

RESEARCH ARTICLE



Spatiotemporal Dynamics of Land Cover Changes and Local Sustainability Index of Cianjur Regency, West Java Province, Indonesia

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ABSTRACT

Rapid land cover changes, primarily driven by urbanization and deforestation, present critical sustainability challenges for rural landscapes, particularly in developing regions such as Cianjur Regency, West Java. These transitions threaten ecological integrity, disrupt water resource systems, and compromise biodiversity, ultimately impacting land productivity and the achievement of sustainable development goals. This study addresses the need for localized, spatially detailed assessments by integrating remote sensing and spatial analysis to evaluate land cover transitions and their sustainability impacts. Landsat imagery (30 m resolution) was analyzed using GIS and spatial statistical techniques, including overlay analysis, spatial autocorrelation (LISA), and hierarchical clustering. A Local Sustainability Index (LSI) was constructed at the village level, incorporating environmental, social, and economic dimensions. Findings reveal that between 2011 and 2021, rice fields decreased by approximately 29,212.6 ha, while dry agricultural and residential lands expanded by 43,428.5 ha and 4,889.7 ha, respectively. The LSI analysis indicates a spatial trade-off: environmental sustainability has declined particularly in the northern development area, whereas social and economic dimensions have improved, especially in Cianjur, Cipanas, and Pacet Sub-Districts. Spatial clustering classifies villages into four typologies: urban village (Cluster One), developing village (Cluster Two), environmentally strong village (Cluster Three), and underdeveloped village (Cluster Four). This study provides spatially disaggregated policy insights for balancing land development with ecological integrity. The identification of village-level sustainability typologies supports targeted land-use planning and resource allocation, enabling local governments to formulate adaptive, place-based strategies that align with sustainable development objectives.

Introduction

Land cover changes, particularly the conversion of agricultural and forest lands to urban and industrial uses, are accelerating in many developing regions, with profound environmental and socio-economic implications [1–8]. In Monsoon Asia, for instance, rampant urban expansion often engulfs surrounding rural areas and forms extended metropolitan regions [9]. Such unchecked sprawl commonly leads to land-use conflicts, infrastructure challenges, and environmental degradation [4,10,11], including the loss of agricultural land [8,11,12] and the emergence of fragmented land-use patterns that are inefficient and unsustainable [13]. Indonesia exemplifies these trends. Rapid population growth and economic development have driven widespread land-use changes across the country [14]. However, development has frequently prioritized short-term economic gains over environmental protection and social equity [12–14], resulting in ecological harm and rising inequalities. This tension between development and sustainability is acutely visible in regions undergoing rapid rural-urban transitions.

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Cianjur Regency in West Java, Indonesia, is a telling case of these dynamics. Land cover changes have become an increasingly critical issue in Cianjur Regency, which has a population of approximately 2.5 million [15]. Positioned between the sprawling Jakarta and Bandung metropolitan areas, Cianjur has increasingly become a peri-urban corridor influenced by both mega-cities [16]. In particular, the northern part of the regency has experienced surging urban expansion [17–19]. Over the 2004–2019 period, North Cianjur experienced a more than 100% increase in built-up area as new urban centers, such as the Puncak–Cipanas cluster, rapidly developed [3]. The rapid urban expansion of the Jakarta Metropolitan Area (JMA) and Bandung Metropolitan Area (BMA) has profound implications for the northern part of Cianjur, which serves as a buffer zone or hinterland. Regions functioning as hinterlands for major cities, such as Jakarta and Bandung, typically experience faster development compared to other sub-districts in Cianjur Regency [12–14,17–19]. This growth has largely come at the expense of natural land covers, forests, mixed agro-forest gardens, and paddy fields, which have been extensively converted into settlements and other built uses [20]. Contributing to this trend, regional planning policies in the early 2010s enabled the promotion of new urban zones without sufficient land-use controls [21]. The outcome is a sprawl pattern that local authorities have struggled to manage, accompanied by mounting environmental issues.

Already, signs of ecological stress are evident, for example, long-term land degradation in parts of North Cianjur has triggered landslides during the rainy season and water scarcity in the dry season, severely affecting local communities [22,23]. Such incidents underscore the fragility of the region's ecosystems under rapid land cover change. Beyond the environmental effects, the socio-economic fabric of Cianjur is being reshaped in tandem with these land changes. Historically an agrarian region, Cianjur's rural communities depend on agriculture and related livelihoods that are now under pressure as farmland shrinks [24]. Many farmers face displacement or must adapt to new forms of employment when their land is sold or repurposed, a process that can disrupt traditional livelihood strategies and social networks [25]. Experiences from other Indonesian regions show that land loss often forces rural households into difficult transitions entailing career changes, relocation, and challenges in managing sudden compensation incomes [26]. In Cianjur, the rapid, urban-centric growth concentrated in the north has also accentuated spatial socio-economic disparities: the northern districts benefit from new infrastructure and investment, while the predominantly rural southern areas lag behind [27]. This imbalanced rural-urban transformation is widening the development divide, with inequality rising between fast-urbanizing and lagging communities [17]. As resources and opportunities become unevenly distributed across the regency, there is growing concern that social vulnerability will increase among those left behind by the current development trajectory.

The convergence of environmental degradation and socio-economic upheaval in Cianjur raises urgent sustainability challenges. At stake are both ecological integrity and the long-term viability of local livelihoods. Continued loss of forest cover and agricultural land threatens biodiversity and key ecosystem services such as water regulation and soil stability while also jeopardizing food security and income for rural households [14,19]. The situation is particularly critical given projections of future land use: one analysis forecasts that, if current trends persist, the proportion of land remaining available for new development in Cianjur will plummet from roughly 85% in 2018 to a mere 2% by 2030 [13]. Moreover, uncoordinated planning between different levels of government has exacerbated the problem. National authorities have designated much of Cianjur as a strategic agricultural and water catchment area to buffer the mega-urban region [4], yet local and provincial plans have simultaneously encouraged urbanization in the north [16]. This asynchronous policy framework has led to uncontrolled expansion and governance gaps, meaning that without corrective measures, the regency could face even more severe long-term consequences [21]. There is a pressing need to better balance development with environmental stewardship and social well-being to ensure Cianjur's transformation does not irreversibly undermine its future resilience.

In light of these multidimensional challenges, existing studies have often examined environmental or socio-economic impacts of land cover change in isolation, relying on descriptive or univariate spatial methods. This study advances the analytical frontier by integrating local indicators of spatial autocorrelation (LISA) with clustering techniques to assess spatial sustainability typologies. Unlike earlier applications of LISA focused on single-variable distributions, this combined approach enables the identification of localized clusters that reflect multidimensional disparities in economic, environmental, and social indicators). The integration enhances spatial resolution, provides deeper insight into intra-regional inequalities, and supports the design of geographically targeted policies for sustainable land management.

Given the complexity of these interlinked issues, a more integrative analytical approach is required. This study responds by employing two complementary frameworks, sustainable livelihoods and ecological modernization (EM), to connect micro-level community experiences with macro-level development processes. The sustainable livelihoods framework [2,3] provides a lens to assess how households and communities draw on various assets and capital (natural, human, social, physical, and financial) to sustain their well-being in the face of change. It emphasizes how external stresses or shocks, such as land cover change and declining access to natural resources, affect livelihood security, and how people adapt (or fail to adapt) as a result [3]. Meanwhile, EM [2–5,28] provides a theoretical framework for examining the broader development trajectory and its environmental implications. EM theory posits that economic development and environmental sustainability need not be opposing forces; with enlightened policies and innovative technologies, modern societies can reconfigure their institutions to decouple development from environmental degradation. Through this lens, we can critically analyze whether Cianjur's policies and growth patterns align with sustainable development principles or perpetuate trade-offs.

Moreover, uncontrolled land conversion is often undertaken without sufficient planning, exacerbating social inequalities. Rapidly developing urban areas tend to attract investment and infrastructure development, while less developed rural areas lag behind in access to basic services, including education, healthcare, and transportation. This disparity creates a dependency cycle, where rural areas supply cheap labor to more advanced regions without benefiting from balanced development. This phenomenon also carries long-term implications for social structures. Land use changes that shift lifestyles from agrarian to industrial or urbanization can alter the social fabric, erode traditional community cohesion, and accelerate the marginalization of groups unable to adapt swiftly to economic changes. Therefore, managing land use change in Cianjur requires a comprehensive approach that not only addresses economic aspects but also considers social impacts and long-term sustainability. Integrated spatial analyses, coupled with socio-economic indicators, can offer valuable insights to identify vulnerable regions and inform policies that are more inclusive, equitable, and sustainable. However, land cover changes can present significant challenges, particularly in areas with conservation functions [29]. A lack of synchronization between government regulations and spatial planning (RTRW/*Rencana Tata Ruang Wilayah*) can lead to issues and threats to sustainable development. In this context, sustainability has become a crucial framework in regional development [30]. Sustainable development relies on three pillars: economic, social, and environmental sustainability, all of which must progress.

Materials and Methods

Location Study

This research was conducted in Cianjur Regency, West Java Province, which spans an area of approximately 361,434.98 hectares (ha). Geographically, Cianjur Regency is situated between the coordinates of 106°42'–107°25' East Longitude and 6°21'–7°25' South Latitude. The regency is divided into 32 sub-districts and 360 villages, with the governmental center in Cianjur Sub-District (Figure 1).

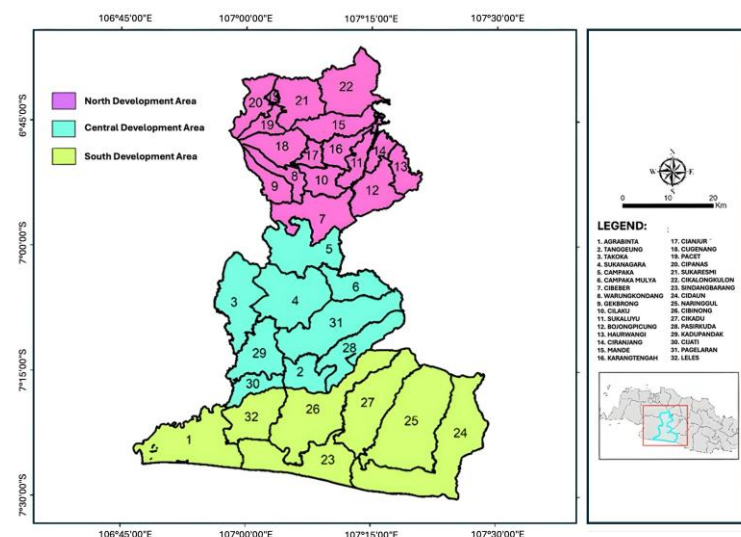


Figure 1. Research location map of the development area in Cianjur Regency, West Java, Indonesia.

Based on Spatial Planning of Cianjur Regency No.12/2012 [31], the region is strategically organized into three main development area *wilayah pengembangan* (WP), each with distinct characteristics and priorities. Each of these development zones plays a crucial role in the overall planning and implementation of regional policies, reflecting the regency's diverse geographical, economic, and social conditions. The study focuses on these distinct zones to assess land cover changes and variations in the sustainability index across different regions within Cianjur Regency, thereby providing a comprehensive understanding of the regional development dynamics.

Identify Land Cover Changes and Local Sustainability Index (LSI)

The methodology employed in this study was meticulously designed to capture the spatial and temporal dynamics of land cover changes and local sustainability in Cianjur Regency through an integrated and precise approach incorporating a methodological innovation that combines spatial autocorrelation analysis with cluster detection using an integrated LISA-clustering framework. The identification of land cover types in the region was conducted by overlaying land cover data from 2011 and 2021 with administrative boundaries using ArcGIS Pro 10.8 Software. To ensure the reliability of the classification, an accuracy assessment was conducted using confusion matrix analysis, yielding an overall accuracy of 89.6% and a Kappa coefficient of 0.85. This process resulted in detailed maps that visualize the extent of land cover changes over the past decade. Land cover change calculations were performed using the field calculator in ArcGIS Pro 10.8 Software, and the results were tabulated and systematically analyzed with Microsoft Excel to provide both quantitative and interpretive insights. This methodological approach goes beyond previous studies, which often employed spatial or temporal analysis in isolation, by offering a more comprehensive view of land change patterns and trends over time. The integration of spatial and temporal dimensions ensures a deeper understanding of land use dynamics, which is crucial for data-driven decision-making.

The assessment of the Local Sustainability Index (LSI) in this study was conducted using factor analysis, a robust statistical method that simplifies complex datasets by identifying latent variables underlying the relationships between correlated indicators. Factor analysis assumes that the variance of observed indicators can be explained by a smaller number of unobserved latent factors that capture shared information among them. Specifically, each observed indicator is modeled as a linear combination of common factors plus a unique error term. Mathematically, the factor score for the k -th dimension (social, economic, or environmental), m -th factor, in the i -th village is expressed as Equation (1).

$$S_{kmi} = \sum_{j=1}^n \lambda_{kjm} X_{ji} \quad (1)$$

where λ_{kjm} is the loading of the j -th indicator on the m -th factor for dimension k , and X_{ij} is the standardized value of the j -th indicator for village i [32]. The strength of each factor's contribution to explaining the variance in its corresponding dimension is represented by its eigenvalue E_{km} , and factors with eigenvalues greater than 1 were retained for interpretation following the Kaiser criterion.

This method reduces data complexity by grouping indicators into a smaller, manageable number of latent components that represent the core dimensions of sustainability namely, social, economic, and environmental aspects. By applying factor analysis to the data collected from these three dimensions, this study successfully identified key factors that capture the interconnections and underlying patterns of sustainability. The LSI score for each village was then calculated as a weighted aggregation of normalized factor scores S_{kmi} , where the weights were proportional to the corresponding eigenvalues E_{km} of each retained factor. This ensures that factors explaining more variances have a stronger influence on the overall sustainability score. In contrast to previous studies that often combined indicators using simple arithmetic means or subjective weights, this approach offers a multidimensional and empirically grounded perspective, enabling a deeper understanding of how sustainability dimensions interact. Furthermore, the LSI scores were normalized using the minimum–maximum method to ensure consistent comparisons across villages, enhancing the robustness and comparability of the results.

To ensure a comprehensive sustainability evaluation, this study utilized a variety of indicators across the three sustainability dimensions. In the environmental dimension, variables such as the frequency of disasters (inverted), the percentage of rice paddy and forest land area, and the number of slum settlements were used to represent ecological resilience. The social dimension included indicators such as access to educational and healthcare facilities, medical staff ratios, and malnutrition rates to reflect community well-being. The economic dimension encompassed indicators such as the number of industries, markets, and access to essential infrastructure like electricity and telecommunications. This broad selection of variables allowed the

study to capture the multifaceted nature of sustainability in Cianjur Regency while addressing the limitations of previous research, which often focused on a single dimension or a small set of indicators.

The mathematical rigor underlying the factor analysis model further strengthens the research. This model expresses each observed variable as a linear combination of factors and an error term, enabling the estimation of factor loadings that measure the relationship between variables and sustainability dimensions. These factor loadings are crucial for interpreting the contribution of each factor to sustainability, providing a solid foundation for evidence-based policy recommendations. By integrating advanced spatial analysis with in-depth statistical modeling, this study bridges the gap between academic research and the practical needs of regional planning. The findings not only offer a detailed understanding of land cover changes and sustainability dynamics but also facilitate the development of targeted policy interventions to address specific challenges in Cianjur Regency. Therefore, this research not only contributes to the sustainability literature but also provides strategic insights that can be applied to foster sustainable regional development.

The land cover types in Cianjur Regency were identified by overlaying the region's land cover data with its administrative boundaries. This resulted in a detailed map of the various land cover types across the regency. Land cover data from 2011 and 2021 were overlaid and compared to analyze changes over time. This comparison involved calculating the extent of land cover changes, which was accomplished using a field calculator in ArcGIS Pro 10.8 Software [33–34]. The results were then systematically tabulated and analyzed using Microsoft Excel to quantify and interpret the land cover transformations over the ten years. This methodological approach provided a clear and comprehensive understanding of the spatial and temporal dynamics of land cover in Cianjur Regency. The local sustainability index in this research was assessed using factor analysis, a powerful statistical method designed to identify and describe the underlying relationships among observed, correlated variables. Factor analysis, a significant tool, reduces the complexity of data by grouping these correlated variables into a smaller set of unobserved variables, known as factors, which capture the essential dimensions of sustainability. This technique is particularly effective in studies where multiple indicators are used to measure complex constructs, such as sustainability, as it allows for the distillation of these indicators into a more manageable number of factors, thereby clarifying the process for the audience.

In this study, factor analysis was applied to the data collected from various indicators of economic, social, and environmental sustainability within Cianjur Regency. By examining the correlations among these indicators, the analysis identified key factors that represent the major dimensions of local sustainability in the region [35]. These factors, by providing a more nuanced understanding of how different aspects of sustainability are interrelated, make the audience feel knowledgeable and insightful about the topic. The factor analysis model used in this research is mathematically formulated to describe how the underlying factors influence the observed variables. Each observed variable is expressed as a linear combination of the factors plus an error term.

The model enables the estimation of factor loadings, which indicate the strength of the relationship between each observed variable and the underlying factors. These loadings are crucial for interpreting the meaning of each factor and understanding the contribution of each variable to the sustainability index. Through this methodological approach, the study provides a robust framework for evaluating the sustainability of local development in Cianjur Regency. The factor analysis not only simplifies the complex data set into key factors but also offers insights into the multidimensional nature of sustainability in the region. This, in turn, facilitates the formulation of targeted policy recommendations that address the specific sustainability challenges identified by the analysis. The formula for calculating the LSI is expressed in Equation (2) and (3), while the variables for each dimension shown in Table 1.

$$LSI = \sum_{m=1}^{nk} E_{km} \cdot S_{kmi} \quad (2)$$

Where:

LSI : LSI for k-th dimension on i-th village

k : Dimension

E_{km} : Eigenvalue for k-th dimension on m-th factor

S_{kmi} : Factor score for k-th dimension, m-th factor on i-th village

i : 1,2,3, ,360

To standardize LSI scores using the minimum maximum standardization method to obtain scoring scores from each village:

$$LSI (std) = \frac{LSI ki - LSI ki (min)}{LSI ki (max) - LSI ki (min)} \times 100 \quad (3)$$

Where:

LSI (std) : LSI standardization for k-th dimension in the n-th village i

LSI ki : LSI for the k-th dimension in the n-th village i

LSI (max) : Maximum LSI value for the n-th k dimension in the n-th village i

LSI (min) : Minimum LSI value for the n-th k dimension in the n-th village i

Table 1. LSI variables for each dimension.

Code	Variables	Unit	Source
ENVIRONMENT			
V1	Invers the number of landslide events	Number	Village potential data [36]
V2	Invers the number of flood events	Number	Village potential data [36]
V3	Invers the number of earthquake events	Number	Village potential data [36]
V4	Invers the number of settlements on the riverbanks	Unit	Village potential data [36]
V5	Invers the number of slum settlements	Unit	Village potential data [36]
V6	Rice fields area	Percentage (%)	Village potential data [36]
V7	Forest area	Percentage (%)	Land cover map [37]
SOCIAL			
V8	Invers average distance to formal education	Kilometers (km)	Village potential data [36]
V9	Invers average distance to health facilities	Kilometers (km)	Village potential data [36]
V10	Number of formal education facilities	Unit	Village potential data [36]
V11	Number of informal education facilities	Unit	Village potential data [36]
V12	Number of health facilities	Unit	Village potential data [36]
V13	Ratio of medical personnel	Number	Village potential data [36]
V14	Invers sufferers of malnutrition	Number	Village potential data [36]
V15	Invers patients suffering from plague	Number	Village potential data [36]
V16	Invers the number of poor letters that come out	Household	Village potential data [36]
ECONOMY			
V17	Invers average distance to the nearest bank	Kilometers (km)	Village potential data [36]
V18	Invers average distance to the nearest shop	Kilometers (km)	Village potential data [36]
V19	Number of banks	Unit	Village potential data [36]
V20	Households using landline telephones	Household	Village potential data [36]
V21	Household electricity users	Household	Village potential data [36]
V22	Number of industries	Unit	Village potential data [36]
V23	Number of hotels and inns	Unit	Village potential data [36]
V24	Number of restaurants and shops	Unit	Village potential data [36]
V25	Number of stores	Unit	Village potential data [36]
V26	Number of markets	Unit	Village potential data [36]
V27	Residential area	Area percentage (%)	Land cover map [37]

Local Indicator of Spatial Autocorrelations (LISA) and Cluster Typology

In this study, Local Moran's Index, a LISA, was used to examine the spatial distribution of the LSI across Cianjur Regency. The LSI was constructed from economic, social, and environmental indicators selected for their relevance and data availability. As introduced by Anselin [38] and further developed in his earlier spatial econometric work [39], LISA provides localized measures of spatial autocorrelation, enabling researchers to assess the degree of spatial clustering at the individual unit level, rather than relying solely on global statistics such as Global Moran's Index. This makes LISA especially valuable for regional analysis where spatial heterogeneity is expected and local patterns matter for targeted intervention. The analysis employed a first-order queen contiguity spatial weights matrix to model spatial dependence, assuming spatial stationarity under the null hypothesis of no autocorrelation; the statistical significance of local Moran's I values was assessed using 999 random permutations to generate pseudo p-values, and local clusters were deemed significant at the 0.05 level.

This method was specifically chosen to address the need for identifying spatial patterns in sustainability, a crucial component of regional planning and policy formulation, as outlined by Pravitasari et al. [40]. Unlike traditional statistical methods that may treat observations as independent, LISA recognizes the inherent spatial dependency between neighboring areas. This enables a more accurate understanding of how sustainability indicators are interrelated across different regions, a factor often overlooked in non-spatial

analyses. One of the key advantages of using the Local Moran's Index is its ability to detect spatial clustering, which is essential in understanding how areas with similar sustainability characteristics (either high or low) tend to group. This capability is particularly important in the context of Cianjur Regency, where socio-economic and environmental factors vary significantly across the region. By analyzing the spatial autocorrelation of LSI values, the LISA method helps reveal regions where high sustainability (high-high) or low sustainability (low-low) values are concentrated, providing valuable insights into regional disparities and the distribution of sustainability performance. This method also helps identify spatial outliers, which are regions where a particular area's LSI value significantly differs from those of its neighbours. This is especially useful for pinpointing areas that may require targeted interventions, either due to their isolated high sustainability or their starkly low sustainability despite proximity to more sustainable areas. Detecting such outliers enables policy-makers to tailor interventions more effectively and efficiently, addressing areas that might otherwise be overlooked in traditional analyses.

Furthermore, the choice of the Local Moran's Index represents an advancement over previous studies that often relied on global or aggregate measures of sustainability without addressing the localized nature of the data. While global measures such as Global Moran's Index, Geary's C Index, or regression-based spatial lags are informative, they assume spatial homogeneity and may mask significant local. LISA, by contrast, is capable of decomposing global autocorrelation into location-specific values, enabling finer spatial insight into sustainability dynamics [38,39]. Prior research typically used broader methods like simple regression analysis or global spatial autocorrelation, which assume that spatial data is homogeneous across regions or do not account for local variations in sustainability performance [39]. In contrast, LISA's localized approach enables a finer-grained analysis, highlighting regional disparities and specific clusters of sustainability values that may not be captured through global indices or other less spatially sensitive techniques.

By incorporating LISA, this study addresses the limitations of earlier research, which often failed to consider the intricate spatial dependencies between neighboring regions [39]. The inclusion of spatial lag and the local interaction of sustainability values improves the precision of the findings, as it allows for a more nuanced interpretation of the data. This approach, therefore, not only strengthens the validity of the study but also enhances its policy relevance by offering actionable insights into regional sustainability dynamics. The formula used to calculate the Local Moran's Index in this study was specifically adapted to account for both the magnitude and spatial distribution of LSI values across Cianjur Regency. This ensures that the results reflect not only the intensity of sustainability indicators but also how they are spread geographically, offering a more comprehensive examination of local spatial patterns. The ability to measure clustering and dispersion provides a holistic view of the regional sustainability landscape, making the methodology particularly useful for planning and decision-making processes aimed at addressing both socio-economic and environmental challenges within the region.

The application of the Local Moran's Index in this study provides a more robust, spatially-aware approach to analyzing sustainability (Equation 4). It improves upon previous research by addressing the spatial interdependence of sustainability indicators, offering more localized insights, and identifying both clusters of similar values and spatial outliers. This methodology thus ensures a deeper understanding of the regional dynamics of sustainability, making it an invaluable tool for policy formulation and regional planning in Cianjur Regency.

$$I_i = \frac{\sum_{j=1}^n W_{ij} (LSI_{ki} - LSI_k) (LSI_{kj} - LSI_k)}{\sum_{j=1}^n W_{ij} (LSI_k - LSI_k)^2} \quad (4)$$

Where:

I_i : Moran index

N : Number of incident locations

LSI_{ki} : k-th LSI value at location i

LSI_{kj} : k-th LSI value at location j

LSI_k : Average of the number of variables

W_{ij} : Element in standardized weighting between regions i and j

Cluster analysis is employed in this study to classify various areas within Cianjur Regency into distinct groups based on similar or nearly identical characteristics [41–43]. The core objective of this approach is to identify clusters groups of regions that share comparable features allowing for more precise and targeted regional planning and development. The clustering process is grounded in a metric that measures the proximity

between each region, commonly referred to as distance. In this study, the analysis utilizes the Euclidean Distance metric, a well-established and widely used method for calculating the straight-line distance between two points in multi-dimensional space.

The Euclidean distance metric is particularly valuable in spatial analysis, as it provides a measurable and quantifiable gauge of similarity between regions. By evaluating the "closeness" of attributes across various dimensions such as geographical, economic, social, and environmental characteristics it effectively captures the degree of similarity or difference between regions. For example, if two regions share similar socio-economic conditions, the Euclidean Distance between them would be small, indicating that they are close in terms of these attributes. Conversely, regions with differing characteristics would have a larger Euclidean Distance, reflecting their greater dissimilarity. This ability to calculate the distance between individual regions or between groups of regions allows the analysis to identify clusters of areas that are more similar to each other than to regions outside of their cluster. These clusters are defined by minimizing the within-group variance (i.e., the differences between regions within the same group) while maximizing the between-group variance (i.e., the differences between clusters), thus ensuring that the clusters are as distinct and meaningful as possible.

The formula used to calculate the Euclidean Distance in this study follows the method outlined by Rustiadi et al. [19], which has become a foundational technique for spatial clustering in regional studies. The equation considers the differences between the values of selected variables (such as population density, land use, and infrastructure availability) across the various regions. This allows for the precise identification of regions that share similar characteristics based on a range of socio-economic and environmental variables. The flexibility of the Euclidean Distance metric in this context is particularly beneficial because it enables the incorporation of multiple dimensions, allowing for a holistic view of regional characteristics in Cianjur Regency. By using this method, the study is able to group regions into clusters that reveal patterns in how these regions are spatially distributed. The clustering process minimizes the variance within each group and maximizes the variance between groups, which enhances the clarity and usefulness of the analysis. For example, regions with similar economic development, land use patterns, or infrastructure characteristics will be grouped together, and this grouping provides valuable insights into the geographical spread of these characteristics within the regency. The resulting clusters then serve as a starting point for further analysis, as they offer a way to examine how and why certain areas share common attributes.

The advantage of this method lies in its ability to group regions objectively based on actual data, rather than relying on subjective interpretations or arbitrary categorizations. By using a rigorous statistical foundation, cluster analysis ensures that the regions are classified based on measurable, quantifiable characteristics, offering a data-driven approach to understanding spatial patterns. This statistical rigor enhances the reliability of the results and ensures that the identified clusters accurately reflect the underlying characteristics of the regions within Cianjur Regency. Once the clusters are formed, the study can delve deeper into understanding the factors that contribute to the similarities between the regions within each cluster. For instance, one cluster might consist of regions with high agricultural productivity and strong rural infrastructure, while another might include more urbanized areas with higher industrial activity. Understanding these factors is crucial for regional development strategies, as it allows planners and decision-makers to tailor policies and interventions to the specific needs of each cluster. For example, clusters that exhibit high economic potential but lower environmental sustainability may require policies that balance economic development with environmental conservation, while more rural clusters might benefit from interventions focused on infrastructure improvement or agricultural support.

The methodical application of cluster analysis in this study ensures that the regional classification process is both objective and statistically robust. This provides a reliable foundation for decision making in regional planning, where the goal is to develop targeted, effective strategies that account for the unique characteristics of different areas within Cianjur Regency. By allowing the identification of clusters with similar characteristics, this approach helps to avoid one size fits all solutions and promotes a more nuanced, localized approach to regional development. Ultimately, this clustering method provides valuable insights that can guide policymakers in crafting strategies that are more aligned with the realities on the ground in Cianjur, ensuring that resources are allocated efficiently and development efforts are optimized for each distinct region. Cluster analysis is designed to classify various areas within Cianjur Regency into distinct groups with similar or nearly identical characteristics [41–43]. The primary objective is to identify clusters of regions that exhibit comparable features, thereby allowing for a more targeted approach to regional planning and development. The grouping process is based on a metric of proximity between each region, commonly

referred to as distance. Specifically, this analysis employs the Euclidean Distance metric, a widely used measure that calculates the straight-line distance between two points in a multi-dimensional space (Equation 5).

$$dpq = \sqrt{\sum_{i=1}^n (X_{pi} - X_{qi})^2} \quad (5)$$

Where:

dpq : Euclidean distance

p : (p1,p2.... Pn)

q : (q1,q2.... Qn)

The variables utilized in the cluster analysis for this study include social LSI, economic LSI, environmental LSI, and the percentage of residential area. Each variable contributes critical dimensions to assessing regional sustainability and development within the Cianjur Regency. The social LSI Pravitasari et al. [22] represents the social dimensions of sustainability, capturing factors such as community well-being, access to services, and social equity. This variable provides insights into how social conditions and quality of life vary across different regions, allowing for an understanding of how social sustainability influences and interacts with other aspects of development. The economic LSI reflects the economic health and performance of the regions, including indicators such as income levels, employment rates, and economic activity. This measure is essential for understanding how economic factors contribute to regional sustainability and how economic development correlates with social and environmental conditions.

The environmental LSI assesses the ecological sustainability of the regions, incorporating factors such as land use, environmental quality, and resource management [44,45]. This variable is crucial for evaluating the impact of human activities on the environment and for identifying regions that are performing well or poorly in terms of environmental stewardship. The percentage of residential area provides a spatial measure of urbanization and land use patterns within each region [46–48]. By analyzing this variable, the study can assess how residential development influences and interacts with social, economic, and environmental sustainability. Incorporating these variables into the cluster analysis allows for a comprehensive evaluation of regional characteristics and their interplay. By grouping regions based on these multifaceted variables, the analysis can identify patterns and clusters that reflect different sustainability profiles, offering valuable insights for targeted regional planning and policy development [49–51].

Results

Land Cover Changes in Cianjur Regency and Its Implications

The land cover in Cianjur Regency consists of 8 types of land cover. The land cover was analyzed using data from two time points, namely 2011 and 2021 (Table 2 and Figure 2). The analysis reveals that in 2011 and 2021, the land cover was predominantly dryland farming, which covered approximately 40.3% of the area in 2011 and increased to 52.3% in 2021. This significant increase in dryland farming indicates notable changes in land use in the region over the decade.

Table 2. Land cover changes (LCC) from 2011 to 2021.

Land cover	Total area (ha)						Percentages area (%)					
	2011	2021	WP1	WP2	WP3	LCC from 2011–2021	2011	2021	WP1	WP2	WP3	LCC from 2011–2021
Forest	95,388.9	85,611.9	–3839	–2,432.1	–3,505.9	–9,777	26.4	23.7	–2.7	–2.7	–2.1	–8.20
Shrubs	6,203.7	1,601.2	–3,794.7	–401.8	–406	–4,602.5	1.7	0.4	–1.3	–2.7	–0.3	–3.40
Water body	4,535.6	4,224.9	–20.7	–48.9	–241.1	–310.7	1.3	1.2	–0.1	0.0	0.0	–0.29
Open field	1,127.8	347.5	–373.6	–324.1	–82.6	–780.4	0.3	0.1	–0.2	–0.3	–0.3	–0.62
Dryland farming	146,053.6	189,482.1	7,838.9	33,259.3	2,330.3	43,428.5	40.3	52.3	12	5.5	28.2	35.96
Rice field	77,270.4	48,057.8	–137.9	–25,468.1	–3,606.6	–29,212.6	21.3	13.3	–8.1	–0.1	–21.6	–25.21
Plantation	25,888.6	22,253.5	–2,313.7	–4,796.6	3,475.2	–3,635.1	7.2	6.1	–1	–1.6	–4.1	–2.26
Built-up area	5,505.5	10,395.2	2,640.7	212.3	2,036.7	4,889.7	1.5	2.9	1.4	1.9	0.2	4.04
Total	361,974	361,974					100	100				

This shift might be driven by the rising demand for agricultural land to support population growth and local economic development. However, the increase also points to ecological changes that warrant attention, particularly the reduction of other land cover types. Several types of land cover have decreased in area,

including forests, which declined from 26.4 to 23.7%, shrubs from 1.7 to 0.4%, plantations from 7.2 to 6.1%, open fields from 0.3 to 0.1%, water bodies from 1.3 to 1.2%, and rice fields from 21.3 to 13.3%. The decrease in forested areas and rice fields suggests that land might have been converted for other uses, such as dryland farming or infrastructure development, posing potential risks to the region. Built-up land and dryland agriculture experienced an increase in area, with built-up land expanding from 1.5 to 2.9% and dryland agriculture from 40.3 to 52.3%. The increased built-up land is likely linked to urbanization and more intensive infrastructure development in Cianjur Regency.

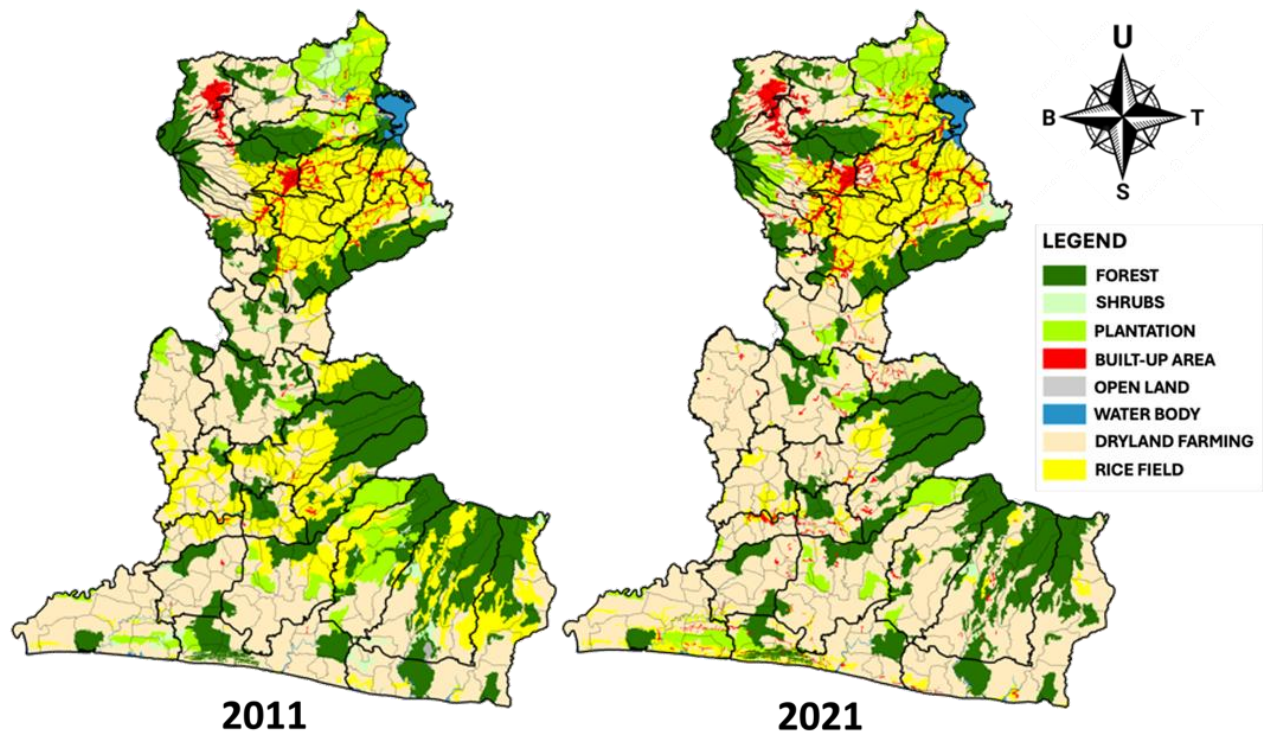


Figure 2. Land cover changes in 2011–2021.

Significant changes were observed in the conversion of rice fields to dryland farming, covering an area of approximately 37,401.1 ha. This transformation predominantly occurred in the central and southern WP regions of Cianjur Regency. The findings, which are based on a comprehensive analysis of satellite imagery and field surveys, align with the previous research [52], which identified several key factors influencing this land cover change. One of the main factors is the area's topography, which is less accessible to water supplies from mountainous regions. This, coupled with lower rainfall levels compared to the northern parts of Cianjur Regency, made these areas more suitable for dryland farming rather than rice cultivation. The shift from rice fields to dryland farming significantly indicates how environmental conditions, such as water availability and rainfall patterns, can drive changes in agricultural practices. In regions where water supply is limited and inconsistent, farmers may find it more sustainable and economically viable to switch to crops that require less water, hence the increase in dryland farming.

Additionally, converting various dominant land covers, including agricultural lands, into built-up areas is another critical trend observed in the region. This phenomenon is particularly pronounced in the northern WP of Cianjur Regency, where urbanization and the demand for space are more intense [53–56]. The research by Rustiadi et al. [19] supports this observation, stating that land conversion tends to occur from activities with lower land rent to those with higher land rent. In this context, agricultural lands, which typically have lower land rent values, are increasingly converted into non-agricultural uses, such as residential or commercial developments, offering higher economic returns. Prabowo et al. [57] further emphasize that the land rent value for agricultural activities is generally lower than non-agricultural activities. This economic pressure accelerates the conversion of agricultural lands into built-up areas, especially in regions where urban expansion is prevalent. The need for space to accommodate growing populations, infrastructure, and economic activities drives this land use change, often at the expense of agricultural land and natural ecosystems.

Trends in The Local Sustainability Index (LSI) in Cianjur Regency

The LSI for each village in Cianjur Regency is evaluated across three key dimensions: environmental, social, and economic. This assessment uses a total of 27 variables and compares data from the years 2011 and 2021. Over the period from 2011 to 2021, the environmental LSI values in the southern WP of Cianjur Regency have shown a tendency to decline (Figure 3). This decline, primarily attributed to the conversion of forest land into other land uses, such as rice fields and dryland farming, has significantly impacted the area's environmental sustainability. The reduction in forest area in the southern WP region, closely linked to the expansion of agricultural activities, has led to worsening environmental conditions. One critical impact is the reduced capacity of the soil to absorb water, which increases the risk of natural disasters.

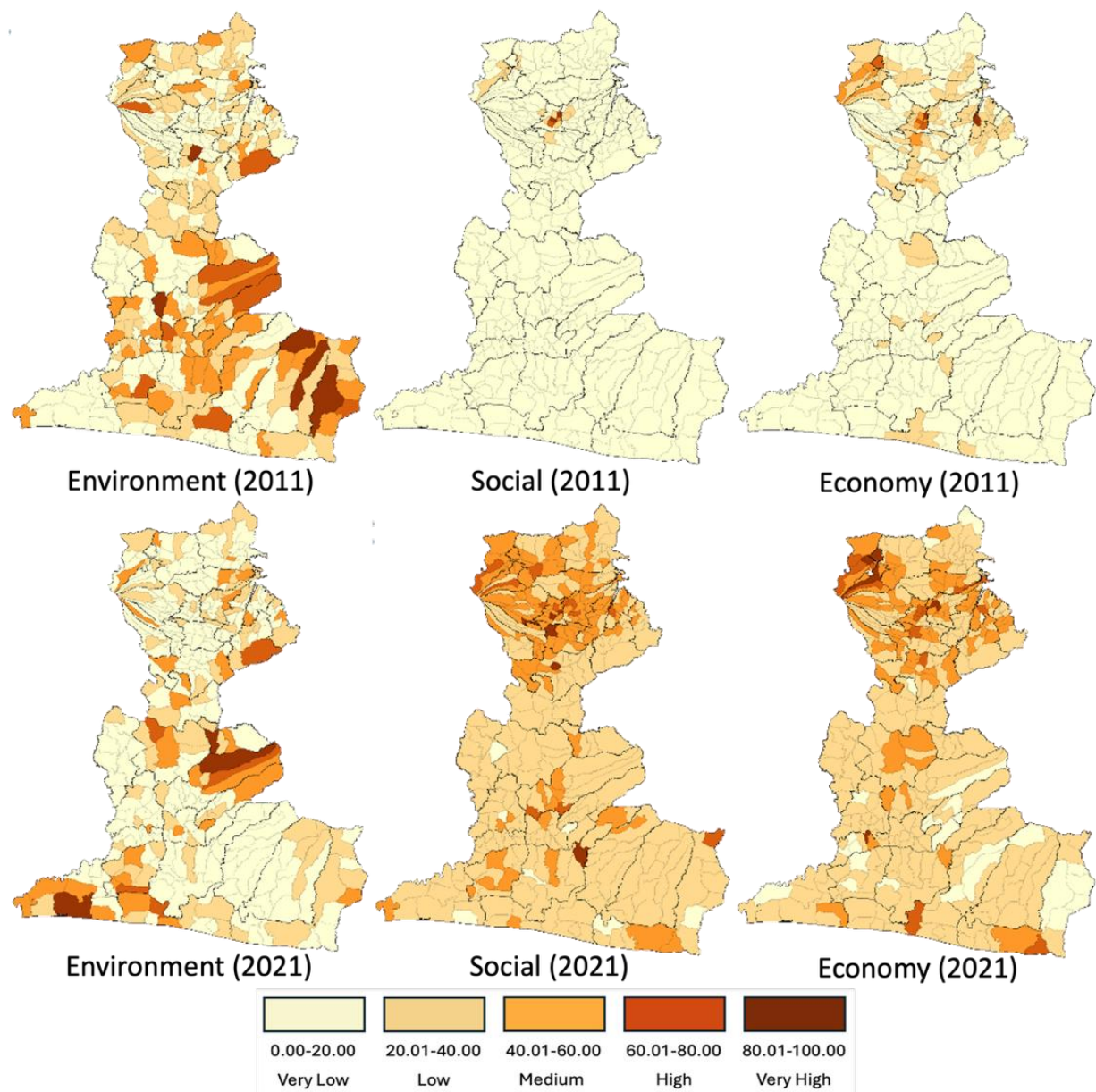


Figure 3. Local sustainability index of each dimension in 2011 and 2021.

On the other hand, the social and economic LSI values have improved, particularly in the northern WP of Cianjur Regency during the same period. This improvement reflects better accessibility and an increase in the number of health and educational facilities in the northern region. Education and healthcare are essential pillars for developing robust human capital, as Todaro and Smith [58] noted. Human resources are fundamental to a region's competitiveness and drive social development [59]. The growth of the Cianjur sub-district, as the central urban area, has positively impacted the development of accessibility and social

infrastructure in surrounding sub-districts. According to Jatayu et al. [60], Cianjur's city center is becoming denser, a trend that aligns with the city planning strategy outlined in the RTRW. This zone serves as a hub for the transportation network that connects various parts of Cianjur Regency, indicating the potential for further development. The urbanization process, initiated by the Jabodetabek Punjur urban agglomeration, is another factor driving the transformation of rural areas into suburban regions [61]. The road network in this area has been continuously upgraded due to its strategic importance, particularly the Puncak arterial road, which links the JMA with the BMA [61]. This region has developed in response to market demand driven by the needs of urban residents. Additionally, the emergence of a new activity center in Puncak-Cipanas, which has become a focal point for trade, services, and tourism, contributes to the high concentration of development in this zone [62].

Spatial Association of Sustainability Dimensions in Cianjur Regency

In both 2011 and 2021, the southern WP of the Cianjur Regency was characterized by a dominant environmental LSI HH (High-High) cluster. This means that the villages in this region not only had high environmental sustainability index values, but other villages with similarly high values also surrounded them. This clustering indicates that the environmental sustainability of the southern WP is more robust and consistent than other areas in the Cianjur Regency. The differences in hotspot locations over time are closely related to the specific land cover characteristics within each spatial distribution pattern. Generally, when forest land cover is converted to other land use types, these hotspot locations show a noticeable shift. Conversely, the LL (Low-Low) environmental LSI cluster, which indicates areas of environmental degradation, was notably concentrated in the northern and central WP of Cianjur Regency during both years. Villages within this cluster are those experiencing significant environmental degradation, often due to excessive human activity disrupting the natural balance, as noted by Suleman et al. [63].

For the social dimension, the LSI HH (High-High) cluster type in 2011 and 2021 remained unchanged, concentrated in the northern WP of the Cianjur Regency. This suggests that villages in this area consistently demonstrated high social sustainability, with solid social development indices mirrored by neighboring villages. The presence of this cluster indicates a region with high levels of social welfare. Similarly, the economic LSI HH (High-High) cluster type in 2011 and 2021 also showed an intense concentration in the northern WP (Figure 4). Villages in this area consistently exhibited high economic sustainability, reflecting robust economic growth supported by surrounding villages with similar economic indices. The northern WP's economic and social strength is partly due to its location within the southern JBMUR corridor [61], a strategic area that connects major cities.

This corridor influences the transformation of rural areas, often blurring their rural character as urbanization intensifies [61]. Urban expansion from the *Jabodetabekpunjur* region and Greater Bandung, particularly in Cianjur Regency, has led to a spread of built-up areas from city centers to the outskirts. This expansion has driven economic growth, social development, and regional urban activity [30]. However, the LL (Low-Low) cluster type for both social and economic dimensions in 2011 and 2021 was predominantly found in the southern WP of the Cianjur Regency. Villages within this cluster are marked by social inequality and are often pockets of poverty. These areas face significant social and economic development challenges, contrasting sharply with the more prosperous northern regions of the regency.

The results of the LISA analysis indicate that villages with high environmental sustainability in both 2011 and 2021 are predominantly located in the Southern WP area of Cianjur Regency. In contrast, villages experiencing environmental degradation are more prevalent in the Northern and Central WP regions. Regarding the social and economic dimensions during the same period, villages with high social welfare and economic growth levels are primarily situated in the Northern WP, particularly in Cianjur, Pacet, and Cipanas Sub-District. Conversely, villages identified as pockets of poverty are concentrated mainly in the Southern WP.

These findings align with the research conducted by Pravitasari et al. [22], which suggests that regions with high economic and social sustainability often exhibit low environmental sustainability. This pattern indicates an imbalance in development, where the focus on economic and social aspects comes at the expense of environmental considerations. The uneven distribution of development resources and the neglect of environmental sustainability underscore the need for integrated development efforts across the Cianjur Regency. Consequently, insufficient effort has been made to achieve balanced and equitable development in the region, leading to disparities between the environmental, social, and economic dimensions.

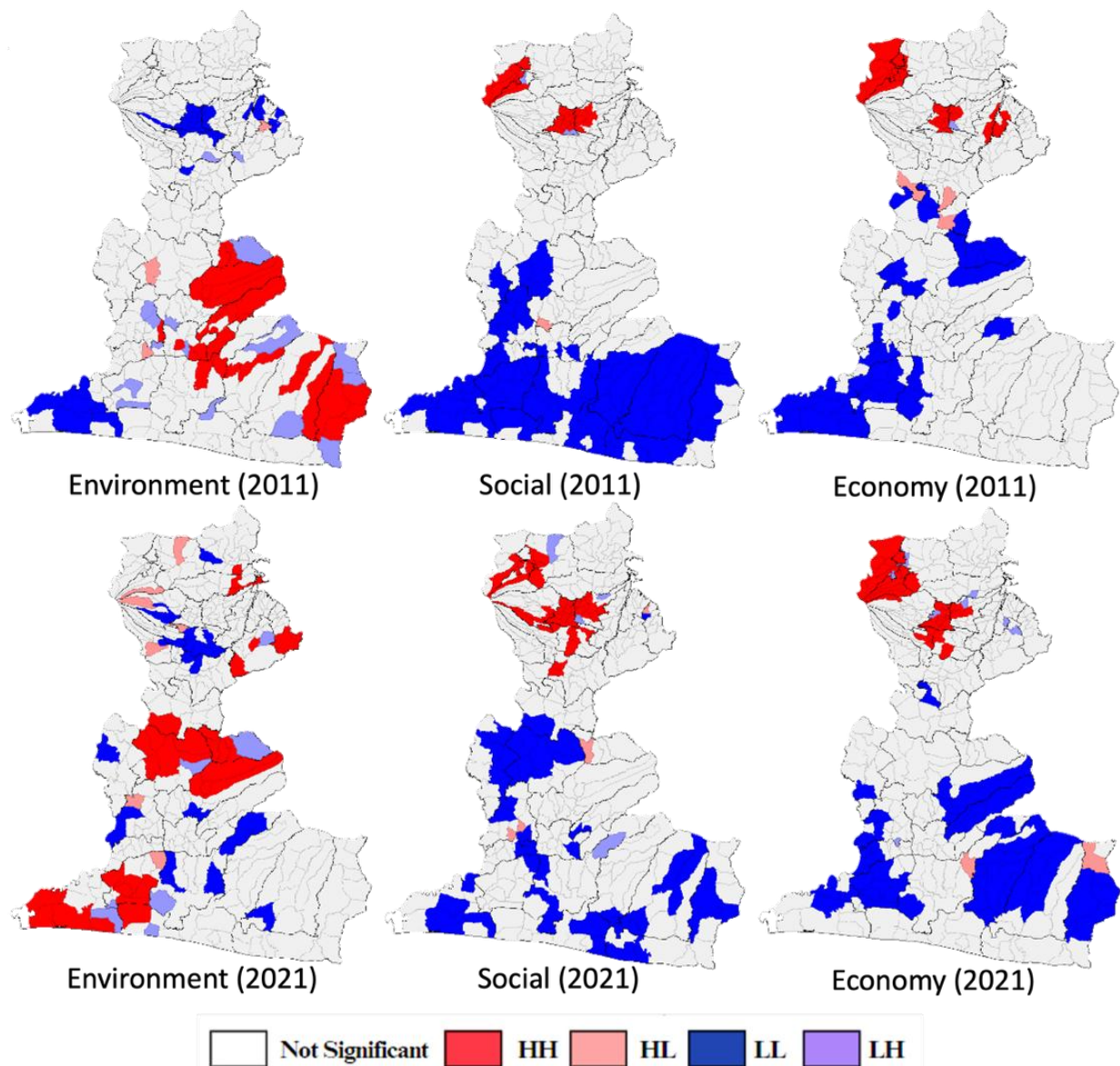


Figure 4. Spatial association distribution patterns in 2011 and 2021.

Regional Typology of Cianjur Regency Based on Local Sustainability Index (LSI)

The regional typology of Cianjur Regency is determined through an analysis based on the LSI, which evaluates the environmental, social, and economic dimensions, alongside the percentage of land cover dedicated to residential areas. Residential areas are treated as a distinct factor in this analysis due to their unique and significant impact on all three dimensions of sustainability. Environmentally, the expansion of residential areas directly influences land use patterns, potentially leading to environmental degradation, such as the loss of agricultural land and the increased pressure on natural resources. Socially, areas with higher residential development often experience challenges related to population density, access to essential services, and socio-economic disparities. Economically, residential areas are a key indicator of urbanization, which affects local economies through changes in infrastructure needs, service provision, and labor market dynamics. By isolating residential areas as a separate cluster, this approach allows for a more focused and precise analysis of areas requiring specific interventions in infrastructure development, social welfare, and sustainable land management.

This differentiation helps policymakers allocate resources more effectively, ensuring that development strategies are tailored to the unique needs of each region within Cianjur Regency, ultimately guiding sustainable development efforts. This typological analysis employs the k-means clustering method,

classifying Cianjur Regency into four distinct clusters (Figure 5 and Table 3). The k-means clustering method is a statistical technique used to partition objects into clusters based on their characteristic similarity [19,41–43,64]. The purpose of establishing this regional typology is to guide the formulation of policies, strategies, plans, and development programs in a more targeted manner. By identifying clusters with similar characteristics, the government can prioritize its budget and resources toward developing social, economic, and environmental aspects in most needy areas. This approach ensures that efforts to achieve sustainable development in Cianjur Regency are focused and effective, directing investments where they will significantly improve overall sustainability across the region.

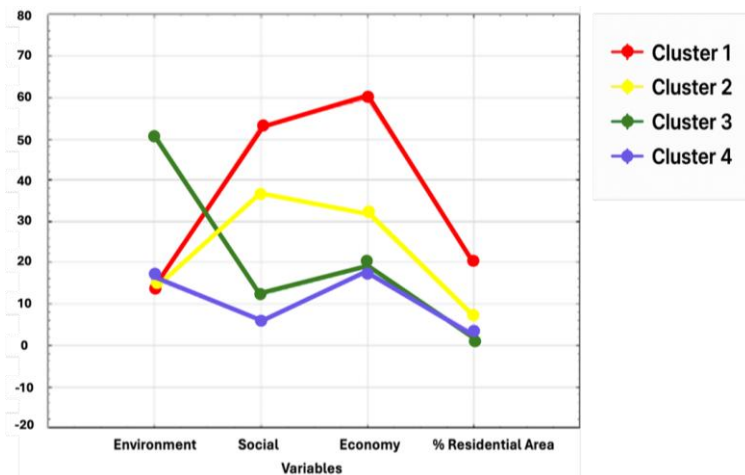


Figure 5. Result plot of means for each cluster.

Table 3. Cluster typology of Cianjur Regency based on environmental, social, economic, and residential area dimensions.

Typology	Environment	Social	Economy	Residential area	Characteristic
Cluster 1	Low	High	High	High	Urban village
Cluster 2	Low	Medium	Medium	low	Developing village
Cluster 3	High	low	Low	Low	Good environmental village
Cluster 4	Low	Low	Low	Low	Underdeveloped village

Cluster 1 comprises villages with low environmental sustainability, high social and economic sustainability, and a large residential area percentage. These villages exhibit the characteristics of an urban village or economic activity center. This cluster's high social and economic sustainability is strongly influenced by adequate public facilities such as access to education, healthcare, and social services and good accessibility to economic centers and markets. This accessibility drives economic activities, subsequently enhancing the residents' living standards. On the other hand, the low environmental sustainability observed in these villages is attributed to extensive land conversion. Forests and agricultural lands (rice paddies or drylands) have frequently been converted into built-up areas, including housing, offices, and infrastructure. This land conversion contributes to environmental degradation, reduction of green spaces, and increased air and water quality risks in the region. These findings align with Pravitasari et al. [22], which indicates that regions with high social and economic sustainability often experience low environmental sustainability, primarily due to the high rate of land conversion in developed areas.

Cluster 2 includes villages with low environmental sustainability, moderate social and economic sustainability, and a relatively low percentage of residential areas. Villages in this category display the characteristics of a developing region, marked by potential for social and economic growth. Although not as intense as Cluster 1, these villages still experience land conversion pressure, especially in strategic areas or locations near the village's economic hubs. The unoptimized potential includes resources such as natural (agriculture, forestry, or plantations), social (community institutions and local wisdom), and economic (small and medium-sized enterprises or local market potential). As Pravitasari et al. [40] mentioned, these villages possess substantial resources, yet resource management remains suboptimal, thereby not fully supporting long-term sustainability. The low environmental sustainability in this cluster is primarily due to insufficient resource management rather than extensive construction, as seen in Cluster 1.

Cluster 3 consists of villages with very high environmental sustainability but lower social and economic sustainability and a limited residential area. Villages in this cluster show the characteristics of areas prioritizing environmental sustainability. Generally, these villages have relatively undisturbed ecosystems, with well-maintained vegetation cover and green spaces, and they apply sustainable conservation practices. These characteristics make this cluster an essential environmental support area, as it contributes to ecosystem services that sustain water, soil, and biodiversity health. Nevertheless, these villages' low social and economic sustainability suggests limited access to public facilities, education, healthcare, and economic opportunities. Accessibility and infrastructure deficiencies hinder improvements in the quality of life for residents in this cluster, leading them to depend primarily on natural ecosystems and environmentally sustainable economic practices that yield limited economic margins.

Cluster 4 comprises villages with low environmental, social, and economic sustainability and a low percentage of residential area. Villages in this cluster are characterized as the most underdeveloped regions. These areas face challenges across nearly all development aspects, from basic infrastructure and public facilities to economic opportunities. According to Liu et al. [65], disadvantaged villages are typically located in remote areas with limited accessibility and constrained natural resources within protected zones. Several factors contribute to the underdevelopment of these regions, including geographic isolation, a lack of basic infrastructure such as roads and bridges, limited healthcare and educational services, and the absence of economically viable natural resources. These areas are also often affected by natural disasters or social conflicts, which exacerbate the social and economic conditions of the communities. Geographic challenges remain a primary barrier to connecting these villages with economic and social activity centers, thus restricting the mobility of residents and goods. As highlighted by Guo et al. [66], improvements in accessibility and transportation can help reduce geographic barriers that have impeded development processes. Guo et al. and Long et al. [67,68] also noted that infrastructure development encourages increased mobility, positively impacting economic and social activities, which is crucial for accelerating the development of disadvantaged villages. Figure 6 showed map of Cianjur Regency typology in 2011 and 2021.

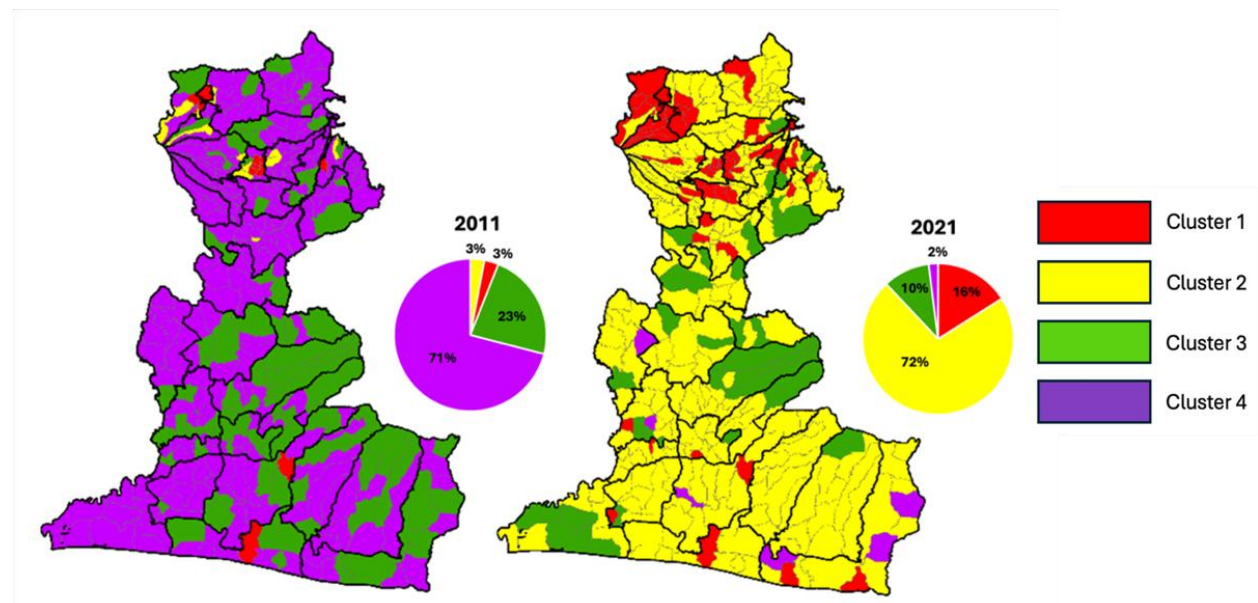


Figure 6. Cianjur Regency typology in 2011 and 2021.

Discussion

Balancing Growth and Sustainability?

This research highlights the significant land cover changes in Cianjur Regency, providing insights into the complexities of urbanization and its far-reaching implications for environmental sustainability. Between 2011 and 2021, a substantial reduction of 29,212.6 ha of paddy fields was observed, coinciding with the expansion of dry farmland and residential areas. This trend indicates a clear shift from agricultural to urban uses, a change that is emblematic of broader urbanization patterns in the region. The conversion of agricultural land to urban uses, as evidenced by this reduction, is a critical issue, especially in the context of food security.

The loss of productive agricultural land, often exacerbated by unregulated urban expansion, significantly increases the risk of food insecurity, a concern that mirrors trends seen in other urbanizing regions globally [11,12]. The theoretical concept of urban sprawl provides a useful framework for understanding these changes. Urban sprawl, as a phenomenon, often leads to the consumption of agricultural land and natural resources, resulting in environmental degradation. The findings of this study confirm that the rapid urbanization occurring in northern Cianjur is driven largely by unplanned growth, which, as previous studies have shown, can result in negative externalities such as increased pollution, loss of biodiversity, and disruption of local ecosystems. This uncontrolled urban expansion aligns with broader discussions in urban theory, which suggest that without comprehensive spatial planning, urban growth can threaten both the environment and public health [22,60].

The decline in the LSI reinforces the notion of sustainability trade-offs, particularly the delicate balance between economic growth and environmental health. As urbanization and agricultural intensification outpace the region's capacity for environmental management, the findings of this research resonate with the sustainability challenges identified in earlier studies [51,69]. The decline in LSI suggests that while economic development continues to progress in Cianjur, it is not being matched by improvements in environmental governance. This imbalance aligns with the theory of EM, which argues that economic growth can be compatible with environmental sustainability, but only if policies are implemented to encourage sustainable practices in land use, resource management, and industrial development [44].

Further, the LISA analysis revealed significant spatial disparities within Cianjur, with the southern region, which remains relatively less developed, exhibiting higher levels of environmental sustainability. In contrast, the northern and central regions, which have experienced more intense urbanization, face greater ecological challenges [60,69]. These spatial differences reinforce the need for integrated regional planning that balances socio-economic growth with environmental preservation. This study suggests that regional planning must address these disparities by incorporating both socio-economic and environmental factors, a sentiment echoed in prior research emphasizing the importance of holistic, coordinated development strategies for sustainable regional growth [54,62].

The regional typology developed in this study further illuminates the necessity for targeted interventions in urban clusters. These areas, characterized by high socio-economic sustainability but low environmental sustainability, are at the forefront of development challenges. The application of the sustainable livelihoods framework offers a potential solution, advocating for a multi-dimensional approach to addressing both poverty reduction and environmental management in urban contexts [8,38]. Policies for urban areas must, therefore, not only stimulate economic growth but also ensure the protection of ecological integrity through sustainable land use practices. For underdeveloped rural areas, the study calls for comprehensive strategies that integrate economic, social, and environmental considerations. The concept of spatial justice could inform such strategies, ensuring equitable distribution of development benefits and empowering vulnerable communities to engage in decision-making processes [66–68].

The findings of this study highlight the critical importance of implementing integrated and sustainable development strategies that address the complex dynamics of land cover change and socio-economic disparities in Cianjur Regency. The observed spatial patterns underscore how rapid urbanization, shifts in land use, and uneven access to resources can exacerbate regional inequality and environmental degradation. In comparing the empirical results with existing literature, this study reaffirms the persistent tension between economic growth and environmental sustainability, particularly in rapidly urbanizing peri-urban and rural urban fringe regions. These findings underscore the necessity of policy interventions that promote coordinated spatial planning across urban and rural areas, aimed at achieving more equitable and ecologically balanced development outcomes.

However, several limitations of the current study must be acknowledged. First, the reliance on secondary data for land cover analysis, while practical and widely used, may not capture the full range of land use dynamics particularly informal or small scale changes that are common in transitional regions. The temporal scope, limited to two time points (2011 and 2021), provides a useful snapshot of decadal change but may overlook short-term fluctuations driven by policy shifts, socio-economic shocks, or environmental disturbances. Furthermore, the methodological approach to constructing the LSI, although analytically robust, may oversimplify the interdependent nature of environmental, social, and economic factors. Notably, the social sustainability dimension lacks granularity with regard to socio-cultural dynamics, community resilience, and local governance, which are critical for contextualizing sustainability at the local scale.

To advance the analytical depth and policy relevance of future research, several avenues are proposed. Expanding the temporal resolution of land cover data using high frequency remote sensing techniques could offer more nuanced insights into land use transitions, especially in rapidly changing environments. Moreover, integrating qualitative methods such as participatory mapping, stakeholder interviews, and community surveys would enhance the understanding of local perceptions, institutional arrangements, and lived experiences that shape sustainability outcomes. Refining the LSI framework by incorporating additional indicators related to governance quality, cultural practices, and rural urban linkages could improve its sensitivity to local variations and policy contexts. Additionally, future studies should explore the socio-economic impacts of land use change on vulnerable populations to ensure that sustainability interventions are inclusive and socially justice.

Conclusion

This study reveals the complex interplay between land cover change and sustainability dynamics in Cianjur Regency from 2011 to 2021. The marked decline in rice fields and concurrent expansion of dryland farming and residential areas reflect a broader transition driven by urbanization and shifting agricultural priorities. These changes underscore a critical trade-off between economic growth and environmental sustainability, particularly in rapidly urbanizing northern regions. While social and economic indicators have improved due to better infrastructure and growing economic activities, these gains often come at the expense of ecological integrity, as seen in declining environmental sustainability scores and increased land degradation. The integration of LSI, LISA, and typological clustering offers a multidimensional view of regional disparities and development trajectories. The findings demonstrate that environmental benefits are concentrated in the less-developed southern areas, while socio-economic gains are centered in the north, resulting in spatial asymmetries and sustainability trade-offs.

This typology highlights the need to resolve competing demands: enhancing socio-economic opportunities in environmentally rich but underdeveloped areas, while mitigating ecological degradation in urbanized zones. To address these tensions, the study recommends differentiated, cluster-specific policy interventions that align with local conditions. Urban areas require green infrastructure and sustainable design to balance development with ecological preservation. Environmentally sustainable yet economically lagging villages can leverage eco-tourism and sustainable agriculture, while underdeveloped regions demand comprehensive support to improve infrastructure and reduce poverty. Overall, this research underscores the importance of integrated, place-based planning that reconciles development with conservation, ensuring that sustainability is not sacrificed for growth, but achieved through deliberate, context-sensitive trade-offs.

Author Contributions

MFR: Analysis, Software, Writing – original draft; **ERU:** Conceptualization, Supervision, Validation, Writing – Review; **VBR:** Supervision, Validation, Writing, and Editing; and **AEP:** Supervision, Analysis, Validation.

Conflicts of Interest

There are no conflicts to declare.

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