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A Scientific Analysis of Vegetation-Based Air Quality in Sidoarjo and its Implications for Extreme Temperature Events and Extended Drought Periods

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Abstract: Indonesia, as an archipelagic country with a high diversity of ecosystems, faces significant challenges in maintaining a balance between economic growth and environmental sustainability. One of the major impacts of urbanization is the alteration of vegetation cover, which affects air quality, extreme temperatures, and drought conditions. This study focuses on analyzing vegetation cover in Sidoarjo Regency, East Java, using Landsat imagery and the Normalized Difference Vegetation Index (NDVI) method to assess its impact on air quality and extreme temperatures. The analysis results indicate a decline in vegetation cover from 2020 to 2024, contributing to deteriorating air quality and increasing extreme temperatures in the region. The reduction in vegetation, driven by land-use changes for development purposes, has decreased the capacity of plants to absorb air pollutants such as PM2.5 and PM10, which pose health risks to the population. Although a slight improvement was observed in 2023, the overall declining trend continues, highlighting the urgent need to strengthen environmental conservation efforts. This study recommends raising public awareness and implementing stronger environmental preservation policies to address these issues and maintain the quality of life for the residents of Sidoarjo.

Keywords:- *Air Quality, NDVI, Vegetation, Sidoarjo Regency, Extreme Temperatures.*

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I. INTRODUCTION

Indonesia, as the world's largest archipelagic country, possesses a rich diversity of ecosystems and occupies a strategic position between two continents and two oceans. With over 17,000 islands, Indonesia faces significant challenges in maintaining a balance between economic growth and environmental sustainability. One of the major impacts of population growth and urbanization is the change in vegetation cover, particularly in urban areas. These changes not only affect air quality but also contribute to environmental phenomena such as extreme temperatures and prolonged droughts (Airin, 2010).

Sidoarjo, located in East Java Province, is one of the strategic regions with a high level of urbanization. Bordered by Surabaya to the north and the Java Sea to the east, Sidoarjo plays an important role as an economic and industrial center. However, the rapid development in this area has led to significant changes in vegetation cover. The reduction in vegetation due to land-use change has become one of the causes of declining air quality and increasing extreme temperatures in the region (Budianto, 2015).

The use of remote sensing technology has become an effective solution for identifying and analyzing changes in vegetation cover spatially. One of the commonly used methods is the Normalized Difference Vegetation Index (NDVI), which can measure the density and health of vegetation based on the reflection of red and near-infrared light spectra (Susilo & Hartini, 2018). When combined with ArcGIS software, NDVI provides a comprehensive overview of vegetation distribution and its impact on environmental conditions.

This study aims to analyze vegetation cover in Sidoarjo using Landsat imagery and the NDVI method, as well as to evaluate its impact on air quality, extreme temperatures, and prolonged droughts. The results of this analysis are expected to provide in-depth insights to support spatial planning

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policies and more sustainable environmental management (Rahmawati, 2020). Furthermore, this research is expected to make a tangible contribution to mitigating the impacts of local climate change through better vegetation management (Prasetyo, 2021).

II. METHODOLOGY

- *Study Area*

The study area is located in Sidoarjo Regency, as shown in (Figure 1). Geographically, Sidoarjo Regency lies between 7°21' – 7°48' South Latitude and 112°33' – 112°54' East Longitude. The total area covers approximately 634.89 km², consisting of 18 sub-districts (kecamatan), 322 villages (desa), and 31 urban wards (kelurahan).

Sidoarjo is a regency in East Java Province, Indonesia, situated to the south of Surabaya City. The regency is recognized as one of the main buffer zones for the provincial capital, Surabaya, experiencing rapid development in the industrial, trade, and tourism sectors. Sidoarjo is often referred to as the "Delta City" due to its geographic location between major rivers such as the Brantas River and the Porong River, which form a fertile delta region.

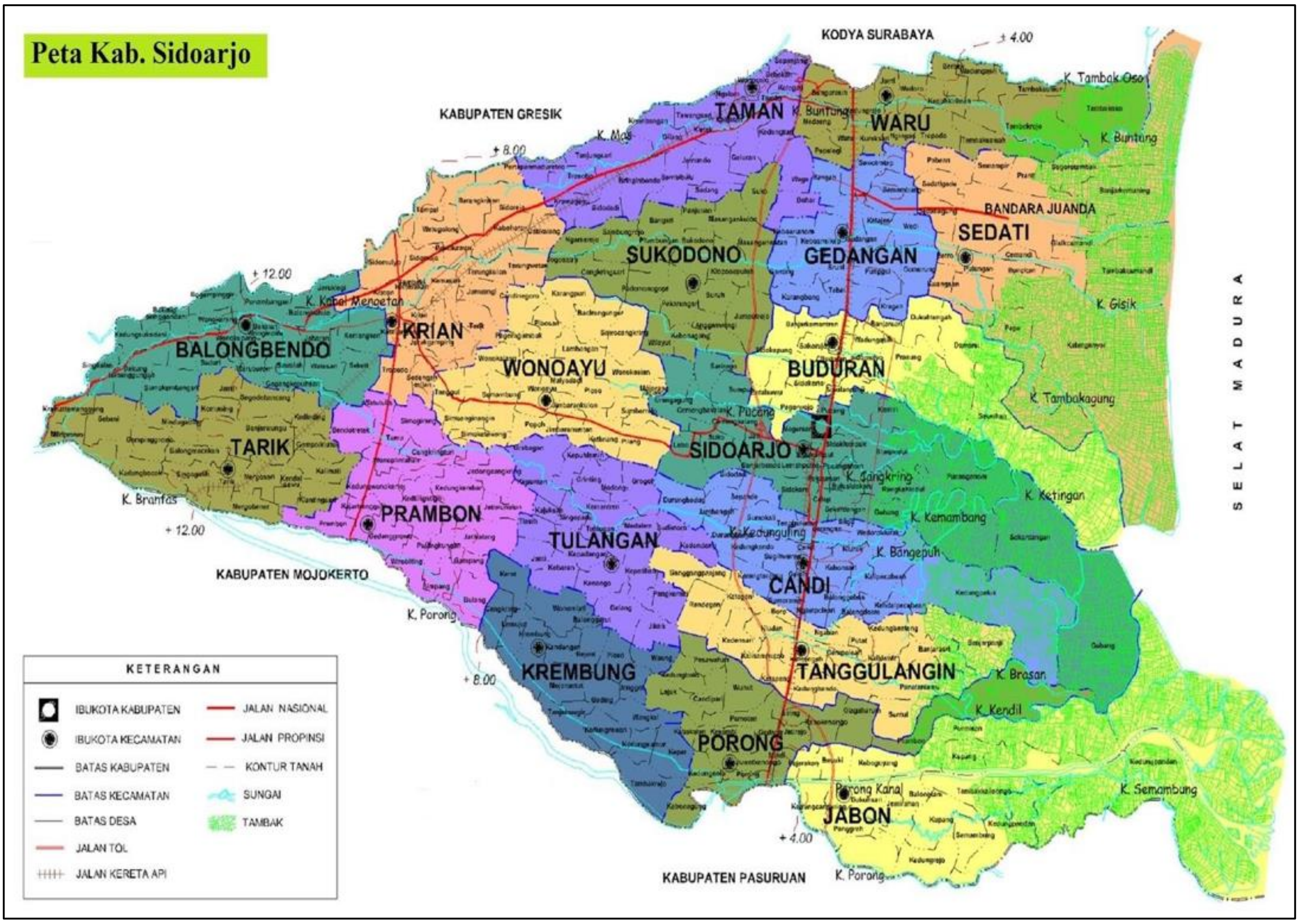

Fig 1 Map of the Research Area – Sido Arjo Regency

- *Landsat Imagery*

The satellite imagery used in this study is Landsat 8 OLI/TIRS, equipped with two types of sensors: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), consisting of a total of 11 spectral bands. Of these, 9 bands (Bands 1–9) are associated with OLI, while the remaining 2 bands (Bands 10 and 11) belong to TIRS (Surmaini, 2016). The wavelengths captured by the Landsat satellite and their respective uses are presented in (Table 1).

- *Vegetation Index*

The vegetation index is a value that describes the degree of vegetation greenness, derived from the digital signals resulting from the brightness of specific satellite sensor bands. To analyze vegetation in this study, the Normalized Difference Vegetation Index (NDVI) algorithm was used, which serves as a tool to measure vegetation greenness. NDVI is effective for assessing the green leaf biomass parameter, which is then used to classify vegetation types (Yudistira et al., 2019). The NDVI classification can be seen in (Table 2).

Vegetation indices such as NDVI have broad applications in ecosystem studies and land cover change monitoring. NDVI measures the difference between red and near-infrared reflectance to distinguish green vegetation from other land cover types such as soil or water. This makes NDVI a highly valuable tool in identifying vegetation health,

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such as moisture level and chlorophyll content, which indicate potential biomass and plant productivity.

For instance, higher NDVI values generally indicate healthier vegetation with greater biomass, while lower values typically represent stressed vegetation or a lack of vegetation (Houghton et al., 2009).

The classification and interpretation of NDVI data enable the analysis of vegetation in the context of climate change, deforestation, and land degradation. The use of NDVI in this study supports the mapping of vegetation distribution in the study area, aiming to understand its impact on air quality, extreme temperatures, and prolonged droughts.

Table 1 Landsat 8 OLI/TIRS Band Classification and Applications

Spectral Band	**Wavelength (µm)**	**Application in Mapping**
Band 1 – Coastal Aerosol	0.43 – 0.45	Coastal area observation and atmospheric aerosol detection
Band 2 – Blue	0.45 – 0.51	Bathymetry mapping (seafloor), differentiation of soil and vegetation
Band 3 – Green	0.53 – 0.59	Highlights actively growing vegetation
Band 4 – Red	0.64 – 0.67	Differentiates vegetation slopes
Band 5 – Near Infrared (NIR)	0.85 – 0.88	Detects biomass variations and coastal features
Band 6 – Shortwave Infrared (SWIR 1)	1.57 – 1.65	Identifies soil and vegetation moisture; penetrates thin cloud cover
Band 7 – Shortwave Infrared (SWIR 2)	2.11 – 2.29	Enhances detection of moisture in soil and vegetation; penetrates thin clouds
Band 8 – Panchromatic (Grayscale)	0.50 – 0.68	15-meter resolution; provides sharper imagery
Band 9 – Cirrus	1.36 – 1.38	Improves detection of cirrus cloud contamination
Band 10 – Thermal Infrared (TIRS 1)	10.60 – 11.19	100-meter resolution; thermal mapping
Band 11 – Thermal Infrared (TIRS 2)	11.50 – 12.51	100-meter resolution; thermal mapping and soil moisture detection

Source: WordPress.com, 2016.

Tabel 2 Klasifikasi NDVI

Kelas	**Nilai NDVI**	**Tingkat Kehijauan**
1	$-1 < NDVI < -0,03$	Lahan tidak bervegetasi
2	$-0,03 < NDVI < 0,15$	Kehijauan sangat rendah
3	$0,15 < NDVI < 0,25$	Kehijauan rendah
4	$0,25 < NDVI < 0,35$	Kehijauan sedang
5	$0,35 < NDVI < 1$	Kehijauan tinggi

NDVI Formula

The NDVI (Normalized Difference Vegetation Index) formula is as follows:

$$NDVI = (NIR-RED)/(NIR+RED)$$

Description:

NIR = Reflectance value of the near-infrared band (Band 5)

RED = Reflectance value of the red band (Band 4)

NDVI values range between -1 and 1.

Areas with NDVI values below 0.3 are generally not considered vegetated.

Areas with NDVI values above 0.3 are classified as dense or healthy vegetation.

Data collection was conducted by obtaining Landsat imagery over the past five years (2020 to 2024), focusing on the September–October period. The satellite images used in this study include Band 4 (Red) and Band 5 (NIR) of the Landsat data. In addition, air temperature and air quality data were collected from the IQAir website, which provides direct measurements from real-time air quality monitoring stations.

Next, the Landsat images were radiometrically and geometrically corrected before being analyzed using the NDVI vegetation index to identify the vegetation condition in Sidoarjo. Geographic Information System (GIS) technology was then used to conduct spatial analysis, correlating vegetation data with air quality information.

The analysis focused on the relationship between vegetation cover and air quality, as well as how vegetation influences extreme temperatures and droughts. The results of this analysis were interpreted to identify existing patterns and provide insights into how vegetation management can contribute to mitigating air quality issues and the effects of climate change.

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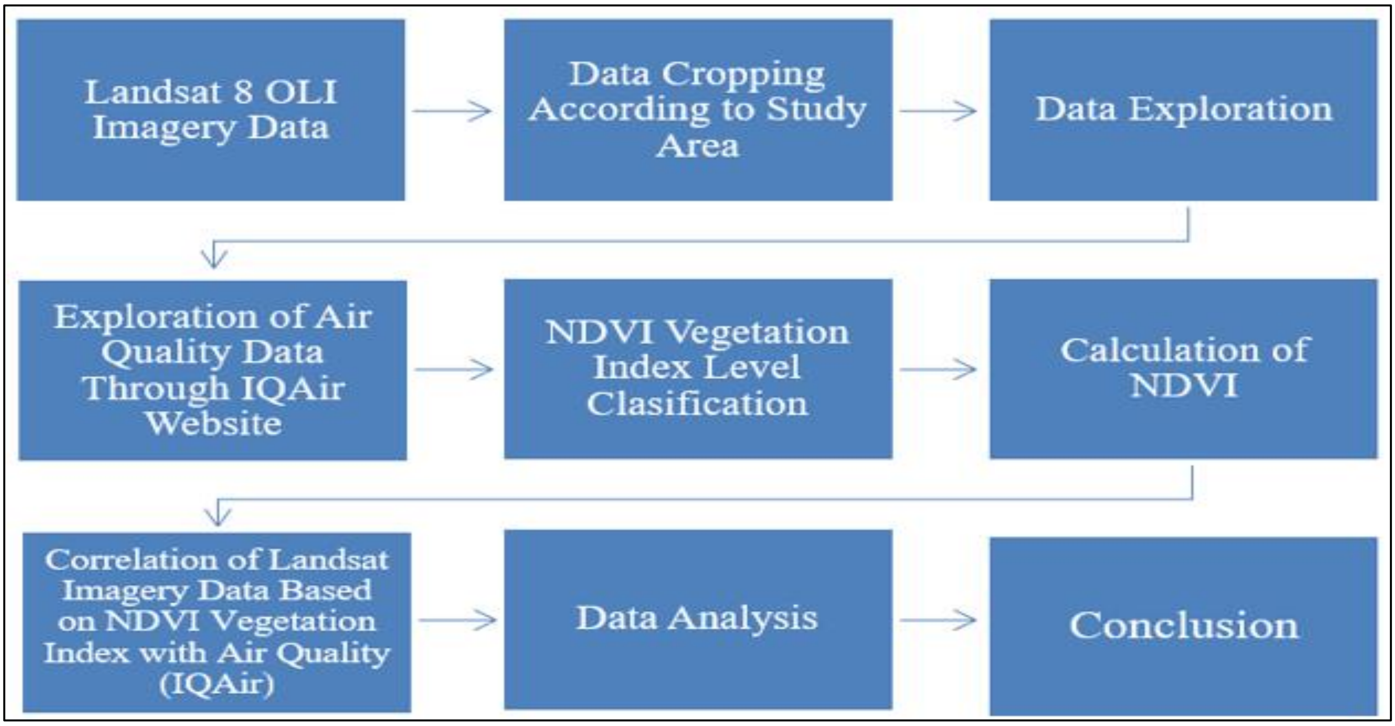

Fig 2 Research Stages

III. RESULT AND DISCUSSION

This study utilized Landsat 8 OLI imagery captured during the peak of the dry season over the past five years, namely in 2020, 2021, 2022, 2023, and 2024, as reference data to determine the condition of the vegetation index (NDVI).

➢ *The Peak Dry Season in These Years Occurred Between August and November. Based on the Analysis of Landsat Imagery and the Application of the NDVI (Normalized Difference Vegetation Index) Values, the Vegetation Index Can be Classified into Five Categories:*

- Non-vegetated land (-1 < NDVI < -0.03)
- Very low greenness (-0.03 < NDVI < 0.15)
- Low greenness (0.15 < NDVI < 0.25)
- Moderate greenness (0.26 < NDVI < 0.35)
- High greenness (0.36 < NDVI < 1)

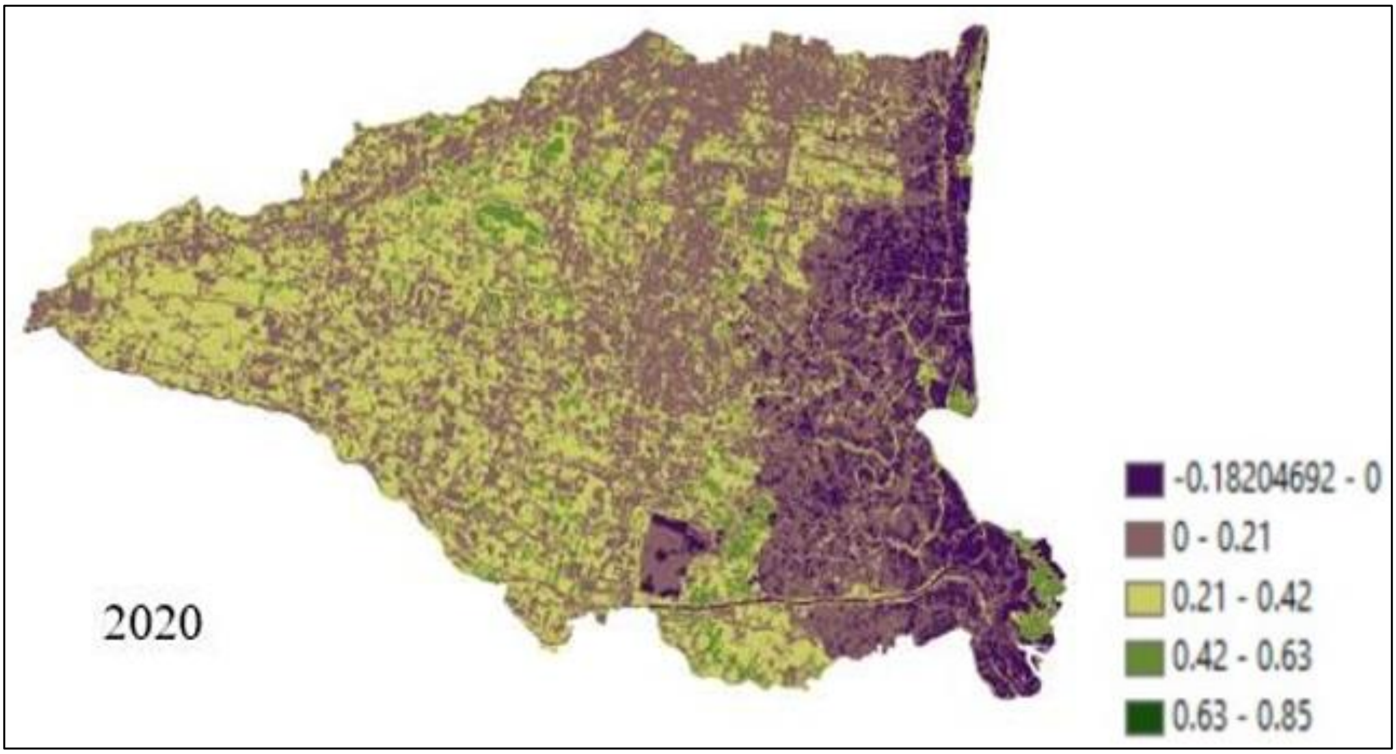

Fig 3 Distribution of Vegetation in the Sidoarjo Area 2020

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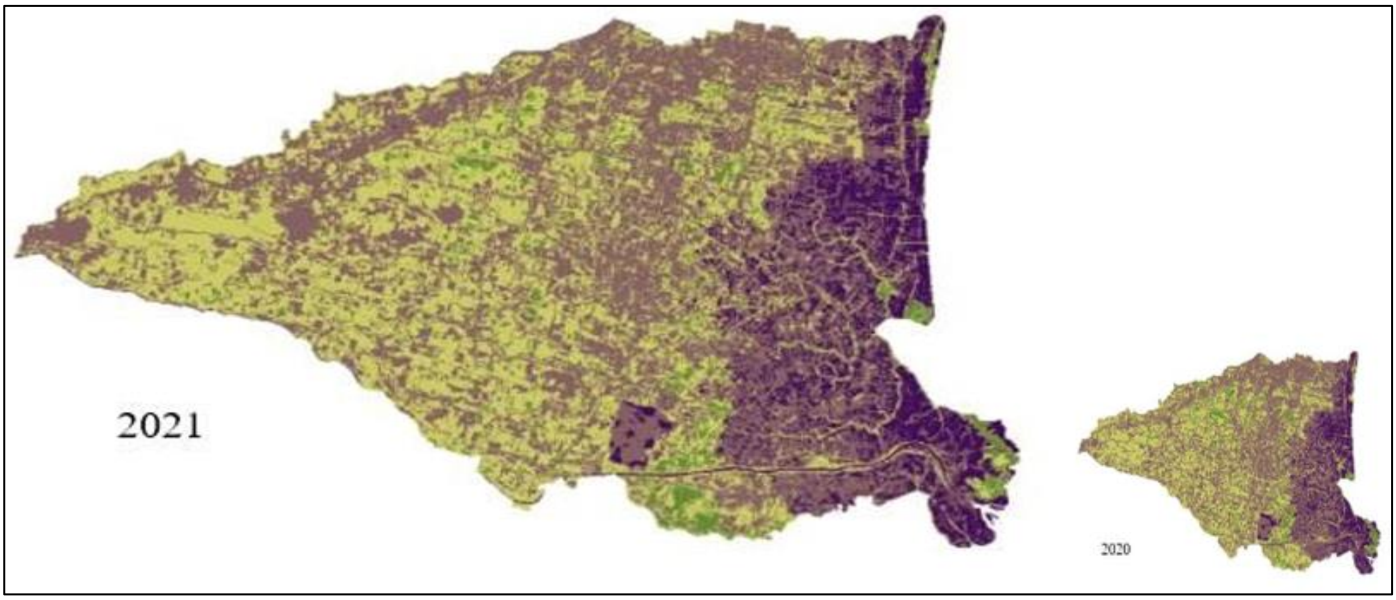

Fig 4 Distribution of Vegetation in the Sidoarjo Area 2021

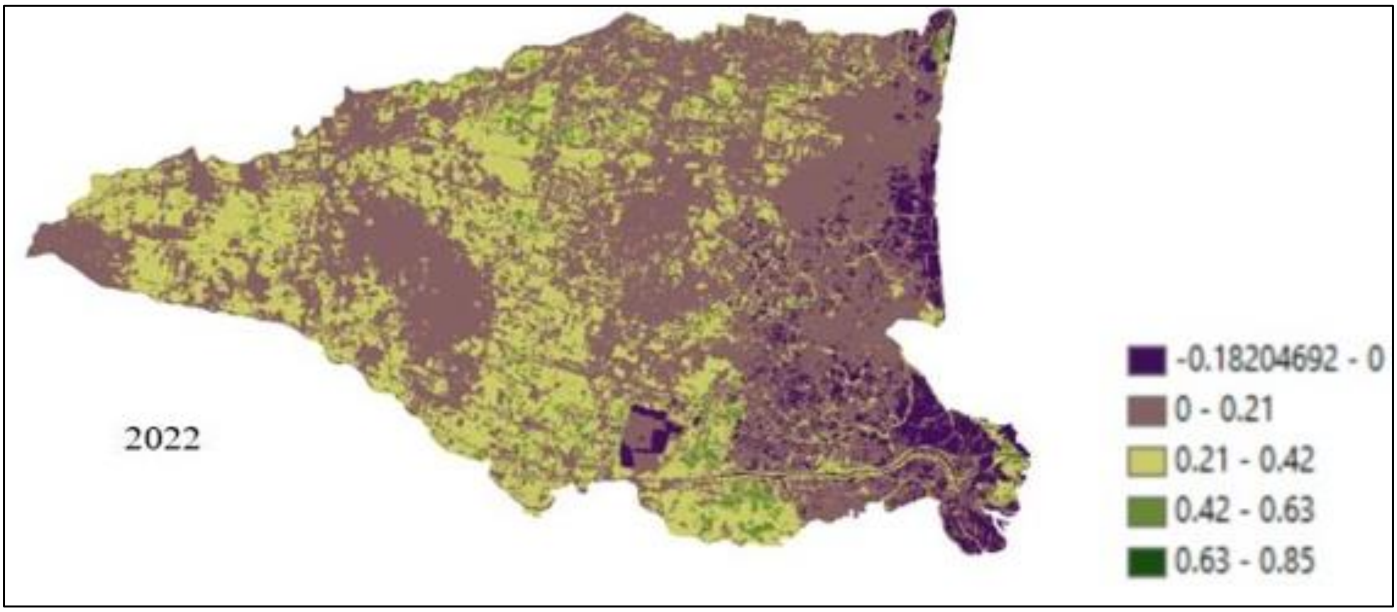

Fig 5 Distribution of Vegetation in the Sidoarjo Area 2022

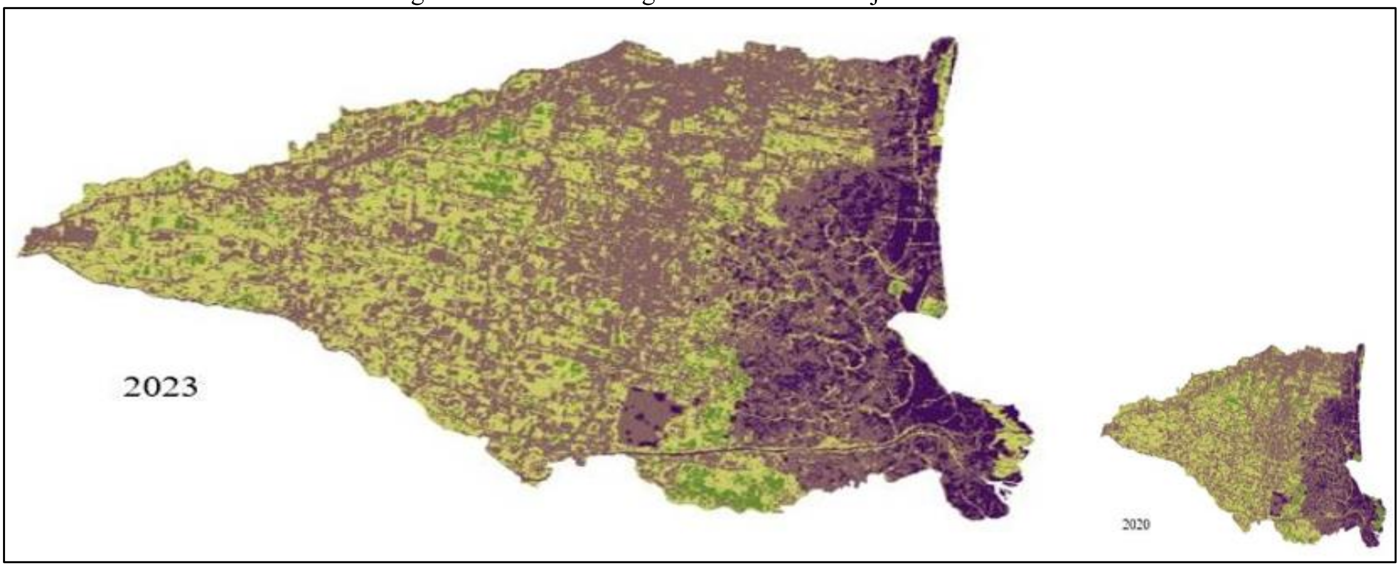

Fig 6 Distribution of Vegetation in the Sido Arjo Area 2023

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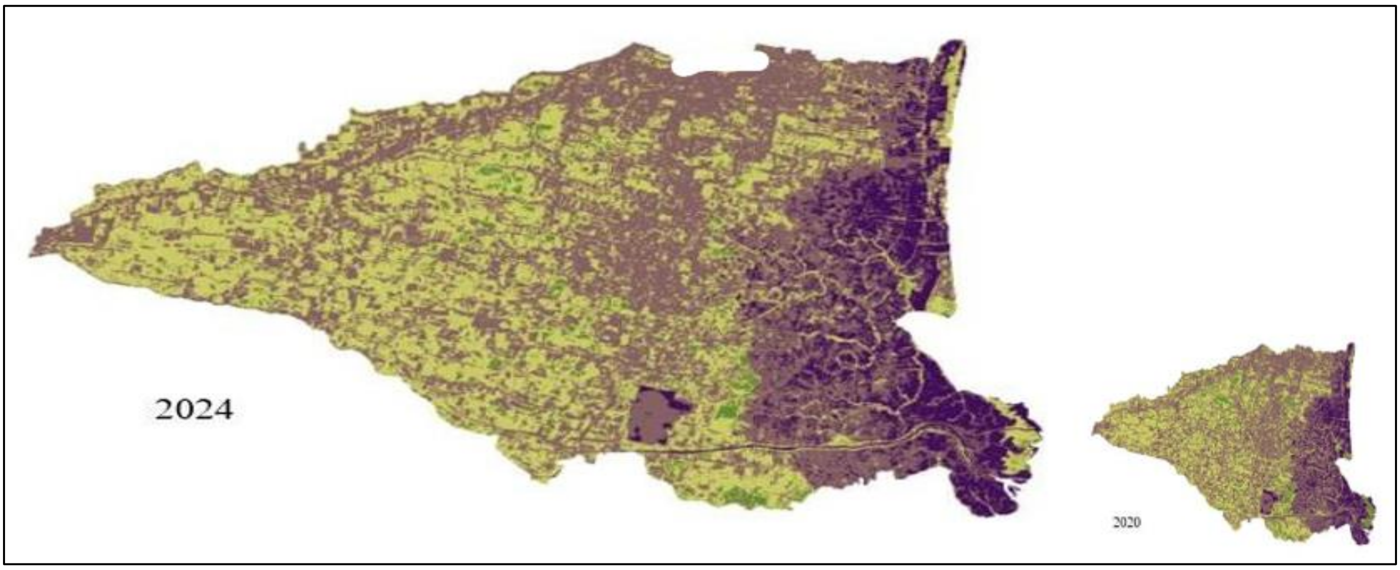

Fig 7 Distribution of Vegetation in the Sido Arjo Area 2024

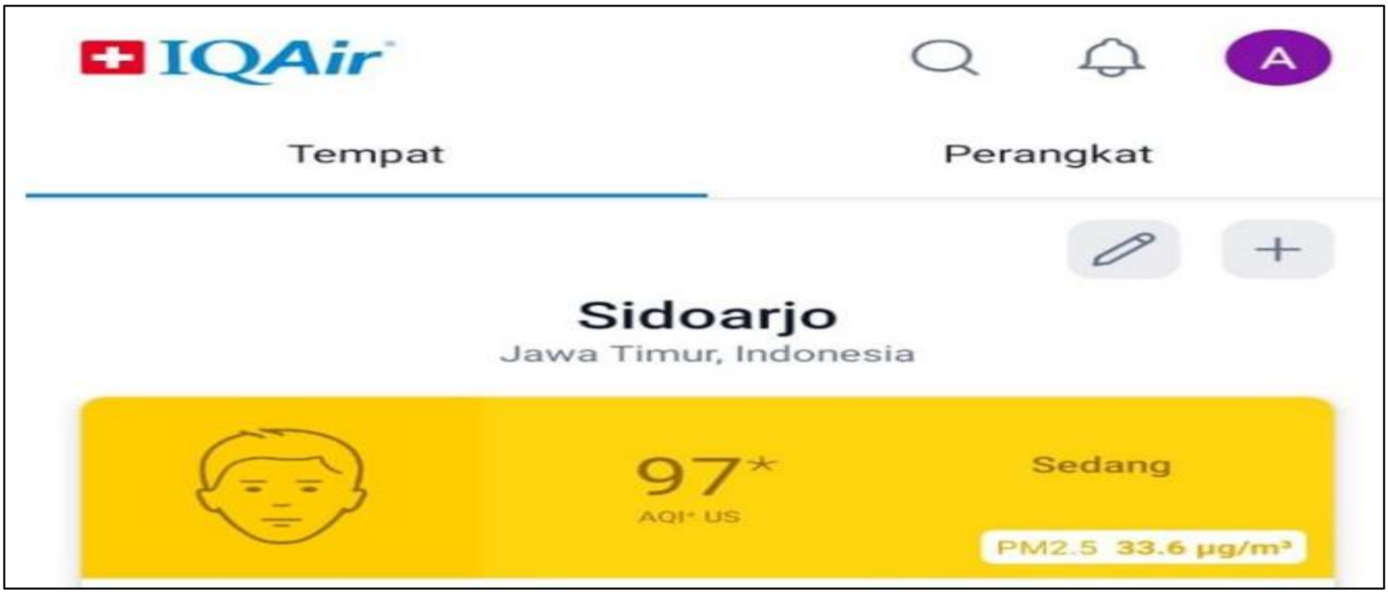

Fig 8 Results of Air Pollution Particles Through the IQ Air Website
(Source: IQ Air., 2024)

Fig 9 Air Pollution Particle Results Through AQI Website
(Source: AQI., 2024)

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Figures 3, 4, 5, 6, and 7 present the condition of the NDVI vegetation index. From these images, it can be observed that the distribution of vegetation from 2020 to 2024 has progressively worsened. This is illustrated by the green areas (indicating more vegetation) and purple areas (indicating land use change from vegetation to development). This decline is mainly due to the increased use of land for real estate development, which is considered one of the factors supporting the quality of life for the surrounding community.

This shift indirectly leads to a decline in air quality, as the reduction in vegetation limits the plants' ability to absorb air pollutants effectively. Vegetation acts as a natural filter for pollutants, reduces harmful gases, provides essential oxygen, and plays a role in regulating air temperature. All of these functions positively impact air quality and the surrounding environmental health.

This fact is supported by Figures 8 and 9, which show that the dominant air pollutants in Sidoarjo Regency are PM2.5, with concentrations ranging from 15 µg/m³ to 35 µg/m³, and PM10, with a concentration of 31 µg/m³. PM2.5 and PM10 are considered hazardous air pollutants based on their particle size. PM2.5 has a diameter of ≤ 2.5 micrometers and can penetrate the respiratory tract down to the lungs, potentially causing diseases such as asthma, bronchitis, and heart problems. Its sources include vehicle emissions, wood burning, and forest fires.

Meanwhile, PM10 has a diameter of ≤ 10 micrometers and poses risks to the upper respiratory tract and lungs. Its sources include dust from construction activities, agriculture, and fires. Both of these pollutants are commonly used as indicators of air quality and have serious impacts on human health and the environment. Moreover, if PM2.5 and PM10 levels exceed the recommended limits, they can disrupt daily activities due to poor air quality, which may cause excessive heat effects, making people feel physically uncomfortable.

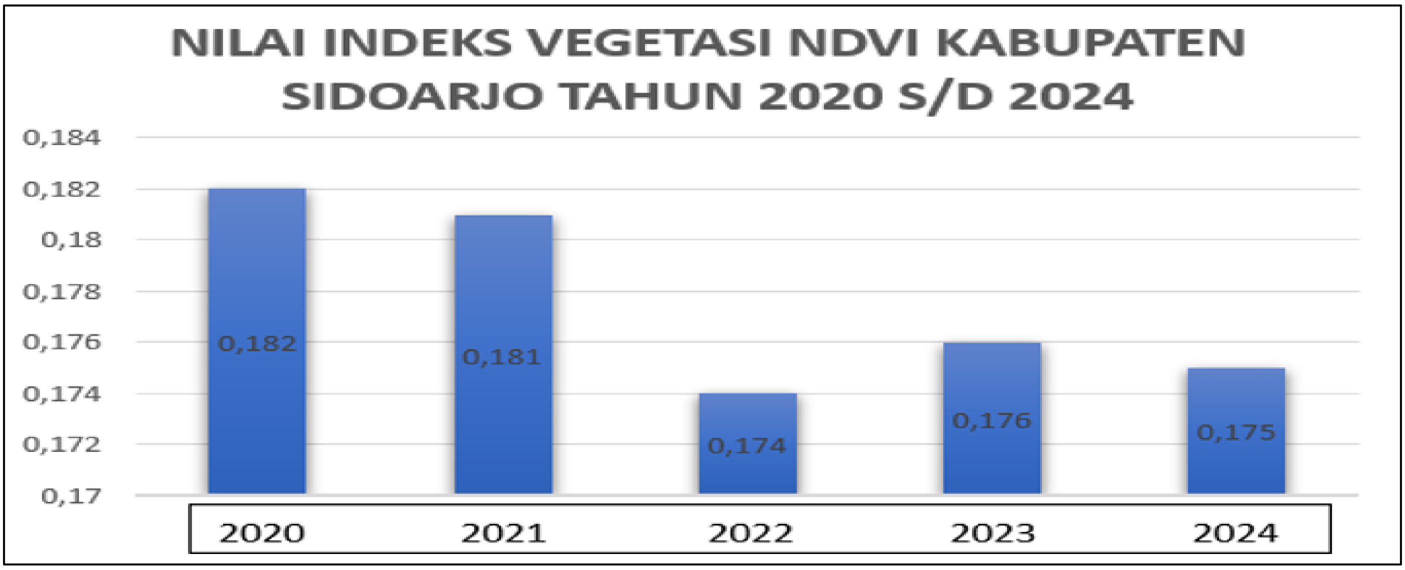

Fig 10 Graph of Distribution of NDVI Vegetation Index in Sidoarjo Area 2020 – 2024

Tabel 3 NDVI Vegetation Index Value of Sido Arjo Regency From 2020 To 2024

Year	NDVI Value
2020	0.182
2021	0.181
2022	0.174
2023	0.176
2024	0.175

The analysis of the Normalized Difference Vegetation Index (NDVI) values in Sidoarjo Regency for the period from 2020 to 2024, as illustrated in Figure 10 and Table 3, shows a fairly consistent downward trend. Although there was a slight increase in 2023, overall, the NDVI values have continued to decline. This is in line with visual observations on the vegetation distribution map, which indicate a reduction in green land cover in the area.

The significant decline in NDVI values from 2020 to 2022, followed by a slight increase in 2023 and a subsequent decrease in 2024, indicates fluctuations in the dynamics of land cover (vegetation) in Sidoarjo Regency. These fluctuations are most likely influenced by various factors such as land-use changes due to urbanization, land conversion for intensive agriculture, and the impacts of climate change.

Although the increase in NDVI value in 2023 offers a glimmer of hope, the decline observed in 2024 shows that environmental conservation efforts still need to be strengthened.

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- *This Reduction in Vegetation Cover Has Broad Implications for Environmental Quality and the Well-Being of Sido Arjo's Residents, Including:*

- *Air Quality:*

The decline in vegetation cover can reduce the ecosystem's ability to absorb carbon dioxide and produce oxygen, thereby contributing to a deterioration in air quality.

- *Air Temperature:*

The lack of vegetation may lead to increased surface temperatures, as vegetation plays a crucial role in regulating temperature through the process of evapotranspiration.

- *To Address the Issue of Declining Vegetation Cover in Sido Arjo Regency, Several Efforts are Needed, Such As:*

- *Increasing Public Awareness:*

Through campaigns and education, the public should be actively involved in environmental conservation efforts.

- Implementation of Environmental Conservation Policies:

The government needs to establish firm policies to protect green areas and encourage the development of new green zones.

IV. CONCLUSION

Based on the NDVI data analysis, it can be concluded that vegetation cover in Sidoarjo Regency has continued to decline in recent years. This condition should be a serious concern for all stakeholders, as it has significant impacts on environmental quality and the sustainability of life for the people of Sidoarjo.

Based on the analysis of NDVI (Normalized Difference Vegetation Index) using Landsat 8 imagery over a five-year period (2020–2024), it can be concluded that vegetation cover in Sidoarjo Regency has experienced notable changes due to increasing urbanization and land-use conversion. The results show a trend of declining green coverage in some areas, particularly in highly urbanized zones. The classification of NDVI values indicates a distribution ranging from non-vegetated land to high-density green vegetation, which reflects the level of environmental stress in various parts of the region.

Vegetation plays a crucial role in regulating microclimate conditions, especially in controlling air temperature, improving air quality, and reducing the risk of prolonged drought. The use of remote sensing technology and spatial analysis through GIS proves to be effective in mapping and monitoring vegetation health, offering valuable insights for environmental management and urban planning.

RECOMMENDATIONS

- *Policy Implementation:*

Local governments should adopt vegetation monitoring as a tool for sustainable spatial planning. Integrating NDVI-based analysis into decision-making can help maintain ecological balance in rapidly urbanizing areas.

- *Green Infrastructure Development:*

Urban development plans should include the establishment of green belts, urban forests, and reforestation zones to mitigate the effects of extreme temperatures and poor air quality.

- *Public Awareness and Engagement:*

Community involvement in tree planting and land conservation programs should be encouraged to enhance vegetation sustainability at the grassroots level.

- *Continuous Monitoring:*

Further research and regular NDVI-based assessments are necessary to track vegetation trends and respond swiftly to any signs of degradation, especially under the influence of climate change.

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