Application of LEI (Landscape Expansion Index) for Monitoring Flood-Prone Areas in Bekasi City in 2005, 2015, and 2025

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Abstract *Rapid population growth and accelerated urbanization in metropolitan areas, including Bekasi City, indicate uncontrolled land use change. One of its main impacts is the reduction of natural infiltration areas such as rivers, wetlands, and vegetation, which increases surface runoff and exacerbates flood risk. Therefore, it is essential to monitor urban growth spatially and temporally as a foundation for disaster mitigation and land-use management. This study aims to analyze land use changes in Bekasi City in the years 2005, 2015, and 2025, and to identify the directions of urban expansion using the Landscape Expansion Index (LEI) method. Furthermore, the study seeks to map flood-prone areas based on the patterns of built-up area development. The data used includes Landsat 5 imagery (2005) and Landsat 8 (2015 and 2025). Land use classification is performed using the Random Forest machine learning algorithm to distinguish between built-up and non-built-up areas. Subsequently, new built-up zones are analyzed spatially using buffering and overlay techniques to calculate the LEI value for each period. LEI measures the ratio between the edge of new urban patches that adjoin existing built-up areas and the total edge of the new patch. Through this approach, urban expansion patterns such as infill, edge-expansion, or leapfrog can be identified. The LEI analysis reveals the relationship between the direction of urban expansion and increased flood vulnerability. This information is crucial for supporting more adaptive and sustainable spatial planning and serves as a basis for disaster mitigation policymaking in urban areas such as Bekasi City.*

Keywords: Flood, Landsat Imagery, Landscape Expansion Index (LEI), Land Use Change, Urbanization

Introduction

The swift expansion of global metropolitan regions has prompted substantial changes in land utilization and unregulated urbanization practices (Sharma & Ghuge, 2025). A research by Sharma & Ghuge (2025), indicates that in 2021, 56% of the global population lived in urban regions, with projections suggesting an increase to 68% by 2025. The swift alteration in land

use has resulted in less green spaces, heightened runoff, and reduced soil infiltration. Land use alterations intensify flood hazards, particularly in urban regions (Sugianto et al., 2022).

Bekasi is one of the cities in Indonesia seeing significant population growth and swift urbanization. Bekasi constitutes a segment of the Jabodetabek region (Jakarta, Bogor, Depok, Tangerang, Bekasi), functioning as an industrial and residential buffer for the capital city (Fata Robbany et al., 2019). Bekasi has undergone significant development pressure, resulting in extensive alterations in land use (Fata Robbany et al., 2019). The conversion of land from natural infiltration zones, including wetlands, rivers, and vegetation, to developed areas has transpired swiftly and frequently without regulation. This situation has diminished the environment's capacity to absorb water, resulting in heightened surface runoff and an escalated risk of floods Click or tap here to enter text.. Research by Yuanita & Sagala (2025) reveals that residential areas, which constituted merely 2.38% in 1998, expanded to 23.6% by 2008 and have continued to proliferate through 2025. This indicates a swift increase in residential development. The reduction of infiltration zones in Bekasi has increased the city's susceptibility to flooding. Additionally, substantial precipitation coupled with inadequate drainage might result in flooding during almost every rainy season (Oktavia et al., 2023).

Bekasi is intersected by the Cikeas and Cileungsi rivers in the upstream regions (Marko & Zulkarnain, 2018). Alterations in land use and development in the upper watershed area affect hydrological conditions by augmenting surface runoff in the Cikeas-Cileungsi watershed, resulting in flooding in Bekasi (Marko & Zulkarnain, 2018). According to research by Putu Oktavia & Afifah Nur Anggraeni Oktavia (2023), eight out of twelve districts frequently experience flooding, particularly during the rainy season. This highlights that the increasing rate of land use changes without proper control and planning will lead to more intense flooding in Bekasi.

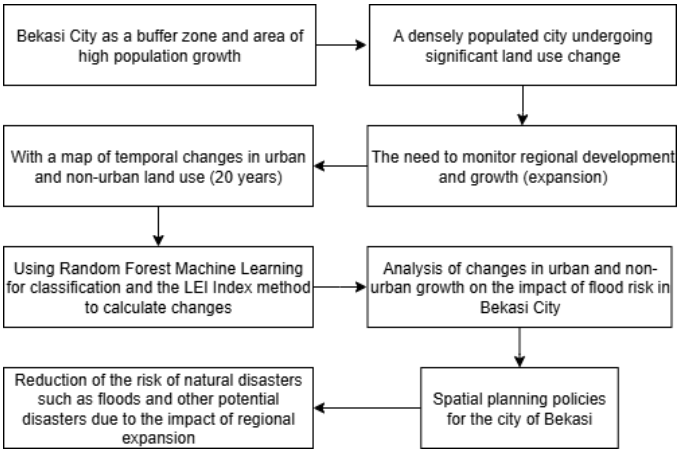
Consequently, the spatial and temporal assessment of urban expansion has emerged as an essential requirement for urban planning and disaster risk reduction. The Landscape Expansion Index (LEI) method serves as a technique for identifying and analyzing the trajectory and pattern of urban expansion (Liang et al., 2025). LEI facilitates the clear identification of expansion types, including infill, edge-expansion, and leapfrog, so enhancing the comprehension of urban growth dynamics (Liang et al., 2025). This approach is crucial for comprehending the influence of urban development patterns on environmental alterations, specifically on heightened flood susceptibility.

This study concentrates on Bekasi, employing data from 2005, 2015, and 2025, and utilizes Landsat satellite images alongside Random Forest algorithms for land cover classification. This research seeks to elucidate the correlation between urban development trajectories and the expansion of flood-prone regions through the integration of spatial-temporal methodologies and LEI. This study aims to examine land use alterations in Bekasi from 2005 to 2025, ascertain the spatial and temporal trajectory of urban expansion utilizing the Landscape Expansion Index (LEI), and identify and delineate flood-prone regions in accordance with the development patterns in Bekasi. The results are anticipated to establish a basis for formulating adaptive and sustainable spatial planning policies, while also aiding disaster mitigation initiatives in swiftly expanding metropolitan regions such as Bekasi.

Literature Review

Rapid urbanization in metropolitan areas like Bekasi has been a major driver of land cover change, transforming agricultural landscapes and green open spaces (RTH) into dense residential, industrial, and commercial areas (Firman, 2009). This transformation significantly increases the proportion of impervious surfaces, disrupting the natural hydrological cycle by reducing infiltration, accelerating surface runoff, and increasing runoff volume (Arnold & Gibbons, 1996). These hydrological impacts directly exacerbate flood risks in urban areas like Bekasi, which are relatively flat and intersected by rivers prone to flooding, such as the Bekasi and Cakung Rivers (BNPB, 2021). The combination of extreme rainfall, limited drainage capacity, river sedimentation, and the reduction of infiltration areas makes flooding an increasingly complex annual threat (Jha, 2012; Chan et al., 2018).

Understanding the spatial patterns of built-up area expansion is crucial, as not all forms of urban development have the same hydrological impact. This is where the Landscape Expansion Index (LEI), introduced by Liu et al. (2010), offers an innovative approach. LEI quantifies three main types of expansion: (1) Infill (development within the gaps of existing built-up areas, LEI 50-100), (2) Edge-expansion (expansion on the edges of existing areas, LEI 0-50), and (3) Outlying (isolated development, LEI = 0). The outlying and edge-expansion types are often the most at risk for flooding because they convert active infiltration areas (agriculture, RTH) on the urban fringe or fragment natural hydrological corridors, while infill can reduce intra-urban RTH that functions as a local buffer (Liang et al., 2025). Temporal LEI analysis (2005, 2015, 2025) allows for the identification of where and how urban expansion patterns contribute to the spatial increase in flood vulnerability.



Source: Author, 2025

Figure 1: framework of thinking

One of the common issues in urban areas is that population growth and urbanization activities impact land development and changes, which are difficult to control. This leads to several problems, such as the reduction of natural drainage systems like rivers, wetlands, and other infiltration areas, which increase surface runoff and, consequently, the flood risk. There is a need to monitor the direction of urban development in Bekasi spatially and temporally using Landsat 5 and Landsat 8 imagery, with the application of a machine learning method, specifically Random Forest. This analysis aims to monitor urban development patterns in relation to flood vulnerability.

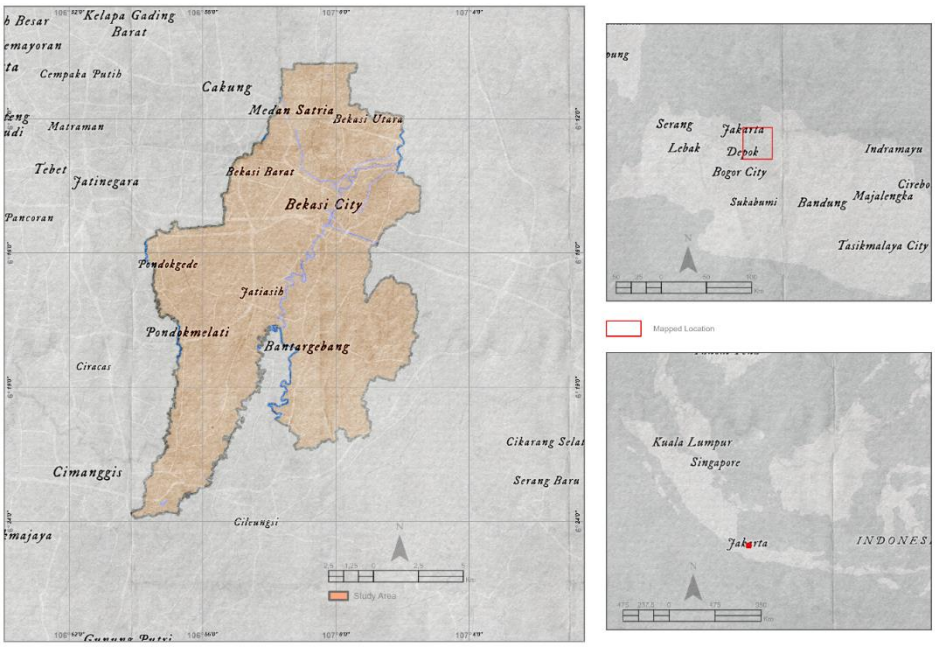
Methodology

Remote sensing technology can easily monitor land mapping temporally by utilizing satellite imagery data, literature studies, and existing documents, such as flood-prone areas every year. In this study, this data is collected to achieve the research goal, which is to monitor potential flood areas temporally using classification of built-up and non-built-up areas. To determine the procedures and effective methods for conducting this research, a research methodology has been developed to achieve the analysis stage of the research results.

Study Area

The research location is in Bekasi City, West Java Province, Indonesia, one of the major cities geographically located to the east of the capital city, Jakarta. In this city, the main issue

is population growth, which increases annually due to activities such as urbanization, impacting land development and changes. Bekasi City, which is part of the metropolitan area, is the focus of our research due to the urgency of the study. Below is the map of our research location shown in Figure 2.



Source: Author, 2025

Figure 2: Study area in Bekasi City

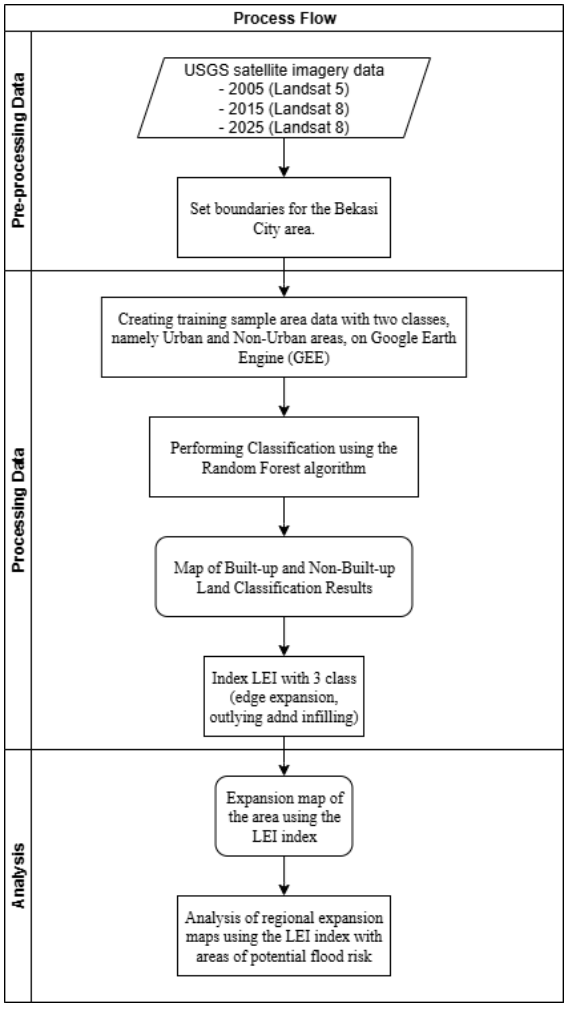
Data Collection

The data collection was conducted using USGS Landsat imagery, with the 2005 image obtained from Landsat 5, and the 2015 and 2025 images obtained from Landsat 8, which were cloud-free and pre-processed. Sample areas were randomly selected for training and validation data in both built-up and non-built-up areas. These sample areas were created using the open-source platform Google Earth Engine (GEE), and the resulting data was integrated into a classification process using machine learning.

Data Preparation

Research Flow

The research phase began with data collection and pre-processing. The data was then processed in Google Earth Engine (GEE) using random forest algorithm to generate a built-up land classification. The classification results were used for LEI Index processing and analysis.



Source: Author, 2025

Figure 3: Research Flow

Land use map processing

Classification was performed using the Random Forest machine learning algorithm to identify built-up and non-built-up areas temporally, with Landsat 5 imagery for 2005 and Landsat 8 imagery for 2015 and 2025. Before processing the data, validation sample points were created in Google Earth Engine (GEE) to differentiate between built-up and non-built-up

areas by delineating the built-up land area on several temporally created maps. Once the validation points were completed, they were input into the machine learning process for each year (2005, 2015, and 2025). After the land use data was analyzed, spatial tools in Arc Toolbox were used with overlay to calculate the LEI value for each time period.

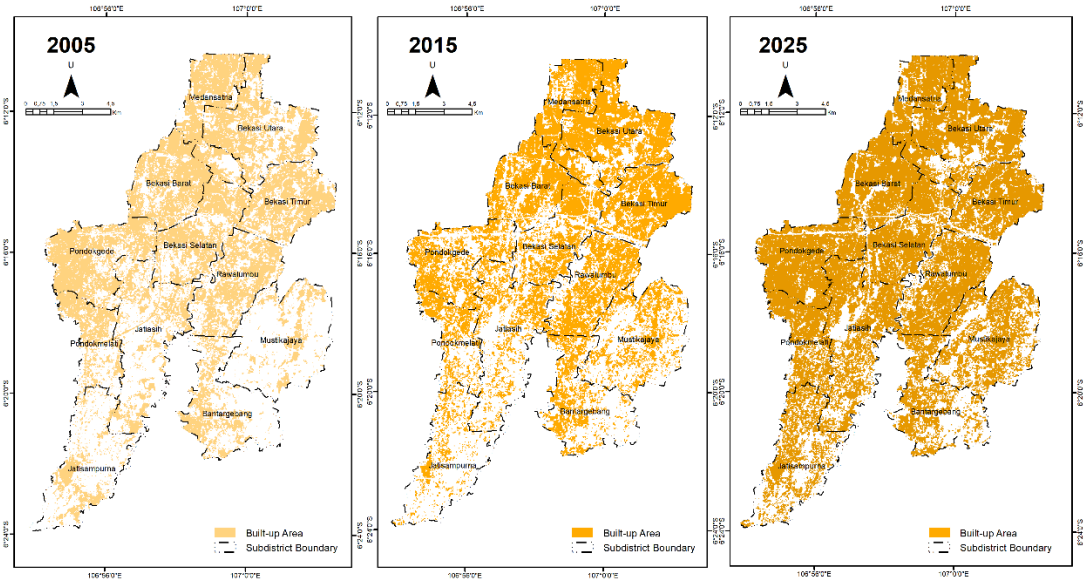
LEI (Landscape Expansion Index) map processing

The new zones resulting from the classification using the Random Forest machine learning algorithm for built-up areas will be analyzed using spatial buffering to calculate the LEI value for each time. By examining the dynamics of built-up area expansion through LEI, this study is expected to provide relevant spatial information for flood risk monitoring and mitigation, as well as contribute to sustainable urban planning in Bekasi City.

Result and Discussion

Changes in built-up land use in Bekasi City in 2005, 2015, and 2025

One of the buffer zones of the capital city of Jakarta is the city of Bekasi, which has experienced rapid economic and industrial growth. One of the main indicators of development dynamics in this area is the change in land use from undeveloped to developed land. The map of changes in developed land use in the city of Bekasi in 2005, 2015, and 2025, processed using Google Earth Engine with the Random Forest algorithm, is shown in Figure x below.



Source: Author, 2025

Figure 4: Changes in built-up land use in Bekasi City in 2005, 2015, and 2025

Based on the map, its changes in built-up land in Bekasi City show a significant increase every 10 years. The area of built-up land use in Bekasi City is shown in table 1 below.

Table 1: Built-up land area in Bekasi City in 2005, 2015, and 2025

Subdistrict	**Area (Ha)**		
	2005	**2015**	**2025**
Bekasi Timur	978,69	1052,78	1139,01
Bekasi Barat	1074,14	971,26	1231,75
Bekasi Utara	**1235,80**	**1522,63**	**1581,91**
Bekasi Selatan	969,78	834,30	1194,64
Rawalumbu	958,83	1007,01	1258,89
Medansatria	918,76	922,89	1005,07

Bantargebang	611,20	669,82	913,38
Pondokgede	1232,74	929,66	1491,53
Jatiasih	745,42	777,51	1521,39
Jatisampurna	444,80	366,41	927,51
Mustikajaya	409,58	838,96	1370,24
Pondokmelati	558,75	461,58	815,26
Total	10.138,47	10.354,78	14.450,58

Source: Author, 2025

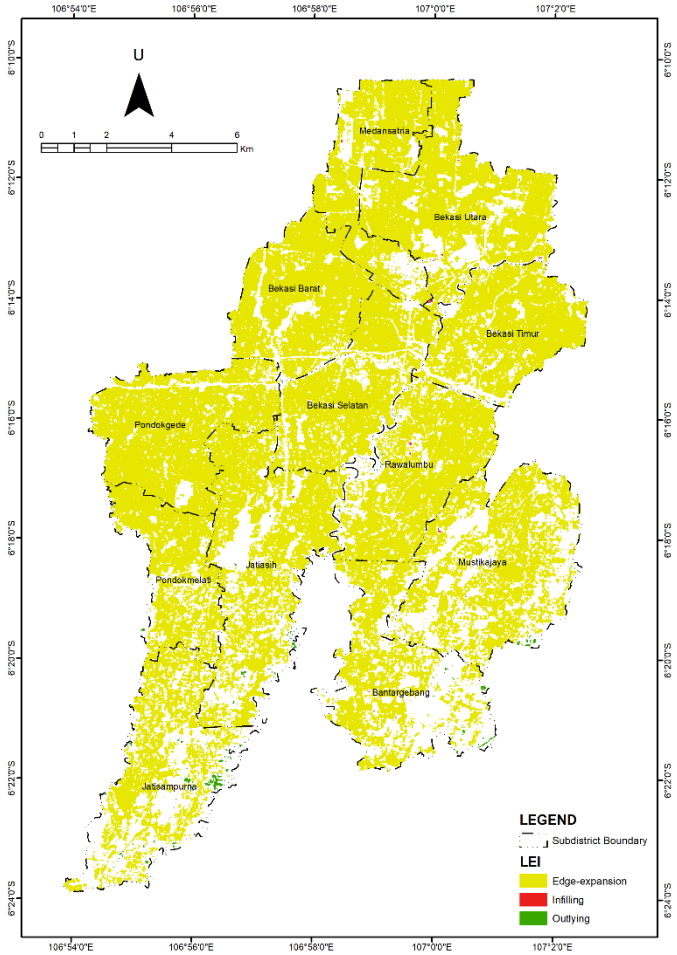
Based on Figure 4 and Table x above, changes in built-up land use in Bekasi City show interesting dynamics during 2005, 2015, and 2025. There was an increase in built-up land area from 10,138.47 hectares in 2005 to 10,354.78 hectares in 2015 and then to 14,450.58 hectares in 2025. The most significant growth occurred in the 2015-2025 period with an addition of 4,095.8 hectares, while the 2005-2015 period only experienced growth of 216.31 hectares.

Based on Table 1, it can be seen that Jatiasih District and Mustikajaya District experienced the fastest growth due to industrial area expansion. This is in line with research conducted by Setiawan et al, 2021, which states that industrial areas in East Bekasi and South Bekasi have spread to surrounding areas due to land limitations. Then, the development of the MM 2100 and Lippo Cikarang industrial areas has triggered increasing urbanization.

In addition, significant changes in built-up land use in Bekasi City are also influenced by rapid population growth (BPS Bekasi City, 2024). According to data (BPS Bekasi City, 2024), the urbanization rate in Bekasi City has reached 4.2% per year. Population migration, especially from Jakarta and other areas, has increased pressure on land conversion. The development of new residential areas such as Grand Wisata and Harvest City in Mustikajaya has further increased the conversion of non-built-up land to built-up land (Dewi et al, 2021).

The direction of development of Bekasi City Using LEI (Landscape Expansion Index)

The calculations visualized on the map show that the LEI index can illustrate data on urban development, which is divided into three classes: edge expansion, infilling, and outlying (Liu et al., 2010; Fan et al., 2018). The first class, edge-expansion, occurs when new areas undergo development or construction following existing patterns at the boundaries of the area, thereby expanding the city limits. Then, the infilling class occurs when new development areas appear between existing built-up areas, resulting in additional buildings or filling empty spaces within the urban network. Finally, the outlying class refers to development that occurs in newly built areas outside the main built-up areas or separately in the suburbs.



Source: Author, 2025

Figure 5: Land use direction map in Bekasi City using LEI (Landscape Expansion Index)

Based on figure 5, The city of Bekasi tends to be dominated by yellow edge-expansion types across all subdistricts, with some showing outlying and infilling at several points in the subdistricts, particularly outlying areas marked with green symbols in the eastern and southern parts of Bekasi City, namely in the subdistricts of Mustikajaya, Jatiasih, Jatisampurna, and Bantargebang. This is assumed to be due to the trend of new housing and industrial area development moving to the outskirts of the city, which can be seen on the LEI calculation map. This indicates that development expansion is occurring in the outskirts of the city around the boundaries of Bekasi City. In addition to the outlying pattern, an infilling pattern symbolized by the color red also occurs in the Medansatria, North Bekasi, and part of East Bekasi areas, indicating increased development in local areas or a tendency to add buildings on vacant land within the Bekasi City area. All of these LEI expansion patterns show a correlation between the expansion or growth of Bekasi City and development that tends to follow existing built-up areas. There is also a transformation of several areas of land use transition, such as open land areas becoming built-up areas.

From the perspective of flood risk, which occurs not only in the edge-expansion pattern found throughout the region, the infilling and outlying patterns can also trigger a crucial impact, namely an increased risk of flooding, due to surface runoff caused by the narrowing of water absorption areas (drainage) and covered by the intensity of regional development around river basins, which continues so that water flow cannot enter the soil absorption and is blocked, causing puddles or flooding in several urban areas. This assumption is related to the research by Setiawan et al (2021), which states that land conversion in the Greater Jakarta metropolitan area significantly increases flood vulnerability. Of all the patterns, the outlying and infilling patterns actually have a greater impact because they are added outside the existing development area. Although the amount seems very small, the change can have a significant impact, as land that was originally used as river catchment areas, drainage channels, and city parks is converted into built-up areas, especially enclosed buildings. If not balanced with strategic spatial planning based on disaster mitigation, the increased risk of flooding in densely populated areas of Bekasi City will have an even greater impact on other cities (Bogor and Depok). Thus, the application of LEI has proven effective in mapping the dynamics of urban expansion while providing a scientific basis for monitoring flood-prone areas in Bekasi City.

Conclusion and Recommendation

This study employs Landscape Expansion Index (LEI) to assess land usage and area alterations in Bekasi City for the years 2005, 2025, and 2025. This study examines urbanization patterns and their correlation with heightened flood susceptibility. The classification of built-up and non-built-up land is facilitated by employing Landsat 5 (2005) and Landsat 8 (2015 and 2025) satellite imagery in conjunction with the Random Forest machine learning technique. The analysis revealed a pattern of suburban expansion and the utilization of vacant land in various sub-districts of Bekasi City, notably Jatiasih and Mustikajaya, which are experiencing rapid development due to the growth of industrial and residential zones.

The expansion of developed land, especially in suburban regions, leads to a reduction in water absorption zones and an elevation in surface runoff volume, hence heightening the risk of flooding. The LEI results for regions exhibiting outlying and infilling growth patterns demonstrate a direct association with heightened susceptibility to floods, particularly in proximity to watersheds and drainage channels. Consequently, sustainable spatial planning and disaster mitigation are essential to mitigate the adverse effects of unregulated urbanization.

The research findings indicate that the Bekasi municipal administration formulate and execute development plans that emphasize sustainability and include disaster mitigation principles into spatial planning. This will mitigate the risk of flooding and enhance the city's resilience to the tangible impacts of climate change.

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