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A Case Study of urban heat island based on Urban Growth and Thermal Impact in Sidoarjo East Java

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ABSTRAK

Sidoarjo merupakan salah satu kabupaten yang berada di wilayah Surabaya Metropolitan Area (SMAs). Hal ini membuat Kabupaten Sidoarjo mengalami laju urbanisasi yang meningkat serta perkembangan pembangunan yang cukup pesat, terutama di sektor industri dan perumahan. Dengan adanya aktivitas antropogenik tersebut, menjadikan Kabupaten Sidoarjo mengalami perubahan area tutupan lahan. Dimana daerah atau wilayah yang pada awalnya merupakan area hijau lambat laun telah berubah menjadi area atau lahan terbangun. Perubahan area tutupan lahan tersebut dapat membuat suhu permukaan di Kabupaten Sidoarjo semakin meningkat, khususnya di wilayah pusat kota dengan laju urbanisasi dan perkembangan pembangunan yang tinggi. Keadaan ini akhirnya dapat memicu terjadinya fenomena Urban Heat Island (UHI). Fenomena pulau panas perkotaan ini akan sangat merugikan wilayah perkotaan apabila tidak ditangani dengan strategi yang tepat, karena akan merusak lingkungan dan ekosistem serta dapat menjadi penyumbang terbesar dalam peningkatan suhu permukaan secara global. Tujuan dari penelitian ini adalah untuk menghitung pertumbuhan fenomena pulau panas di Kabupaten Sidoarjo.

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ABSTRACT

Sidoarjo is one of the districts in the Surabaya Metropolitan Area (SMAs). This has led Sidoarjo Regency to experience an increasing rate of urbanization and rapid development, especially in the industrial and residential sectors. With these anthropogenic activities, Sidoarjo Regency has experienced changes in land cover areas. Areas or regions that were originally green areas have gradually turned into built-up areas or land. The change in land cover area can make the surface temperature in Sidoarjo Regency increase, especially in the city centre area with a high rate of urbanization and development. This situation can eventually trigger the Urban Heat Island (UHI) phenomenon. This urban heat island phenomenon will be very detrimental to urban areas if not handled with the right strategy, because it will damage the environment and ecosystems and can be the largest contributor to the increase in global surface temperatures. The aim of this study is to calculate the growth of the heat island phenomenon in Sidoarjo district.

1. INTRODUCTION

Urban areas generally have great potential for rapid growth, both in terms of population and physical development. High levels of urbanization and anthropogenic activities have triggered environmental changes and altered local climatic conditions (J. D. Yuan et al., 2021). According to A. D. Pereira et al. (2023), rapid global urbanization has had significant ecological impacts, extending beyond urban boundaries. One of the affected areas is the Surabaya Metropolitan Area (SMA), which includes Sidoarjo Regency, a region that directly borders the city of Surabaya. Data from the Sidoarjo Statistics Agency shows that the urbanization rate in 2022–2023 increased by 1.49% compared to the previous two years. Urban growth in Sidoarjo is driven by its proximity to Surabaya, along with increasing industrial development and employment opportunities (East Java Statistics Agency, 2022). This growth has led to rising housing demand and land conversion for residential areas (F. Gultom & S. Harianto, 2022).

Rapid urban development has reduced the extent of green open spaces (R. Setiowati et al., 2018). In Sidoarjo, the conversion of green areas into impervious surfaces like asphalt, concrete roads, and buildings has raised surface temperatures by disrupting the balance of solar radiation and energy exchange (I. Prasasti et al., 2015). Built-up land retains heat longer, creating warmer surface temperatures compared to surrounding rural areas (M. Heinl et al., 2015).

Urban Heat Island (UHI) is a phenomenon where urban areas experience higher temperatures than their surroundings. It is a key feature of urban climates, with city air temperatures being several degrees higher than in rural zones (E. Parlow et al., 2014; N. Prilandita, 2009; I. Fardani & M. R. Yosliansyah, 2022). UHI affects microclimates by raising local temperatures, altering rainfall patterns, and increasing the risk of prolonged droughts and flash floods (N. Debbage & J. M. Shepherd, 2015). In hot-climate cities, UHI worsens air pollution and reduces comfort for urban residents (E. Hermawan, 2015; R. Maru, 2017). To mitigate the negative impacts of UHI in Sidoarjo Regency, it is essential to understand its causes and characteristics. This study aims to identify, analyze, and quantify the factors contributing to the Urban Heat Island phenomenon, in which urban growth and the reduction of green open space significantly increase surface temperature, leading to the occurrence of the Urban Heat Island phenomenon, particularly in Sidoarjo Regency.

2. ETODE

The type of research used in this research is descriptive qualitative. The method used in this qualitative research is the phenomenological method, by making observations of phenomena that affect this research.

3. ASIL DAN PEMBAHASAN

3.1 Sidoarjo District Overview

Sidoarjo Regency is an administrative area and is one of the districts in East Java Province. Based on its astronomical location, Sidoarjo Regency is located between 7.3°-7.5° N (South latitude) and between 112.5°-112.9° E (East longitude). Geographically, Sidoarjo District borders Surabaya City and Gresik District to the north, Pasuruan District to the south, Madura Strait to the east and Mojokerto District to the west. Sidoarjo district has an area of 719.34 km² with 18 sub-districts, 318 villages and 28 urban villages.

3.2 Environmental Conditions in Sidoarjo District

Sidoarjo Regency has an altitude of 0-3 metres above sea level and is in the form of coastal areas and ponds in the eastern region. In the central region, there are residential areas, trade and government centres with an altitude of 3-10m above sea level. And agricultural areas with an altitude of 10-25 metres above sea level are in the western region of Sidoarjo Regency. A tropical climate with an average daytime temperature of around 30 degrees Celsius characterizes Sidoarjo District because it is located in an equatorial country.

3.3 Population Conditions in Sidoarjo District

After downloading the band 10, band 4, and band 5 satellite image data, the next step is to process the Landsat-8 band 10 image data using SeaDAS 7.5.3 and Microsoft Excel software. This processing aims to determine the Temperature of Atmospher (TOA), which will later provide the surface temperature in 5 sub-districts of Sidoarjo Regency in degrees Celsius.

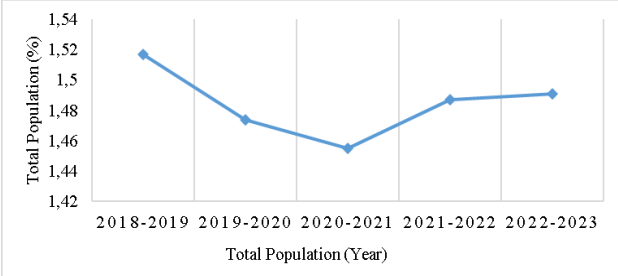

Figure 1. Total population in Sidoarjo district
Source. Sidoarjo in Figures, Annual Publications from 2018-2023

The population condition in Sidoarjo Regency seen in Figure 1 above shows an increase of 1.52% from 2018 to 2019 and a decrease from 2019 to 2020 due to the Covid-19 pandemic. In 2021 to 2023, population conditions in Sidoarjo Regency began to increase by 1.50%.

3.4 Industry and Housing Development in Sidoarjo Regency

The high level of industry and trade in Sidoarjo Regency has made it one of the buffer zones for neighbouring cities, such as Surabaya City. Based on the Sidoarjo District People's Welfare Indicators, there is an increase in the number of industries and housing experienced by Sidoarjo District each year. This is also accompanied by the percentage of the Sidoarjo Regency Employment Opportunity Rate which has increased in 2022 by 91.20% higher than 2020 which is only 89.03% (Badan Pusat Statistik Kabupaten Sidoarjo, 2022). Likewise with the increase in the number of housing or settlements. With the increase in industry, trade and employment rate, the community's interest in being able to have a residence close to the area where they work is increasing. From the observation of Sidoarjo Regency People's Welfare Statistics, (2022), in 2020-2022 the trend to occupy a house with self-owned status increased to 84.83% (Badan Pusat Statistik Kabupaten Sidoarjo, 2022). The increase in the number of industries accompanied by an increase in the number of housing can be seen in Figure 2 below.

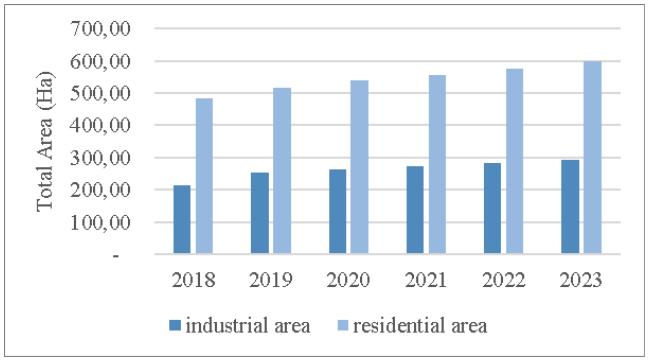

Figure 2. Industry and Residential Development in Sidoarjo Regency
Source. Statistic Indonesia (BPS), Sidoarjo Regency, 2018-2023

3.5 Decrease in Green Open Space (RTH) in Sidoarjo District

With the increase in the number of industries and housing accompanied by an increase in the rate of urbanization, the area of land cover or green open space in Sidoarjo Regency has changed and become increasingly reduced. The change in human activity from working in the agricultural sector to working in the industrial and service sectors has become one example of changes in spatial patterns and structures (I. Prasasti et al., 2015). The logical consequence of this situation is the narrowing and limitation of green areas (Muhammad Chaidir Harist and Iqbal Putut Ash Ashidiq, 2018).

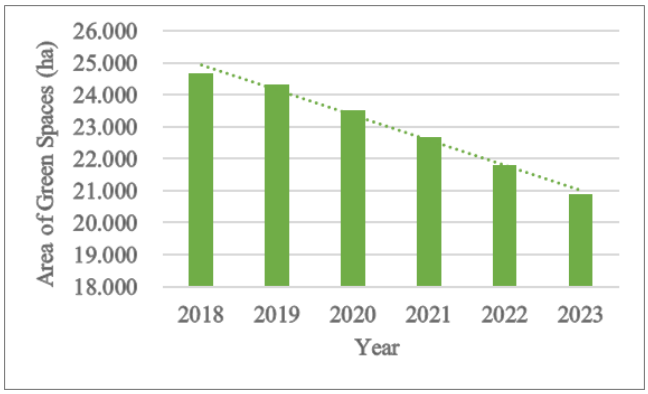

Figure 3. Decrease in green spaces in Sidoarjo Regency in 2018-2023
Source. Statistic Indonesia (BPS), Sidoarjo Regency and Sidoarjo in Figures, Annual Publications from 2018-2023

From the diagram in Figure 3 above, in 2023 the green space area decreased by 4.16% from the green space area in the previous year. This is due to an increase in the percentage of industrial and residential development by 4% each year.

3.6 Surface Temperature Increase in Sidoarjo District

Land cover areas that experience changes from green (natural) areas to paved or concrete road areas, residential buildings, industrial or other commercial buildings will indirectly disrupt the balance of the surrounding environment with an increase in surface temperature, because these changes have changed the exchange of solar radiation and energy on the surface of built-up land (I. Prasasti et al., 2015). Not only that, with this change in land cover area, the temperature and air pollution are increasing.

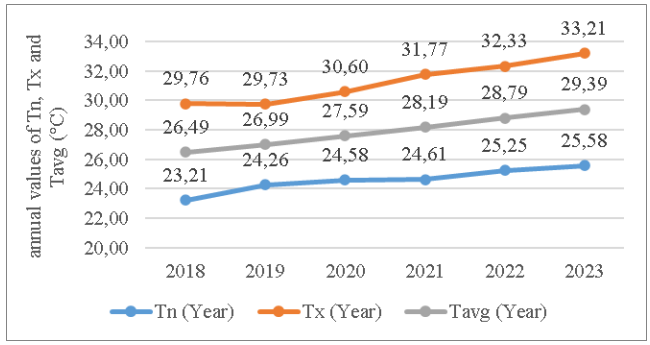

Figure 4. Annual Temperature Increase in Sidoarjo District
Source. Meteorological, Climatological, and Geophysical Agency (BMKG) – Sidoarjo Station, 2018–2023

Based on the diagram in Figure 4, the average temperature in 2023 has an increase of 0.6 °C which is 29.39 °C higher than the previous year.

3.7 Urban Heat Island (UHI) Phenomenon

The trigger for the Urban Heat Island (UHI) phenomenon is influenced by two factors, namely climatic factors and anthropogenic factors from human activities (R. Kotharkar et al., 2019). J. M. Shepherd, (2005), revealed that green land areas in urban areas have been replaced by built-up land areas with different thermal properties (e.g. thermal humidity and heat capacity). The Urban Heat Island (UHI) phenomenon occurs due to complex interactions between land cover, physical properties of building materials, and human activities. One of the main mechanisms of UHI formation is the low albedo value of man-made surfaces such as asphalt and concrete, which absorb more solar radiation than natural surfaces. Building materials such as concrete and metal roofs have high thermal capacity and heat conductivity, causing heat to be retained longer and released slowly during the night. This creates relatively higher temperatures in urban areas compared to surrounding areas with natural vegetation. In addition, hard surfaces such as roads and buildings minimize the natural cooling process through evapotranspiration, which normally occurs on vegetative surfaces. Heat accumulation is also amplified by heat retention due to dense buildings and low air circulation, especially in areas with high-rise buildings that narrow open spaces.

The existence of the Urban Heat Island (UHI) phenomenon will also affect changes in weather conditions and local climate conditions (urban microclimate). These climate changes accompanied by an increase in the rate of urbanization will lead to the development of increasingly significant environmental damage (R. Kotharkar et al., 2019), (L. Tu et al., 2016). J. M. Shepherd, (2005), states that climate change that occurs will affect temperature changes in urban areas, which will have an impact on patterns and

increase the intensity of local rainfall, prolonged drought levels and can cause flash floods. The UHI phenomenon is considered very detrimental, especially in urban areas with hot climates, because it not only causes more hot air to be stored compared to cold air, but also causes air pollution problems and disturbance of the comfort of living things living in these urban areas (E. Hermawan, 2015). R. Maru,(2017), argues that the Urban Heat Island phenomenon can be the largest contributor to the increase in surface temperature if it occurs continuously without an appropriate handling strategy. If this is allowed to happen, then urban resilience, population resilience and food security in it will also be disrupted due to the Urban Heat Island phenomenon that occurs.

This study is in line with research results in big cities such as Jakarta and Surabaya that also show an increase in surface temperature due to intensive urbanization. In Jakarta, for example, Setiowati et al. (2018) showed that a 6% decrease in green open space in the last five years contributed significantly to the increase in UHI intensity. Similarly, a study by Hermawan (2015) found that the air temperature in the center of Surabaya was 2-3°C higher than its periphery. These data suggest that the pattern in Sidoarjo District is similar to other metropolitan areas experiencing rapid land conversion and increased anthropogenic activities.

3.8 Urban Heat Island (UHI) Phenomenon in Sidoarjo Regency

The increase in surface temperature is partly due to the decline in green open space , so that carbon monoxide gas from increased motor vehicle exhaust gas can no longer be reduced by the availability of adequate green open space, due to land use change accompanied by increased urbanization rates, increased industry and housing in Sidoarjo Regency. According to H. S. Tiarani et al., (2016), an increase in the number of industries, mines and housing accompanied by an increase in electricity users and forest fires results in high air temperatures in an area resulting in global warming. This condition will trigger the Urban Heat Island (UHI) phenomenon, because the surface of the city will increasingly have high heat absorption and low water absorption and narrowing of air space due to increasing vertical development in urban areas (Z. Liang et al., 2020), (X. Zhou and H. Chen, 2018). Not only land use changes with high development intensity, the increasing rate of urbanization is also a contributing factor to the occurrence of the UHI phenomenon which generally occurs in urban areas (N. Debbage and J. M. Shepherd, 2015), (X. Zhou and H. Chen, 2018) .

The increase in temperature due to UHI not only affects the physical environment, but also public health and energy consumption. Continuous exposure to high temperatures increases the risk of heat-related illnesses such as dehydration, fatigue, heatstroke, and respiratory problems, especially for vulnerable groups such as the elderly and children. In addition, rising ambient temperatures encourage the use of air conditioning (AC) in the domestic and commercial sectors, which in turn results in a spike in electrical energy consumption and carbon emissions. This creates a negative feedback loop that worsens the city's microclimate conditions.

4. CONCLUSIONS

Sidoarjo Regency has become one of the regions with increased development, especially in the industrial sector and the housing sector. It can be seen that in the industrial sector there was an increase of 19.2% in 2019 from the previous year. Likewise, the housing sector experienced an increase of 24.26% in 2019. These two sectors continue to increase until 2023. With anthropogenic activities in increasing development in the industrial and housing sectors accompanied by an increase in urbanization, Sidoarjo Regency has experienced land cover change.

This land cover change is also known as land conversion. Where areas that were originally green land, along with the development of urban development turned into built-up land. This is done by the community to meet increasing needs, both in the industrial sector and in the housing sector. Without realizing the activities they do are increasingly reducing the fulfillment of green land in urban areas. The decline in green open space area in 2023 reached 4.16%, higher than the previous year. This is due to an increase in the percentage of industrial and residential development by 4% each year. Thus the fulfillment of green open space in Sidoarjo Regency still has an area that is less than the stipulated area.

With this change in land cover area, the temperature and air pollution in Sidoarjo Regency is increasing. The average air temperature in 2018-2023 in Sidoarjo district was 27.91°C and the average air temperature in 2023 was 29.39°C higher than the previous year. This shows an increase of 0.6°C from the previous year. The increase in temperature in urban areas, especially in Sidoarjo District, is caused by high exhaust gases from motorized vehicles, an increase in the number of industries, mines and housing accompanied by an increase in electricity users and forest fires resulting in high air temperatures in an area resulting in global warming. This is because the exhaust emissions from these activities can increase the temperature at the surface of the earth's atmosphere, if it cannot be reduced by the availability of green open space properly.

With the increasing rate of urbanization due to an increase in the number of industries accompanied by an increase in the number of housing in Sidoarjo Regency, the land cover area has been converted into a built-up area. Initially, areas of green space are gradually turning into paved roads and high-rise buildings. As a result, surface temperatures and air pollution have increased, especially in the central part of Sidoarjo District, where the majority of the area is residential, trade and government centers, causing a difference between the surface temperature of the central part of the city and the surrounding suburbs, known as the Urban heat island (UHI) phenomenon.

The findings of this study are expected to serve as a valuable reference for local governments and stakeholders in formulating spatial planning policies that are adaptive to climate change, particularly in managing urban growth and providing adequate green open spaces. The observed increase in surface temperature and the contribution of land cover changes to the Urban Heat Island (UHI) phenomenon can be used as a foundation for more sustainable urban planning in Sidoarjo Regency. As mitigation strategies against UHI, several actions are recommended, such as enhancing urban greening by expanding green open spaces, planting trees in residential areas and along roads, and applying reflective or light-colored building materials to reduce surface heat absorption. Local governments are also encouraged to promote environmentally friendly development through policy incentives and to enforce stricter control over green land conversion. To support more effective policymaking, future research should focus on long-term monitoring of surface temperature and land cover changes using high-resolution satellite imagery, as well as evaluating the effectiveness of spatial planning policies. Additionally, studies on community perceptions and adaptation strategies toward UHI are crucial components of an integrative approach to managing the impacts of climate change in urban areas.

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