the bare ground surface [25]. The study "Changes in albedo

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and its radiative forcing of grasslands in East Asia drylands" also showed a strong link between soil water content, vegetation index (EVI/NDVI) and albedo; when vegetation grows densely and the soil is moist, albedo decreases compared to when vegetation is sparse and the soil is dry [38]. Furthermore, a study in the Amazon forest region of Brazil reported that forests have an average albedo value of around 0.14-0.15, lower than agricultural areas or open areas which can be higher, indicating that forests absorb more energy, while areas supporting vegetation productivity or areas that have been cultivated have a higher albedo [13]. Thus, the albedo results for Tahura Nipa-Nipa can be concluded to be in line with international research findings, with dense vegetative classes, especially forest, having lower albedo, while non-vegetative and built-up land classes have higher albedo. The decrease in albedo in the vegetation class from 2017 to 2022 also indicates vegetation cover degradation or a decrease in vegetativeness, similar to the phenomenon observed in the Loess Plateau and dry grassland areas in East Asia. This is important because changes in albedo affect the surface radiation balance, local temperature, and the potential for the urban heat island effect. Therefore, maintaining vegetation, improving its health, and managing land use in vegetative areas are key to mitigating the negative impacts of albedo changes due to urbanization and land conversion. This condition should be negatively correlated with the NDVI analysis, so an NDVI analysis study is necessary. The results of the NDVI data analysis for the Kendari City area are presented in Figure 4.


**Figure 4**. Distribution of NDVI values for various land uses in 2017 and 2022

The results of the NDVI analysis in the Nipa-Nipa Grand Forest area, Kendari City, in Figure 3 A and B, between 2017 and 2022, reveal a clear shift in vegetation conditions and land use. For 2017, the "forest" class showed the highest NDVI value (±0,6-0,8), reflecting healthy dense vegetation cover, while classes such as plantation and shrub were in the medium range (±0,3-0,5), reflecting moderate to lower density vegetation. Paddy field and moor land classes had high variability (±0,2-0,4), influenced by the planting cycle and seasonal moisture conditions. Conversely, built-up, open land, and pond/water showed very low NDVI values (approaching 0 or even negative), consistent with non-vegetative characteristics. Mangrove was in the medium position (±0,3-0,5), indicating a coastal ecosystem with moderate vegetation productivity. In 2022, although the forest class still maintained relatively high NDVI, a slight decrease was observed—perhaps due to degradation, fragmentation, or the change of parts of the forest into semi-vegetative land or open land. NDVI values in the plantation and shrub classes also tended to decrease, indicating that the quality of vegetation declined. The built-up and open land classes experienced a noticeable expansion, and continued to have low NDVI, signifying the dominance of built-up surfaces or land without vegetation. The paddy field class showed high fluctuations, consistent with seasonal dynamics. Overall, this result indicates that the healthiest vegetation remains in the dense forest area, while land conversion towards settlements and open land suppresses the quality of vegetation outside the forest.

These findings are consistent with a number of international studies that observe NDVI patterns in tropical and coastal areas. For example, the study "Spatial-temporal NDVI pattern of global mangroves: A growing trend during 2000-2018" found that mangroves in Southeast Asia had an average NDVI value up to about 0.80, the highest among global mangrove areas, reflecting relatively healthy and dense tropical coastal vegetation [27].

Furthermore, research in Berau Regency using Sentinel-2A imagery reported that active and dense mangroves exhibited NDVI values in the range of 0.73–0.81, which is considered “dense vegetation” [14]. In Bengkulu, a study of mangrove mapping and carbon stock estimation using Sentinel-2 achieved an overall accuracy of 89.09%, with high-density vegetation having a significant extent and showing a strong correlation between NDVI values and field mangrove biomass [30]. Furthermore, in the coastal region of East Java, annual changes in mangrove area and density (measured using NDVI) also showed that mangroves with high NDVI (dense) dominated coastal areas in the healthy vegetation category compared to those with moderate or low NDVI [37], [31]. This comparison proves that the pattern in Tahura Nipa-Nipa is not an anomaly, but part of a more general trend in tropical areas: natural forests and high-NDVI mangroves maintain good vegetation quality, while non-forest land, built-up land, and open land show low or decreasing NDVI over time. However, there are local differences in the speed of vegetation quality decline on non-forest land in Kendari, which appears to be quite fast, reflecting strong urbanization pressure and land use change.

The condition of the Air Temperature Analysis is highly influenced by the duration of sun exposure. The longer the sun radiates light, the more heat is received. Figure 4 shows the diurnal pattern of average air temperature at different altitudes. Based on the air temperature values, it can be seen that the air temperature at every altitude has the same pattern. The temperature profile tends to drop at night and starts to rise until its peak at two in the afternoon, and starts to drop again until night. At night, the air temperature at an altitude of 21.7 meters has a higher value compared to other altitudes. The opposite happens during the day, where the air temperature at an altitude of 21.7 meters is lower than other altitudes. This is because, during the day, the surface condition is hotter due to the supply of shortwave solar radiation, while at night, the surface condition is cooler because there is no supply of shortwave solar radiation.

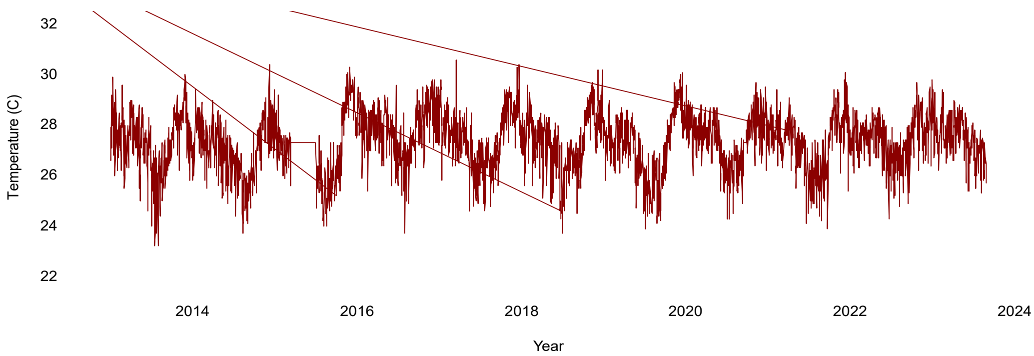


**Figure 5.** Average air temperature profile from 2014 to 2023

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Figure 5 shows the diurnal pattern of average air temperature across different altitudes. Based on the air temperature values, it can be seen that the air temperature at each altitude follows a similar pattern. The temperature profile tends to decrease at night and begins to rise until its peak at 2:00 PM, before decreasing again until evening. At night, the air temperature at an altitude of 21.7 meters is higher than at other altitudes. The opposite occurs during the day, where the air temperature at an altitude of 21.7 meters is lower than at other altitudes. This is because during the day the surface conditions are hotter due to the supply of shortwave solar radiation, while at night the surface conditions are cooler due to the lack of shortwave solar radiation.

**Calculation Results for Various Land Uses**

Tahura Nipa-Nipa is a protected forest / production forest area that stretches around Kendari City, Southeast Sulawesi, with an area of approximately 7,877 ha as stipulated in the Decree of the Minister of Forestry in 1999. The condition of the Tahura Nipa-Nipa area faces a land use conflict between development needs (settlements, infrastructure) and conservation (forests, biodiversity, green spaces). The demand for built-up land continues to increase, often sacrificing vegetation, agricultural land, and even protected areas. Social problems such as encroachment, community management rights, and economic welfare are closely related to how the regulation and management of natural ecosystems are carried out.

The analysis of land use change between 2017 and 2022 shows a decrease in the area of forests, plantations, moors, mangroves, ponds, and water bodies, while built-up areas, open spaces, and shrubs experienced a significant increase. The dominant pattern observed is the conversion of forests and plantations to built-up areas and open spaces, followed by the loss of some aquatic ecosystems. This condition indicates rapid urbanization and pressure on land resources for settlements and infrastructure. The increase in shrubs and open spaces can be interpreted as a post-deforestation transition phase that has not yet been converted to built-up areas. The decline in mangrove ecosystems and water bodies, although relatively small, still has important implications for ecological functions such as coastal protection, flood mitigation, and biodiversity buffers.

**Table 2.** Percentage of land use changes in the Kendari City area

| **Landuse** | **2017** | | **2022** | |
|---|---|---|---|---|
| | **ha** | **%** | **ha** | **%** |
| Forest | 10,593 | 45.4 | 10,229 | 43.8 |
| Plantation | 6,573 | 28.1 | 5,184 | 22.2 |
| Moor | 1,123 | 4.8 | 927 | 4.0 |
| Built Up Land | 3,129 | 13.4 | 4,741 | 20.3 |
| Open Land | 452 | 1.9 | 807 | 3.5 |
| Mangrove | 253 | 1.1 | 211 | 0.9 |
| Paddy Field | 94 | 0.4 | 89 | 0.4 |
| Shrub | 656 | 2.8 | 760 | 3.3 |
| Pond | 378 | 1.6 | 350 | 1.5 |
| Body of Water | 102 | 0.4 | 56 | 0.2 |
| **Total** | **23,354** | **100** | **23,354** | **100** |

These findings align with a study in Central Aceh that reported a decline in forest cover and an increase in built-up areas over a similar period [10]. Similar trends have also been observed across Indonesia, where forest conversion to agricultural land and built-up areas is a dominant phenomenon [46]. However, there is a significant difference with previous studies in Sumatra and Kalimantan, which instead indicated plantation expansion as the primary driver of land use change [47]. In this context, the decline in plantation area in the study area may indicate direct conversion to built-up areas, contrasting with the general pattern of plantation expansion in Indonesia. Similar patterns have also been observed outside Asia, such as in Ethiopia, where urbanization and plantation expansion have resulted in a decline in ecosystem services [48]. Therefore, these results confirm that the dynamics of land cover change in tropical regions follow the global pattern of declining forest cover and natural ecosystems with significant increases in built-up areas, but have local nuances influenced by policies, economic needs, and development pressures.

## CONCLUSION

The Nipa-Nipa Grand Forest in Kendari City has a vital role as a conservation area that serves as an ecological buffer and a local climate balancer. The research results show that this forest faces pressure from urbanization, land conversion, and climate change, which results in increased air temperature, changes in albedo values, and reduced quality of the coastal ecosystem. The presence of dense vegetation in the forest area is still able to maintain the ecological balance, but forest fragmentation and vegetation cover degradation are starting to appear, which if left unchecked can significantly reduce the area's ecological function. Air temperature analysis shows that its variability is influenced by the duration of sun exposure and altitude. The diurnal pattern shows the temperature reaching its peak at two in the afternoon and decreasing again toward evening. The albedo analysis results for 2017 and 2022 show a pattern consistent with international research. Built-up land and open land have the highest albedo values, while forests, mangroves, and water bodies have the lowest albedo values. The decrease in albedo in the vegetation class between 2017 and 2022 indicates vegetation quality degradation and increased urbanization intensity. This albedo change directly implies an increase in surface temperature and the potential for the urban heat island effect, so maintaining and restoring vegetation cover is an important step for climate change mitigation in Kendari City. The NDVI analysis results reveal a decrease in vegetation quality in several land use classes. Forests still maintain the highest NDVI values but show a slight decrease, while plantations, shrubs, and mangroves show a more significant downward trend. Thus, data-based spatial management efforts are very important to maintain the sustainability of the Nipa-Nipa Grand Forest ecosystem while increasing the resilience of Kendari City to environmental risks in the future.

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