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# The Impact of the Trans-Java Toll Road Development on Spatial Planning in the Northern Region of Java Island: A Study Utilizing NDBI and Google Earth Images

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**Abstract:** The primary objective of toll roads is to stimulate economic growth. As the pivotal road network on Java Island, the Trans-Java Toll Road has a significant impact on regional development and spatial planning. However, there has been a lack of research focusing on the specific influence of this toll road on spatial planning. Therefore, this study aims to comprehensively examine the spatial and temporal implications of the Trans-Java Toll Road. To achieve this goal, the Normalized Difference Built-Up Index (NDBI) method is employed using satellite imagery. This method is widely recognized for its effectiveness in detecting changes in built-up areas through remote sensing techniques. The calculated NDBI values reveal substantial expansion of built-up areas in the cities and regencies traversed by the Trans-Java Toll Road. Notably, two specific areas with the highest rates of change are investigated: Gresik Regency and Bekasi Regency, where the built-up areas have experienced remarkable growth of over 186.9% and 61.8% respectively over a five-year period. To validate these findings, Google Earth imagery is utilized for two different years, namely 2016 and 2021. The observed changes in these regions are predominantly attributed to the economic growth facilitated by the establishment of industrial areas. Consequently, the expansion of industrial zones and settlements has resulted in a notable reduction in wetland areas and a simultaneous increase in built-up areas.

**Keywords:** Google Earth; industrial area; NDBI; settlements; Trans-Java Toll Road

## INTRODUCTION

Toll roads play a crucial role in the Indonesian transportation system, particularly in Java. The Indonesia Toll Road Authority (Badan Pengatur Jalan Tol) or BPJT has outlined the objectives of toll road implementation, including ensuring smooth traffic flow, facilitating the distribution of goods and services for economic growth, promoting equitable development, and engaging road users in government initiatives (Maria et al., 2020). Toll roads bring about economic improvements by reducing vehicle operating costs and travel time, providing investment opportunities for businesses through toll rates, and enabling convenient access for people and goods (Maria et al., 2020).

Transportation plays a vital role in the success of development, serving as the lifeblood for economic, social, political, and even security and defense activities (Amin, 2017). It significantly influences regional growth by facilitating the movement of goods, services, and people between areas. As a result, transportation development becomes a foundational requirement before other infrastructure projects can be undertaken (Palilu, 2019). Toll roads also contribute to regional development by supporting industries and alleviating pressure on urban centers (Susanto & Marsoyo, 2019). The Trans-Java toll road infrastructure, in particular, offers multiple benefits, such as efficient travel time and reduced transportation costs, leading to increased value for various commodities (Sumaryoto, 2010).

However, despite the numerous advantages of toll roads, they inevitably have negative impacts. Toll road infrastructure consumes space during construction and operation, leading to various effects on future land use, local traffic patterns, and the economy (Gupta et al., 2006). The expansion of toll roads can contribute to urban sprawl, altering the attractiveness of previously appealing regions and transforming them into different settlements and commercial areas. Furthermore, the introduction of new toll roads generates indirect effects, such as increased population growth, which, in turn, leads to more local traffic and congestion on existing roads (Andani et al., 2019).

The Trans-Java Toll Road comprises 18 routes spanning a length of 1,167 km, with its first inauguration dating back to 1984 and the most recent inauguration being the East Grati-Probolinggo toll road in 2019. This toll road was developed to expedite the establishment of the toll road network as part of the Java Island North-Central Cross national road network, connecting cities in the northern region of Java, including Merak, Cilegon, Serang, Tangerang, Jakarta, Bekasi, Karawang, Cikampek, Pamanukan, Loh Bener, Palimanan, Cirebon, Losari, Brebes, Tegal, Pemalang, Pekalongan, Batang, Kendal, Semarang, Bawen, Salatiga, Boyolali, Kartosuro, Surakarta, Sragen, Ngawi, Caruban, Nganjuk, Kertosono, Jombang, Mojokerto, Krian, Waru, Surabaya, Sidoarjo, Pasuruan, and Probolinggo. The Ministry of Public Works and Public Housing has planned to extend the toll road to Banyuwangi, with a target operational year of 2024. Currently, construction has reached the Section 1 area (Probolinggo-Besuki), bringing the Toll Road Network Planning Policy closer to realization as the backbone of Java Island's road network.

The construction of the Trans-Java toll road has significant implications for various aspects of development. Accessibility improvements often lead to substantial growth in an area. Monitoring the toll road's function can be achieved by examining the changes in spatial development, particularly in terms of built-up areas, over time. Remote sensing techniques, such as the calculation of the Normalized Difference Built-up Index (NDBI), combined with the analysis of Google Earth images at different times, can provide valuable insights into changes in land cover. Google Earth's high-resolution aerial imagery offers images taken several years apart, making it a cost-effective (open-source) method for detailed land cover classification (Garzon et al., 2022; Chapa et al., 2019). Despite the potential advantages of utilizing remote sensing to evaluate land use changes around the Trans-Java toll road, there is a lack of comprehensive research in this area. Therefore, this study aims to observe the spatial changes that occur before and after the operation of the Trans-Java toll road, utilizing remote sensing techniques and Google Earth as a visual validation tool for the calculated results.

The subsequent sections of this paper will delve into the research methodology, present the results, and provide validation. Remote sensing techniques employing NDBI will be utilized to quantify the observed changes, and two cities/regions displaying the most significant changes will be selected for further visual analysis using Google Earth imagery captured in different years.

## METHODS

Given the limitations and resource-intensive nature of conventional methods for obtaining land use information, remote sensing has emerged as a reliable and efficient alternative. Remote sensing utilizes satellite imagery to capture spectral responses from different bands, allowing for the extraction of valuable information about built-up areas (Karanam & BabuNeela, 2018). Google Earth Engine (GEE) serves as an open-source platform that provides access to comprehensive satellite data and tools, making it a valuable resource for environmental and societal applications (Wang et al., 2020). In this study, GEE is utilized to obtain satellite images and calculate the Normalized Difference Built Up Index (NDBI) to assess the distribution and development of built-up areas (He et al., 2010).

NDBI calculation is a widely used method for analyzing remote sensing images and specifically focuses on the spectral response of built-up areas in relation to other land covers. It leverages the reflection of Shortwave Infrared (SWIR), which indicates building reflection and generally has higher values than the reflection of Near-Infrared (NIR) (Handayani et al., 2017). The formula for NDBI calculation is as follows:

$$NDBI = (SWIR - NIR) / (SWIR + NIR) \quad \text{(He et al., 2010)} \tag{1}$$

To validate the obtained built-up area data, the calculated values are reclassified into four classes, as outlined in Table 1 (Watik & Jaelani, 2019). The classification categories include minor built-up areas, which represent small buildings surrounded by minimal soil and vegetation. The built-up area class encompasses housing, while clean water indicates rice fields, forests, or ponds. Landsat 8 Level 2 Collection 2 Tiers 1 imagery from two different years, namely 2016 and 2021, is used in this study to assess changes in the built-up area resulting from the construction of the Trans-Java toll road. The selected images for processing are the annual averages with a maximum of 20% cloud coverage, and additional cloud masking is performed using Landsat 8 band data.

While conventional field data collection for land use change along the toll road is challenging, Google Earth provides a valuable means of validation through real images captured in different years. The validation process focuses on areas with the most significant changes. However, it is important to note that this method has limitations, particularly regarding the availability of images for processing and validation due to issues such as cloud coverage, which can be a significant challenge in tropical countries.

Table 1. NDBI classification (Watik & Jaelani, 2019)

| Class | NDBI value |
|---|---|
| Turbid water | -1 – -0,5 |
| Clean water | -0,5 – -0,01 |
| Soil, vegetation, minor built up area | -0,01 – 0,49 |
| Major built up | 0,49 – 1 |

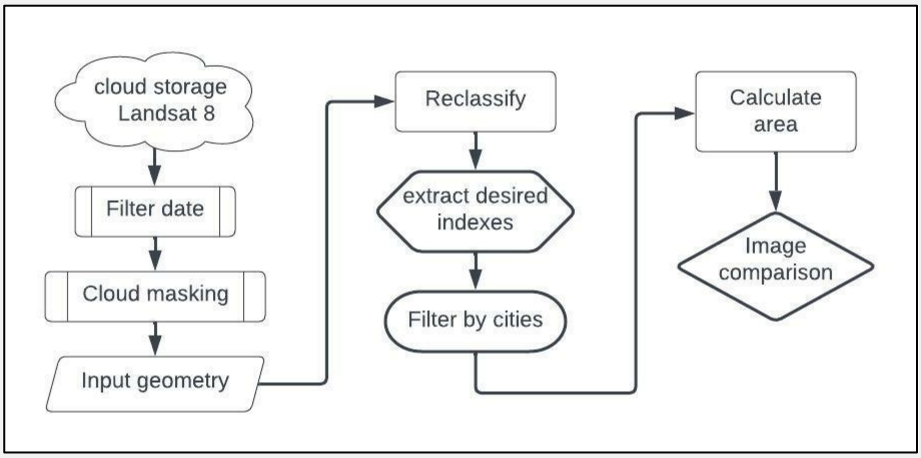



Figure 1. The workflow of deriving the Normalized Difference Vegetation Index (NDVI)

## RESULTS & DISCUSSION

Based on the workflow, the NDBI calculation for Java Island resulted in the determination of the built-up area. This research specifically focuses on analyzing the extent of built-up areas, combining the Class Soil, vegetation, minor built-up area, and Major built-up area from Table 1. The NDBI calculation utilizes Band 6 as Shortwave Infrared (SWIR) and Band 5 as Near-Infrared (NIR) in Landsat 8 imagery. The data retrieval and processing are conducted using the Google Earth Engine (Figure 1).

The classification results are depicted in Figure 2, where the soil, vegetation, minor built-up areas, and major built-up areas are represented in red. Turbid water bodies, such as rivers and lakes, as well as clean water, are depicted in green. The processing results for 2016 indicate that the distribution of built-up areas is concentrated in specific regions, including Jabodetabek (Jakarta, Bogor, Depok, Tangerang, Bekasi), Surabaya, Semarang, and Bandung. These cities are major development hubs in Java Island and even in Indonesia.

The Trans-Java toll road, which spans from Banten to East Java, has been operational since December 2018. Therefore, the NDBI results for 2021 are expected to reveal spatial changes influenced by this road. Over a span of 5 years, the red-colored built-up areas appear to have expanded, with the emergence of new city centers such as Karawang, Tegal, Batang, Pekalongan, and Solo. The analysis also clearly indicates the development of urban sprawl along the Trans-Java toll road, particularly in the northern part of Java Island, from Banten to Central Java, and further toward the island's central regions upon entering East Java. Additionally, the calculation results demonstrate minimal changes in areas that have not yet been traversed or are still under construction by the Trans-Java toll road, such as the East Probolinggo to Banyuwangi areas.

To validate the changes in spatial planning, the built-up area was calculated for each city and regency along the toll road. The toll road passes through a total of 47 cities and regencies, as indicated in Figure 3, sourced from the Ministry of Public Works and Public Housing data. These cities and regencies include Batang, Bekasi, Bogor, Boyolali, Brebes, Cirebon, Gresik, Indramayu, Jombang, Karanganyar, Karawang, Kendal, West Jakarta, Central Jakarta, South Jakarta, East Jakarta, North Jakarta, Bekasi City, Bogor City, Cilegon City, Cirebon City, Depok City, Pasuruan City, Probolinggo City, Salatiga City, Semarang City, Serang City, Surabaya City, Tangerang City, Tangerang Selatan City, Madiun, Magetan, Mojokerto, Nganjuk, Ngawi, Pasuruan, Pekalongan, Pemalang, Probolinggo, Purwakarta, Semarang, Serang, Sidoarjo, Sragen, Subang, Tangerang, and Tegal.

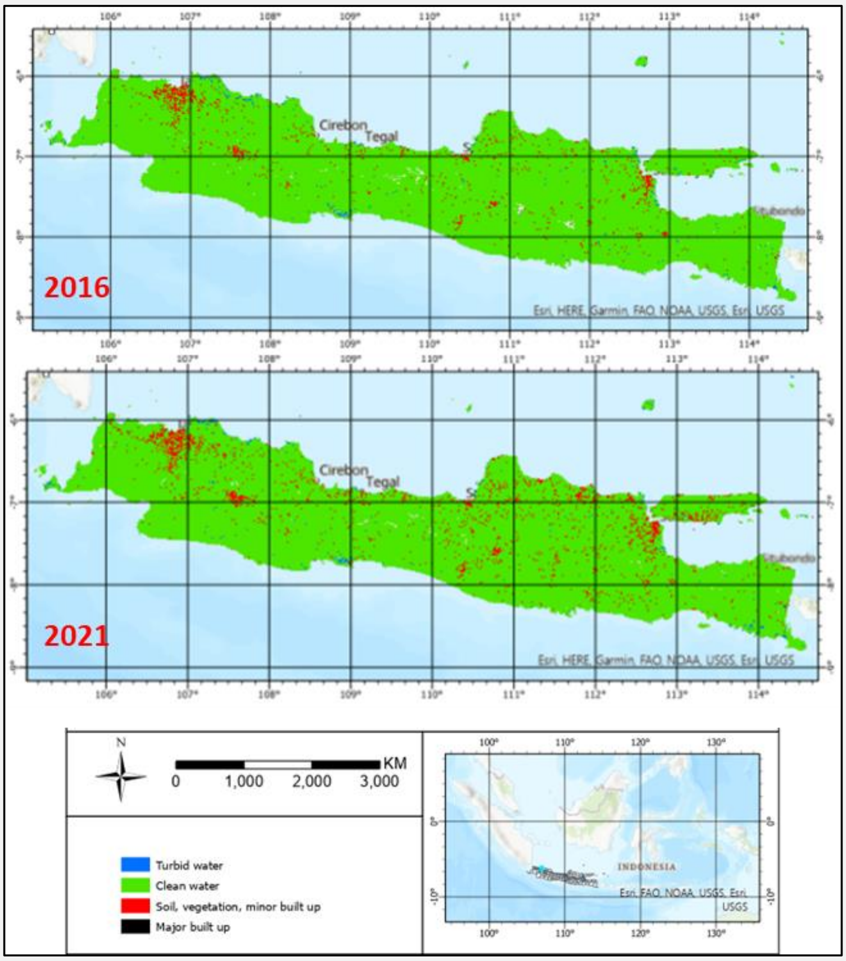
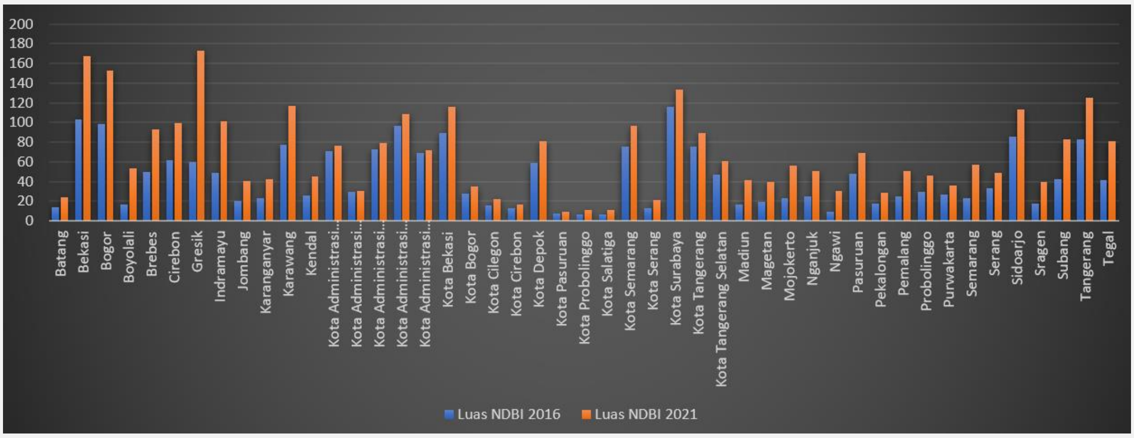


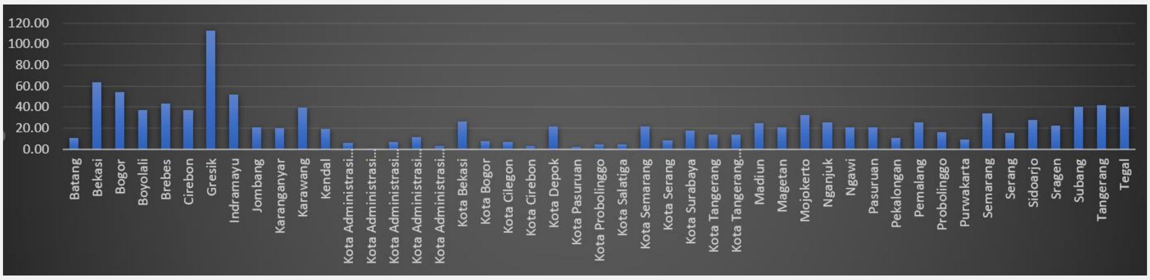

Figure 2. Java Island Land Cover according to NDBI calculation for 2016 and 2021


Figure 3. The locations of toll gates ('Gerbang Tol Jawa') along the Trans-Java toll road, indicating the cities passed ('kotaTolTransjawa') and regency boundaries ('KabKotaJawa')

The presence of toll gates has contributed to the development of urbanization, leading to linear development along the road, radial development with toll gates as centers, and leapfrog developments, resulting in more urban sprawl as the toll road ages (Aditya & Husna, 2022). This has attracted farmers to convert agricultural land into non-agricultural activities, particularly in the northern part of Java Island, which was previously known for its vast paddy fields and has raised concerns about food security in Indonesia (Makbul et al., 2019).




(a)




(b)

Figure 4. Built-up area calculation from NDBI: (a) comparison of built-up area in 2016 and 2021 represented by blue and orange colors respectively and (b) the result of reducing the built-up area in 2021 and 2016

Figure 4 presents a histogram illustrating the changes in the built-up area based on NDBI calculations. The upper part of the figure compares the built-up areas for each year, while the lower part represents the subtraction results between the two years. From the upper figure, it is evident that the built-up area has significantly increased in all cities and regencies, including well-established city centers such as Bekasi, Bogor, Karawang, all parts of Jakarta, Tangerang, Surabaya, and Sidoarjo. To examine which cities and regencies have undergone significant land use changes, the lower figure depicts the subtraction of NDBI values. The changes are most pronounced in Gresik Regency, followed by Bekasi Regency, both of which are industrial areas that support major cities like Jakarta and Surabaya. On the other hand, the Greater Jakarta area and cities/regencies in the eastern part of Java, such as Pasuruan and Probolinggo, have experienced minimal changes despite being traversed by the Trans-Java toll road. Notably, cities and regencies located in the middle section of the Trans-Java toll road, including Karawang, Subang, Indramayu, Cirebon, Tegal, Brebes, Boyolali, and Mojokerto, have witnessed moderate but noticeable changes. A detailed study of the two districts with the highest changes was conducted to confirm these results.

**Gresik Regency**

The NDBI calculation for Gresik Regency, as shown in Table 2, reveals significant changes in the different land cover classes between 2016 and 2021. The largest reduction is observed in the wetlands or paddy fields/ponds category, with a decrease of 186.8868% over the five-year period. This decline is accompanied by a substantial increase in the area of minor built-up or housing, which has nearly tripled in size. Additionally, there is a noticeable decrease of 30.292% in the turbid water area and 8.1426% in the clean water area, which includes rice fields, forests, or ponds. Although the percentage decrease in clean water may seem minor, it amounts to approximately 93.4524 km², which is comparable to the increase in the minor built-up area.

Table 2. Area changes from NDBI calculation in Gresik Regency

| Class | Area for 2016 (km²) | Area for 2021 (km²) | Area change (km²) | Percentage (%) |
|---|---|---|---|---|
| Turbid water | 62.7939 | 43.7724 | -19.0215 | -30.2920 |
| Clean water | 1147.6951 | 1054.243 | -93.4524 | -8.1426 |
| Soil, vegetation, minor built-up area | 60.1911 | 172.6803 | 112.4892 | 186.8868 |
| Major built-up | 0.0108 | 0.0054 | -0.0054 | -50 |

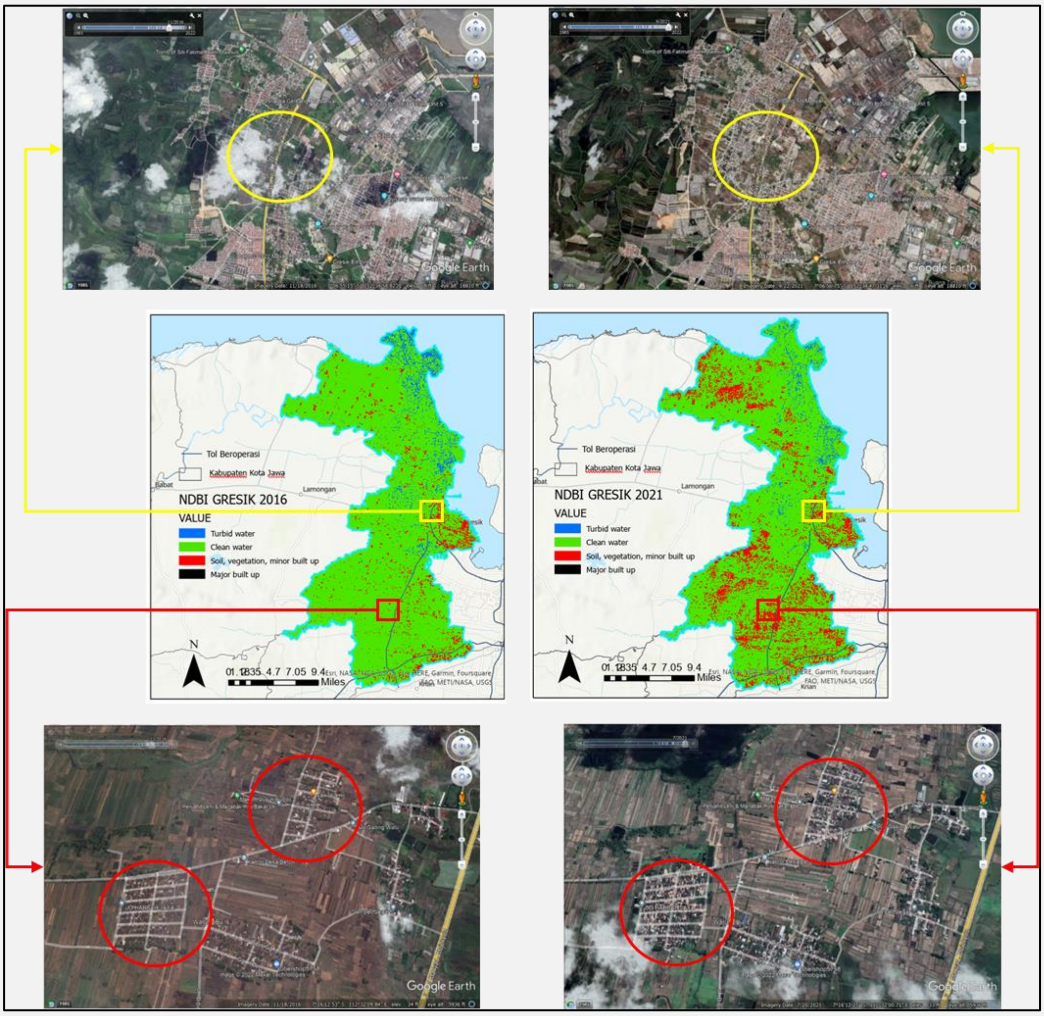


Figure 5. Changes in land cover through Google Earth imagery in Gresik Regency (circled area)

To validate these changes, Google Earth imagery, depicted in Figure 5, can be examined. The image highlights areas with notable land cover transformations, such as the conversion of former paddy fields into minor built-up areas around the Manyar Toll Gate, indicated by a yellow circle. This change is further supported by the expansion of the built-up area in front of the toll gate, including the industrial areas of PT Cargill Indonesia and Maspion Industrial Estate Unit 5. Another significant change can be observed in Beton Village, located in the southern part of Gresik Regency, represented by a red circle in Figure 5. This area has undergone housing developments, which is evident when comparing Google Earth imagery from November 18, 2016, and July 20, 2021.

The emergence of numerous housing complexes further reinforces the change in land cover observed in Gresik Regency. Figure 6 visually depicts the transformation of agricultural lands into large housing complexes, as indicated by the green circles. These areas, which were once dedicated to agricultural activities, have undergone significant urban development and have been converted into residential areas.

The conversion of agricultural lands into housing complexes signifies the growing demand for housing and the expansion of urban areas in Gresik Regency. As the population increases and urbanization progresses, there is a need for additional residential spaces to accommodate the needs of the growing community. Consequently, agricultural lands are being repurposed and transformed into large-scale housing developments to meet this demand.

The transformation of agricultural lands into housing complexes is a characteristic feature of urban sprawl, where urban development extends into previously rural or agricultural areas. This phenomenon is often driven by factors such as population growth, economic development, and the availability of infrastructure, including transportation networks like the Trans-Java toll road.

It is important for local authorities and urban planners to carefully manage the expansion of housing complexes to ensure the preservation of agricultural lands, promote sustainable urban development, and mitigate potential negative impacts on the environment and food security. Balancing the needs of housing and urban growth with the preservation of agricultural resources is crucial for achieving long-term sustainability in land use planning and development.

(a) (b)

Figure 6. Land cover change from agriculture into housings in Gresik Regency: (a) Land cover change in 2016, and (b) Land cover change in 2021

The rapid growth of the industrial sector in Gresik Regency, particularly driven by the Java Integrated Industrial Port Estate (JIIPE), has played a significant role in transforming land use and land cover. Previous studies have reported changes in land cover over a 10-year period from 2002 to 2012, with an increase in the built-up area and a decrease in green open space and vacant land (Hasyim et al., 2019). The industrial sector experienced significant development after 2007, following a trend shift from fish ponds to industrial activities. Paddy fields also experienced decline after the implementation of the 2012 Regional Spatial Plan (RTRW). However, policies aimed at sustainable food agriculture (LP2B) have led to an increase in paddy fields since 2013, as part of local regional policy efforts to ensure food security.

The study conducted by Firmansyah et al. (2021) highlights the significant transformation that has taken place in Gresik Regency, particularly the conversion of paddy fields into settlements and industrial areas. According to their findings, approximately 126.07 hectares of paddy fields have been converted into settlements, indicating a shift in land use and a departure from the previous spatial planning. Additionally, an additional 59.09 hectares of paddy fields have been transformed into industrial areas, further emphasizing the changing landscape of the regency.

These land use changes have important implications for the local government, particularly in terms of ensuring food security. The conversion of agricultural land, such as paddy fields, into other types of development poses challenges to maintaining sufficient food production. In response to these changes, the local government is faced with the task of finding ways to balance urban development and industrial growth while also addressing the need to secure food resources for the population.

It is worth noting that these transformations have occurred despite the existence of the LP2B (sustainable food agriculture) policy. This suggests that additional measures may be required to address the competing demands of urbanization, industrialization, and food security in Gresik Regency. The findings of Firmansyah et al. (2021) underscore the importance of effective spatial planning and the need for comprehensive strategies to ensure sustainable development and address the challenges arising from land use changes in the region.

**Bekasi Regency**

Table 3 presents the results of land cover change calculations in Bekasi Regency using NDBI (Normalized Difference Built-Up Index) analysis. Although the changes observed over the 5-year period in Bekasi Regency are not as extensive as those in Gresik Regency, there are notable transformations, particularly a reduction in wetlands or paddy fields, accompanied by an increase in residential areas and the presence of large buildings.

Table 3. Area changes from NDBI calculation in Bekasi Regency

| Class | Area for 2016 ($km^2$) | Area for 2021 ($km^2$) | Area change ($km^2$) | Percentage (%) |
|---|---|---|---|---|
| Turbid water | 20.3292 | 26.7831 | 6.4539 | 31.7469 |
| Clean water | 1143.1012 | 1072.891 | -70.2099 | -6.1421 |
| Soil, vegetation, minor built-up area | 103.1679 | 166.9743 | 63.8064 | 61.8471 |
| Major built-up | 0 | 0.0072 | 0.0072 | 0.72 |

The area of turbid water, characterized by cloudy or muddy water, experienced an increase from 20.3292 $km^2$ in 2016 to 26.7831 $km^2$ in 2021. This change represents a growth of 6.4539 $km^2$ or 31.7469% compared to the previous year. The clean water class, which includes rice fields, ponds, and forests, witnessed a reduction from 1143.1012 $km^2$ in 2016 to 1072.891 $km^2$ in 2021. The decrease amounts to 70.2099 km2 or -6.1421% in percentage change. The most significant change occurred in the soil, vegetation, and minor built-up area category. It expanded from 103.1679 $km^2$ in 2016 to 166.9743 $km^2$ in 2021, indicating a substantial increase of 63.8064 $km^2$ or 61.8471% compared to the previous year. This class includes areas with limited development, such as small buildings, gardens, and agricultural fields. The major built-up area, encompassing large-scale infrastructure and urban developments, remained negligible in both 2016 and 2021. However, there was a minimal increase from 0 $km^2$ to 0.0072 $km^2$, representing a change of 0.0072 $km^2$ or 0.72% over the five-year period.

These changes in land cover reflect the ongoing urbanization and development in Bekasi Regency. The expansion of minor built-up areas suggests the growth of smaller settlements, while the increase in turbid water indicates changes in water bodies due to human activities or natural processes. The reduction in clean water areas, such as rice fields and ponds, highlights the conversion of agricultural land into residential and industrial zones. Overall, these findings emphasize the dynamic nature of land cover changes in Bekasi Regency and the need for sustainable land management practices to balance urban development with environmental preservation.

The reduction in wetlands or paddy fields covers an area of 70.2099 $km^2$, accounting for a 6.1421% change compared to the previous year. Interestingly, the most significant change is observed in the increase of soil, vegetation, and minor built-up areas, which has experienced a substantial growth of 61.8471%. This finding further supports the similarity in the magnitudes of the decreasing and increasing changes in land cover.

To gain more insight into the specific changes, a detailed investigation using Google Earth was conducted, leading to the depiction of Figure 7. The NDBI calculations reveal a noticeable change in the minor built-up areas along the toll road. The yellow circle in the Google Earth imagery, representing the conditions on November 12, 2016, and August 18, 2022 (due to cloud cover in the 2021 image), illustrates the emergence of small settlements in areas that were previously wetlands. Additionally, the figure highlights the construction of industrial areas, marked by red circles, such as the Greenland International Industrial Center (GIIC) and other industrial zones that have transformed previously vacant land into built-up areas.

The primary driver behind the significant land changes in Bekasi Regency is the development of residential and industrial areas. As a result, there has been a reduction in productive land, including rice fields and moor areas, as highlighted in the study by Suwargana & Haranugraha (2017). Their research conducted over a 23-year period (1990-2013) revealed a decrease of 17,223 hectares of rice fields, equivalent to an average annual decline of 748 hectares, with dry areas also diminishing by 142 hectares per year. Concurrently, the study found that residential land expanded by 406 hectares per year, while industrial areas grew by 191 hectares annually. This finding is in line with another study that emphasized the inconsistency in future spatial planning due to suburbanization, as documented by Kurnianti et al. (2015).

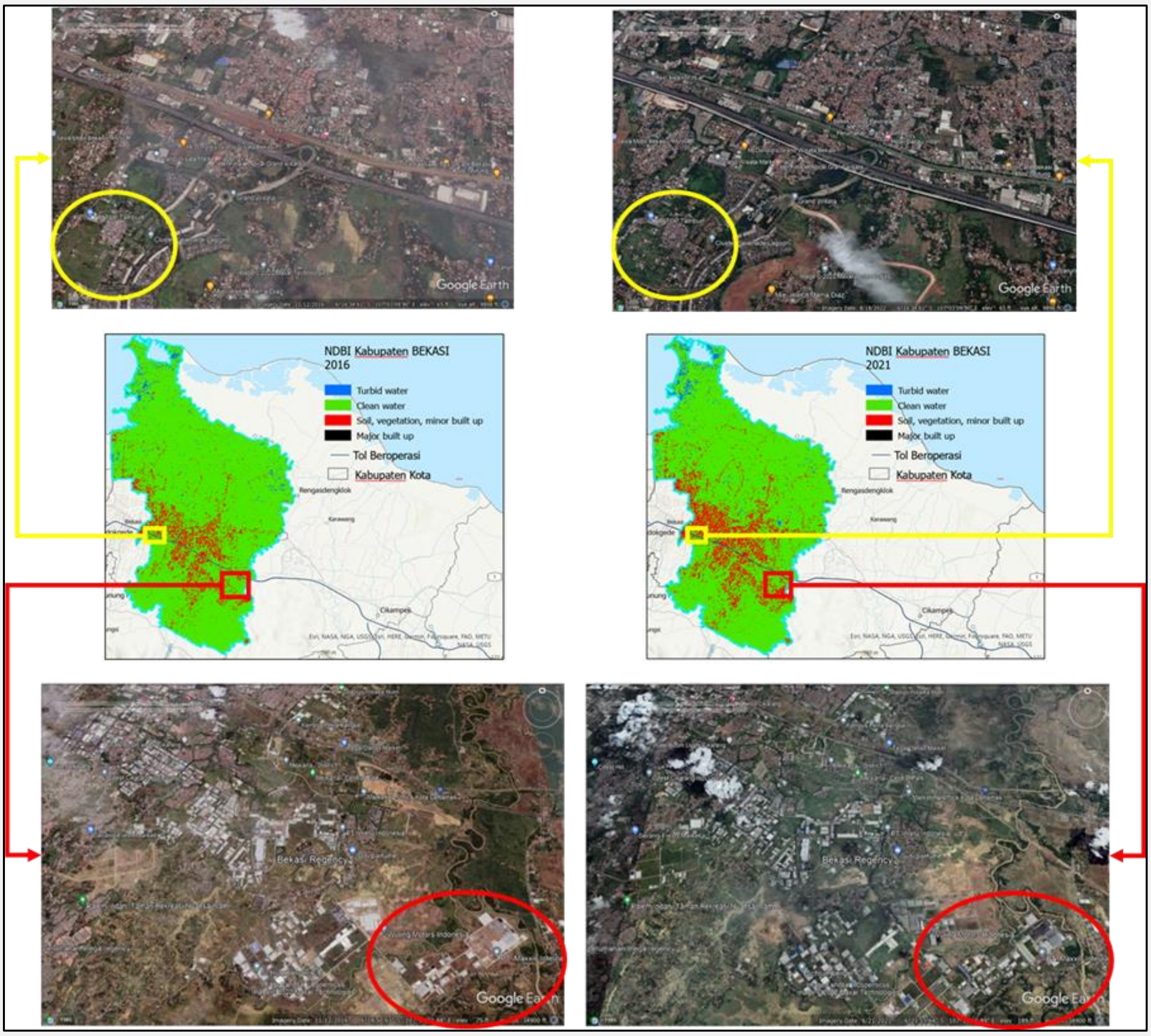



Figure 7. Changes in land cover through Google Earth imagery in Bekasi Regency (circled area)

## CONCLUSION

Transportation infrastructure plays a crucial role in fostering economic and social development by facilitating the movement of people, goods, services, and ideas. However, the construction of infrastructure, such as the Trans-Java toll road, can have implications for spatial planning in the areas it traverses. In this study, the NDBI (Normalized Difference Built-up Index) derived from remote sensing techniques was employed to analyze changes in urban areas along the toll road. By leveraging the spectral characteristics of Landsat 8 imagery in the SWIR (Short-Wave Infrared) and NIR (Near-Infrared) bands, the study examined the transformations that occurred between 2016 and 2021 in a total of 47 cities and regencies.

The analysis of the classified areas revealed notable changes, with particular emphasis on two prominent cities/regencies: Gresik Regency and Bekasi Regency, known for their industrial activities. Gresik Regency witnessed a significant increase in built-up area, expanding by 112.4892 km$^2$ or 186.8868%, accompanied by a decrease in wetlands of 93.4524 km$^2$ or 8.1426%. Similarly, Bekasi Regency experienced an expansion of 63.8064 km$^2$ or 61.8471% in built-up areas, while wetlands diminished by 70.2099 km$^2$ or 6.1421% over the five-year period. These changes primarily manifested as the emergence of industrial areas and the development of housing complexes.

The consequences of residential and industrial development in these two regencies were the significant reduction of productive lands, including paddy fields and dry fields. This transformation is clearly visible in Google Earth imagery, which depicts a noticeable increase in building structures surrounding the toll gates. These findings underscore the impact of infrastructure development on land use patterns and highlight the need for careful consideration of spatial planning to balance economic growth with the preservation of essential ecosystems and productive agricultural lands.

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