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| **Research Article**

Analysis of Urban Growth in Purwakarta Regency 2019–2023 Using Wind Direction Quadrant Method

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Abstract: Purwakarta Regency holds a strategic geographical position that plays a vital role in urban dynamics, driven by population growth and infrastructure demand. The region is located at the intersection of three major transportation corridors connecting Jakarta, Bandung, and Cirebon, which makes it an attractive area for urban expansion. The objective of this study is to analyze the direction and extent of urban growth in Purwakarta Regency between 2019 and 2023 using remote sensing and spatial analysis approaches. Sentinel-2 imagery was employed as the main dataset to classify urban and non-urban areas with the Random Forest algorithm applied to ensure accurate land cover classification. Accuracy assessment was conducted using confusion matrix analysis, producing an overall accuracy of 0.92 in 2019 and 0.90 in 2023, while validation with Google Earth imagery yielded 92% accuracy in 2019 and 90% in 2023. The classified results were further examined using the quadrant method of wind directions to identify the spatial orientation of urban expansion. Both visual interpretation and quantitative analysis indicate that urban growth in Purwakarta Regency was predominantly concentrated in the southwest quadrant. The total change in urban area during the study period was measured at approximately 7.72 hectares. The findings highlight that urban development in Purwakarta is closely linked to strategic transportation networks and regional accessibility. This study concludes that the integration of Sentinel-2 imagery and spatial quadrant analysis provides a reliable approach to monitoring urban growth patterns in rapidly developing regions.

Keywords: Developing Regions; Random Forest; Sentinel-2; Urban Growth; Wind Direction Quadrant.

1. INTRODUCTION

Urban growth is inevitable in developing countries and is often characterised by significant changes in land cover and land use (Mulyani, 2024). It involves land cover changes driven by the expansion of built-up areas over time. (Hasyim et al., 2020). Land use is dynamic, serving as a framework for the community's housing and economic activities. Various factors, including economics, culture, politics, history, and land ownership, drive these changes. The expansion of built-up land, including settlements, offices, and other buildings, is a key indicator of urban growth (Mulyani, 2024). However, this expansion can have severe environmental and socioeconomic impacts, including the loss of fertile agricultural land, damage to natural landscapes, and ecological degradation. Therefore, urban development must be grounded in sustainable development, balancing economic, social, and environmental dimensions and prioritizing environmental protection, with particular emphasis on ecological sustainability (Wijaya et al., 2020).

Purwakarta Regency is one of the regions in West Java Province that has experienced rapid urban growth (BPS, 2020). This regency is located at the intersection of three strategic transportation routes connecting

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Purwakarta with Jakarta, Bandung, and Cirebon. These three routes serve as the primary access points to Central Java, known as the 'Golden Triangle.' From a morphological perspective, the region features a diverse range of landscapes, spanning from lowlands to highlands, with elevations ranging from 150 to 1,500 meters above sea level (masl).

Its strategic location has driven significant population growth. The population growth rate exceeded 1% between 2019 and 2023 (BPS, 2024). The rapid population growth has led to various issues. Ongoing development has also led to the conversion of agricultural land into non-agricultural land, particularly for residential areas (Jakapratama et al., 2021). The high rate of agricultural land conversion poses a fundamental threat to regional food security (Nurlukman et al., 2025). Between 2010 and 2016, Purwakarta District experienced significant changes in land use: the area of built-up land increased by 8,315.45 hectares, while the area of orchards decreased by 9,007.01 hectares, the area of rice fields decreased by 3.70 hectares, and the area of dry fields decreased by 1,720.77 hectares.

In 2021, built-up land exceeded the agricultural land allocation by 753.2 hectares of built-up land above the farm land allocation in accordance with the Purwakarta Regency Spatial Plan (RTRW). This situation led to a land carrying-capacity deficit across all sub-districts in 2020, attributable to population density, poor soil quality, and land-use conversion (Nurlukman et al., 2025). Population growth in Purwakarta Regency has continued, from 950,070 in 2019 to 1,037,068 in 2023, indicating sustained pressure on land resources (BPS, 2024). Regular monitoring and accurate analysis are necessary to develop effective control strategies, given the ongoing land changes and their complex impacts (Rumbiak et al., 2023). Research on patterns of built-up land development is essential as a reference for regional development planning and sustainable natural resource management (Wijaya et al., 2020).

Urban growth mapping is vital for planning and management, particularly for addressing the challenges posed by rapid urbanization. Remote sensing technology offers cost-effective, timely, and efficient means of acquiring spatial data (Dhanaraj & Dasharatha, 2021). This enables fast data acquisition across large areas without the need for time-consuming field surveys and yields resource-intensive results quickly. Cloud-based platforms such as Google Earth Engine (GEE) further enhance analytical capabilities by providing extensive data sets, improved temporal data quality, and powerful computing tools (Tossoukpe et al., 2025). Remote sensing can be integrated with advanced geospatial techniques, including Geographic Information System (GIS), machine learning (e.g., Random Forest, Support Vector Machine), and cellular automata models (e.g., SLEUTH, CA-Markov) (Pushpalatha et al., 2024). This combination enables more in-depth analysis, including the identification of development hotspots, the detection of change patterns, and the simulation of future growth scenarios (Shafizadeh-Moghadam et al., 2021).

Remote sensing and GIS methodologies have enhanced the accuracy and efficiency of urban mapping. For instance, a spatiotemporal dynamics approach that identifies distinct urban growth patterns, such as edge growth and leapfrogging, through extensive urban growth index calculations from 1995 to 2050 (Liang & Liu, 2023). Complementarily, studies like this emphasize the importance of integrating satellite imagery with census data to gain insights into urban growth trends, particularly in humid tropical regions (Astuti et al., 2022). Remote sensing data facilitates detailed analysis of urban expansion and land-cover change, as shown in a national dataset of U.S. urban dynamics (1985-2015) (Li et al., 2020). Furthermore, the application of deep learning methodologies in urban mapping demonstrates potential for advancement, with researchers using street-level imagery to assess urban change (Byun & Kim, 2022).

Research on urban expansion mapping in Purwakarta Regency from 2019 to 2023 is pertinent due to the escalating pressures of population growth, economic development, and land-use demands in the area. This research uses remote sensing data and spatial analysis techniques to identify the spatial and temporal patterns of urban growth, with emphasis on regions most affected by rapid development. Despite numerous studies on urban expansion in other areas of West Java, there remains a significant research gap in applying the wind quadrant method to analyze urban growth dynamics in Purwakarta. This study, therefore, introduces and applies the quadrant-based spatial analysis to this area for the first time, aiming to reveal directional tendencies of urban expansion that have not yet been systematically explored. The results are expected to provide current spatial data to support environmentally sustainable and socially inclusive development methods.

This study aims to conduct a comprehensive examination of land-cover dynamics, with particular emphasis on the proliferation of built-up regions that have substantially transformed the landscape over this

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period. Moreover, the findings of this study will enhance spatial planning coherence, ensuring that urban growth is consistent with long-term sustainability objectives, mitigating environmental degradation, and bolstering the resilience of Purwakarta Regency in confronting future urban challenges.

2. RESEARCH METHOD

a. Research Location

This study was conducted in Purwakarta Regency, one of the administrative regions in West Java Province, Indonesia, with its capital located in Purwakarta District. Geographically, Purwakarta Regency is located at coordinates 6°32' - 6°55' South Latitude and 107°19' - 107°39' East Longitude, bordering Karawang Regency to the north, Subang Regency to the east, West Bandung Regency to the south, and Cianjur Regency to the west. The total area spans 971.72 km², comprising 17 districts, 192 villages, and 9 urban villages. The region is predominantly characterised by hills and highlands in the south and lowlands in the north.

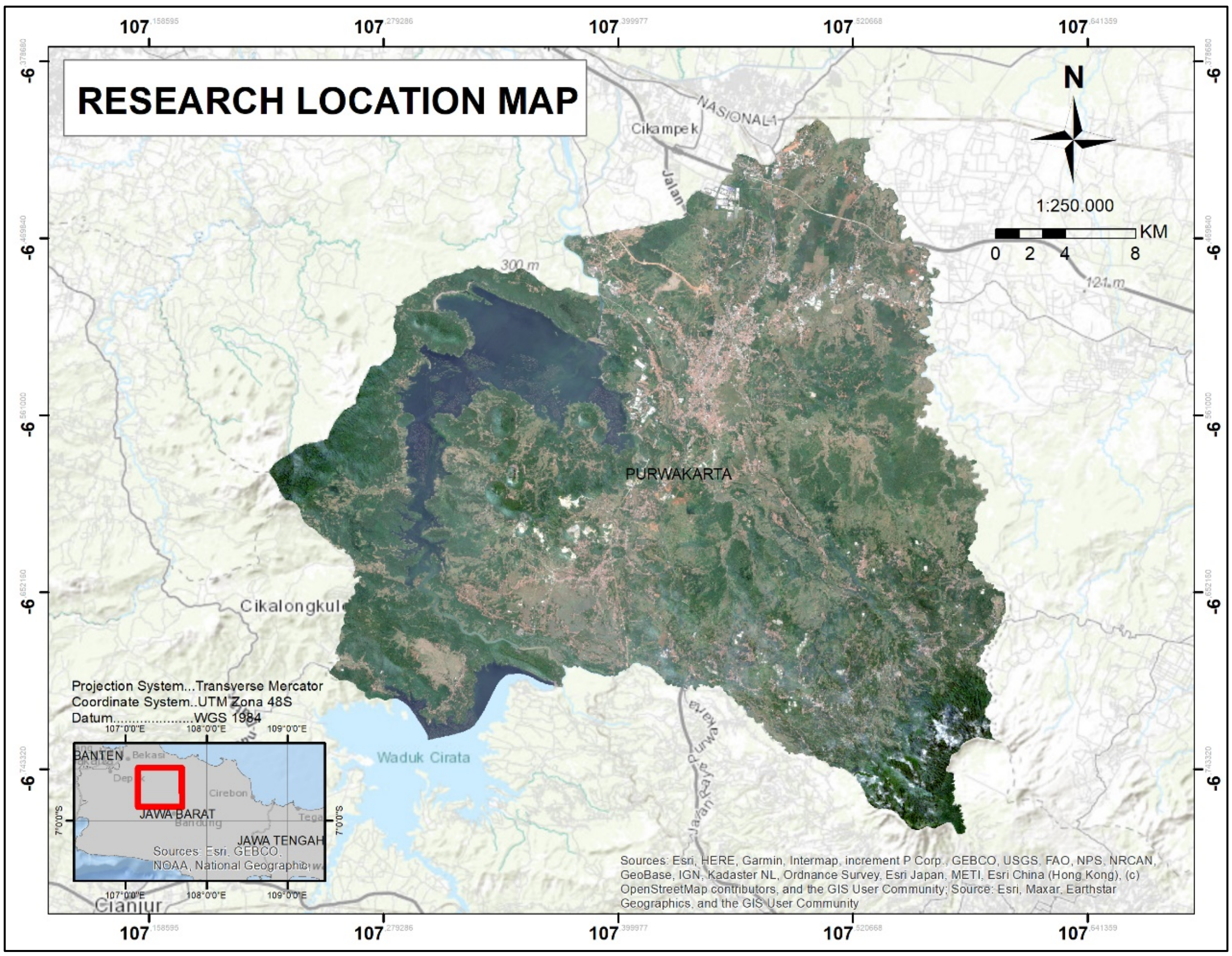

Figure 1. Research Location Map (Source: Data Processing, 2025)

b. Data Collection

The data pre-processing was carried out thoroughly to improve image quality and analysis accuracy. Cloud masking was implemented using the QA60 band to remove cloud and cirrus pixels. In contrast, atmospheric correction was applied to the Copernicus/S2_SR dataset using the Sen2Cor algorithm, ensuring that reflectance values represent the actual surface conditions. In addition, median mosaicking was performed to merge multiple cloud-free images from the same period into a single composite, minimizing noise and temporal variability. These preprocessing procedures enhanced the overall quality of the dataset and improved the reliability of the classification results. The Sentinel-2 data used in this study were accessed from the Google

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Earth Engine Data Catalog. The classification was carried out using all 12 Sentinel-2 reflectance bands, which cover the visible, near-infrared (NIR), and shortwave infrared (SWIR) spectral ranges. The use of this broad spectral band combination enhances the model's ability to distinguish various land-cover types spectrally.

c. Input Data Processing

This study utilized several machine learning methods available on Google Earth Engine (GEE). GEE is a platform that applies machine-learning principles to remote sensing, enabling users to obtain the images they require, including Sentinel-2 imagery (Sukoco, 2022). GEE is a cloud-based platform for efficient large-scale analysis of satellite data, suitable for long-term monitoring. The platform automatically performs advanced data processing operations, including projection, scaling, and compositing, thereby saving time and reducing the need for specialized expertise in technical preparation (Anucharn et al., 2025). Sentinel-2 imagery was selected for its high spatial resolution, which supports detailed analysis in urban growth studies. Additionally, the availability of up-to-date data, which is frequently updated, makes Sentinel-2 more flexible for use in various research and operational analyses.

The classification method used in GEE is random forest (RF). The RF algorithm is an ensemble of decision tree classifiers that improves modeling accuracy. RF is capable of ranking independent variables to explain urban growth. (Shafizadeh-Moghadam et al., 2021). RF is a widely used machine learning algorithm that has proven effective in various studies on remote sensing and land-use mapping (Darmawan & Santoso, 2024). The advantages of RF lie in its ability to handle high-dimensional data, reduce overfitting, and model nonlinear relationships among input variables (Georgati et al., 2023). Furthermore, RF is insensitive to multicollinearity and efficient with training data, making it a strong choice for complex land-use classification (Chang et al., 2020).

The process begins with the search for samples for land-cover classes and for urban and non-urban classes. These samples will then be used for classification with a random forest in GEE. The training data were manually collected by digitizing feature collections for each land-cover class, including vegetation, water bodies, bare land, built-up areas, urban areas, and clouds. A total of 150 polygons were created for each class to ensure balanced and representative samples across all land cover types. This process was carefully conducted to guarantee adequate representation of each class in the classification model. The training dataset was extracted using the sampleRegions function in GEE and split into two portions: 70% for training and 30% for validation, with high-resolution imagery used as a reference to improve classification accuracy. The Random Forest model was constructed using 1,000 decision trees, as specified by the parameter ee.Classifier.smileRandomForest (1000). Other technical parameters, such as the maximum tree depth (maxDepth) and the number of input variables per split (number of variables per split), were set to GEE's default values, which are generally optimized for model efficiency and stability. This approach enables effective classification without requiring complex manual tuning while maintaining consistent accuracy in distinguishing land-cover classes based on their spectral characteristics.

d. Wind Direction Quadrant Method

The classification results will be analysed using the wind direction quadrant method to assess urban growth in the area. This method analyses the anisotropy of urban growth, i.e., differences in growth patterns in various directions. This is important because urban growth rarely occurs evenly in all directions. The classification results were then analyzed using the wind direction quadrant methodto determine the urban growth pattern in the study area. This method is used to analyze anisotropy, the spatial variation in urban growth patterns across directions. Such analysis is essential because urban expansion rarely occurs evenly in all directions (Liu et al., 2025).

This approach was also previously applied by Hegazy and Helmi (2020), who conducted a study entitled Spatial Monitoring of Urban Growth of Mansoura City, Egypt. Their research compared satellite imagery over several decades (1985–2015) to observe urban growth trends and identify the dominant directions of urban expansion, such as growth that tended to move toward the east or north over time. This approach was also previously applied in a similar study by Renita (2022) in Banyumas Regency. In that research, the compass direction analysis method was implemented in a more complex manner to identify spatial changes and the distribution pattern of urban sprawl in Banyumas over two decades (2000–2020). The results demonstrated

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that the compass direction–based analysis provided a more detailed understanding of urban growth dynamics and the dominant directions of urban expansion, highlighting how urban development in Banyumas tended to spread toward specific directions, consistent with regional accessibility and spatial planning policies.

In this study, urban development was quantified as the percentage of built-up area in eight compass directions. The use of eight directions aimed to provide a more detailed overview of urban growth dynamics over four years. The study area was then divided into several rows, each 2 km long, to facilitate the calculation of changes in built-up land. The analysis of urban growth was conducted relative to the urban embryo point, which was located in Purwakarta District, specifically around the State Building. Validation of the results was performed using Google Earth imagery and secondary surveys from the spatial pattern map and spatial planning to ensure the accuracy of the detected spatial changes. The percentage of built-up area growth in each directional sector was calculated using the following formula:

$$Pi = \left(A_{(t2,i)} - A_{(t1,i)}\right)/A_{(t1,i)} x100\% \quad \text{.....................................} (1)$$

Where $P_{(i)}$ represents the percentage growth of the built-up area in the i-t directional sector, $A_{t1,i}$ is the built-up area in the initial year, and $A_{t2,i}$ is the built-up area in the final year. This formula quantifies the relative change in built-up areas across eight directions: north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), and northwest (NW). The compass direction analysis method remains rarely applied in regencies across West Java. Most urban growth studies in the province have focused on general spatial analyses of land-cover change without identifying the dominant directions of urban expansion. Therefore, the application of this method in Purwakarta Regency provides a novel contribution to understanding the anisotropic patterns of urban growth and serves as a complementary approach to data-driven regional spatial planning that accounts for the actual directions of urban development.

e. Accuracy Assessment

Google Earth imagery was used to validate urban growth in Purwakarta Regency. This imagery has high resolution, enabling its use to collect reference data and validate classifications through visual interpretation sampling (Kombate et al., 2022). This validation ensures the reliability of LULC maps, as high-resolution imagery from Google Earth Pro provides accurate ground-truth verification of satellite classifications. (Hernández et al., 2024). In general, the validation method employed in this study involved selecting 150 representative sample points from the classification results and directly comparing them with high-resolution imagery from Google Earth. This approach is widely adopted in remote sensing and land cover change studies because Google Earth imagery provides relatively up-to-date, high-resolution reference data that can serve as a reliable benchmark for assessing classification accuracy. The overall methodological framework is illustrated systematically in Figure 2.

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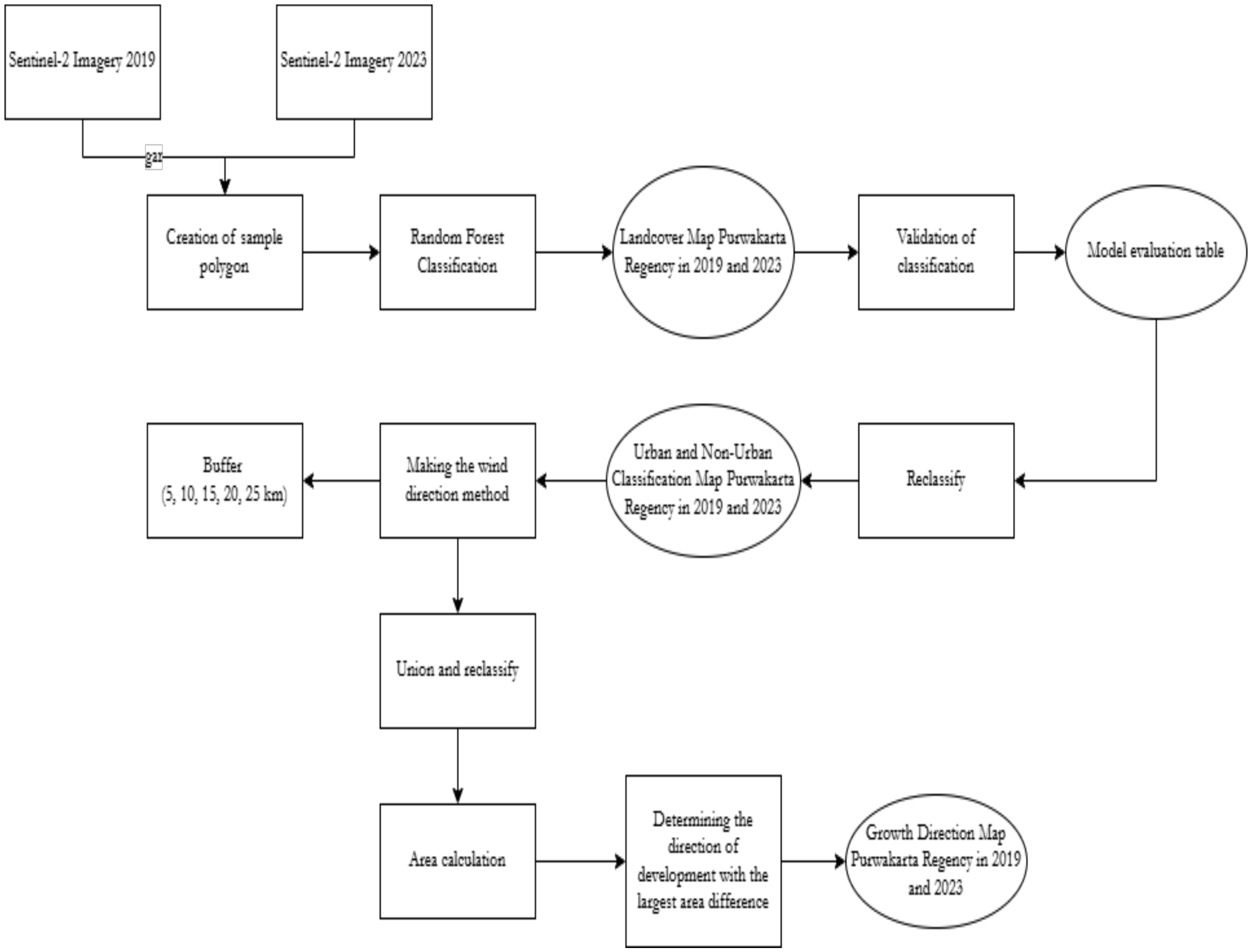

Figure 2. The Research Flowchart (Source: Data Processing, 2025).

3. RESULTS AND DISCUSSION

a. Land Cover Classification in 2019 and 2023 in Purwakarta Regency

The land cover classification of Purwakarta Regency was produced using Sentinel-2 imagery data. Sentinel-2 is a product developed by the European Space Agency (ESA). Various spectral bands in these images can help distinguish land-cover types, such as vegetation, built-up land, water bodies, and open land (ESA, 2023). The land-cover classification results are adjusted to the national standardization agency's small- and medium-scale land-cover classification standards. The classification produced in this study comprises five classes: built-up land, vegetation, water bodies, settlements, and open land (BSN, 2020). Vegetation cover predominates in Purwakarta Regency, as indicated by the color green (Figure 3). Although there were changes between 2019 and 2023, including an increase in residential areas and built-up land, vegetation remains the dominant land-cover category. Land cover that tends to be less changeable is water bodies and open land. The land-cover classification results for Purwakarta Regency were obtained using a random forest algorithm. The Random Forest algorithm produced high-accuracy LULC maps, confirming its effectiveness in classifying land-cover types using Sentinel-2 imagery (Kaur et al., 2024).

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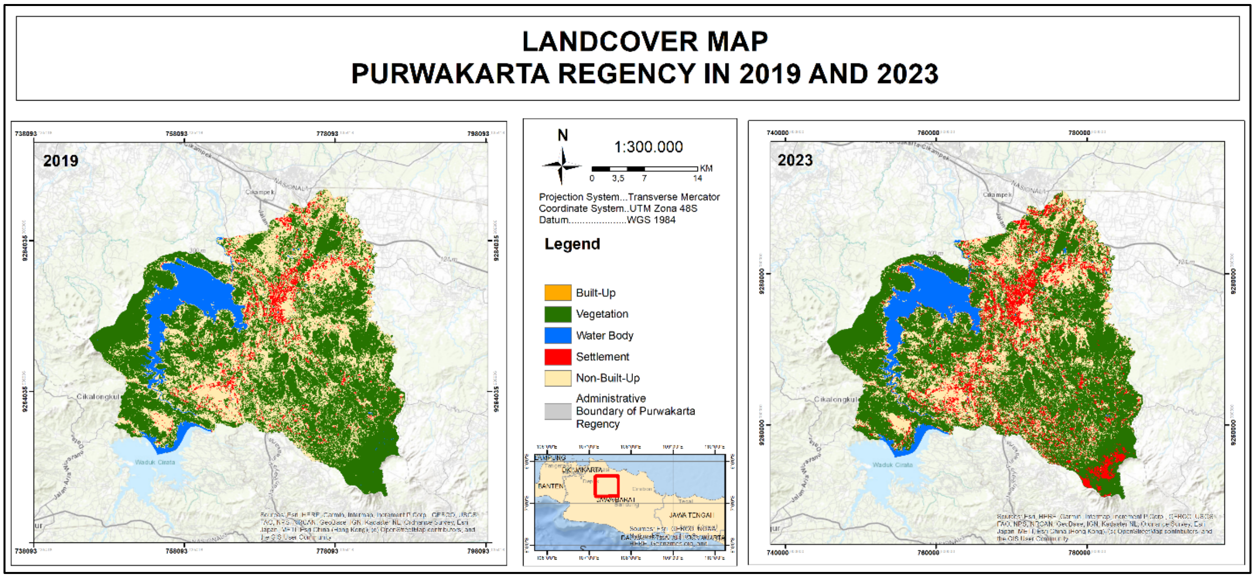

Figure 3. Land Cover Classification Maps for Purwakarta Regency in 2019 and 2023
(Source: Data Processing, 2025).

Overall accuracy denotes the proportion of pixels correctly classified. The higher the overall accuracy value, the more accurate the classification results (Jasim et al., 2024). The 2019 land-cover classification accuracy assessment achieved an overall accuracy of 0.92, whereas the 2023 test achieved 0.90. These values indicate that the classification performed in this study has high accuracy. Details of the accuracy assessment are presented in Tables 1 and 2.

Table 1. Accuracy Assessment Result of the 2019 Land Cover Classification.

Land Cover Class	User's Accuracy (%)	Producer's Accuracy (%)	Overall Accuracy (OA)	Kappa Index (ϰ)
Built-up	93	90.4	92	0.89
Vegetation	91.5	93		
Water Body	92	92.7		
Settlement	90.8	91		

(Source: Data Processing, 2025)

Table 2. Accuracy Assessment Result of the 2023 Land Cover Classification.

Land Cover Class	User's Accuracy (%)	Producer's Accuracy (%)	Overall Accuracy (OA)	Kappa Index (ϰ)
Built-up	91.2	88.7	90	0.86
Vegetation	88.9	91.3		
Water Body	90.1	89.8		
Settlement	90.5	90.2		

(Source: Data Processing, 2025)

b. Classification of Urban and Non-Urban Areas in 2019 and 2023 in Purwakarta Regency

The classification of urban and non-urban areas was derived from the land-cover classification results shown in Figure 3. Land cover classified as settlements was defined as metropolitan, while land cover other than settlements was defined as non-urban. Figure 4 indicates rapid growth around the administrative centre and the leading road network. The existence of roads significantly influences urban development by increasing connectivity, boosting housing development, and attracting investment (Khanani et al., 2021).

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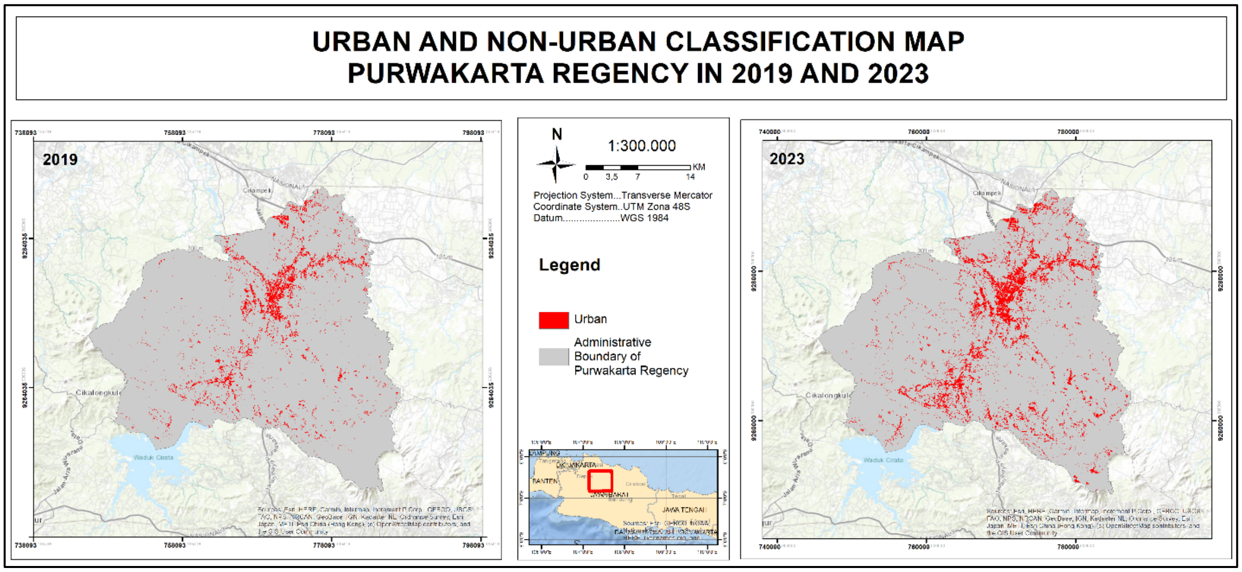

Figure 4. Urban and Non-Urban Classification Maps for Purwakarta Regency in 2019 and 2023
(Source: Data Processing, 2025)

Conurbation corridors significantly influence the growth and development of cities in mega-urban areas undergoing rapid urbanisation and increased connectivity, shaping spatial patterns, land-use dynamics, and the sustainability of these areas. Urban growth, particularly in Monsoon Asia, drives the expansion of core metropolitan cities into Expanded Metropolitan Regions (EMRs) and, in turn, into Mega-Urban Regions (MURs), which are typically polycentric, comprising several interconnected urban zones. The formation of MURs and their conurbation corridors has spatial and structural impacts on urban expansion, increasing regional interaction and competitiveness, and leading to significant population growth and density within the corridors (Jatayu et al., 2023). Purwakarta Regency, located on the Jakarta-Bandung corridor, has also experienced this, where one of the factors triggering urban growth is the existence of the corridor.

The distribution of urban areas in Purwakarta Regency in 2019 remained concentrated in the city's administrative centre and in several areas with good transport access. However, in 2023, urban expansion into the suburbs was more widespread. Quantitatively, the change in urban area size from 2019 to 2023 is 34.19 hectares. Population growth is a key driver of urban expansion.

In 2019, the population of Purwakarta Regency was 962,893 (BPS, 2020), and in 2023 it was 1,037,070 (BPS, 2024). The relationship between population growth and residential area expansion is complex and varies across contexts. Population growth is often assumed to correlate with residential expansion (Schaiavina et al., 2022). This correlation was proven in a study conducted in Cilebut Timur Village, which showed that population growth had led to an increase in residential areas, as evidenced by the emergence of new settlements over five years (Merlina et al., 2023).

c. Growth Direction Map in 2019 and 2023 in Purwakarta Regency

An analysis of the direction of urban growth in Purwakarta Regency was conducted using the Quadrant Wind Direction method with the centre point located in the city centre. The city centre serves as a focal point for physical development, owing to the concentration of governmental, economic, and cultural functions that facilitate social interaction and activities essential to urban growth (Aziz et al., 2023). According to the Purwakarta Regency Government, historical records indicate that urban development began with the construction of the Gedung Negara in 1831. Figure 5 and Table 3 show minimal growth in the west and east, but substantial expansion in the southwest and northeast between 2019 and 2023. The highest increase in the area of non-urban land converted to urban land was in the southwest direction. Meanwhile, the lowest change was in the west. Each change in each direction is shown in Table 3, which is the quantitative result of the area of each urban and non-urban classification in 2019 and 2023 based on the eight cardinal directions used.

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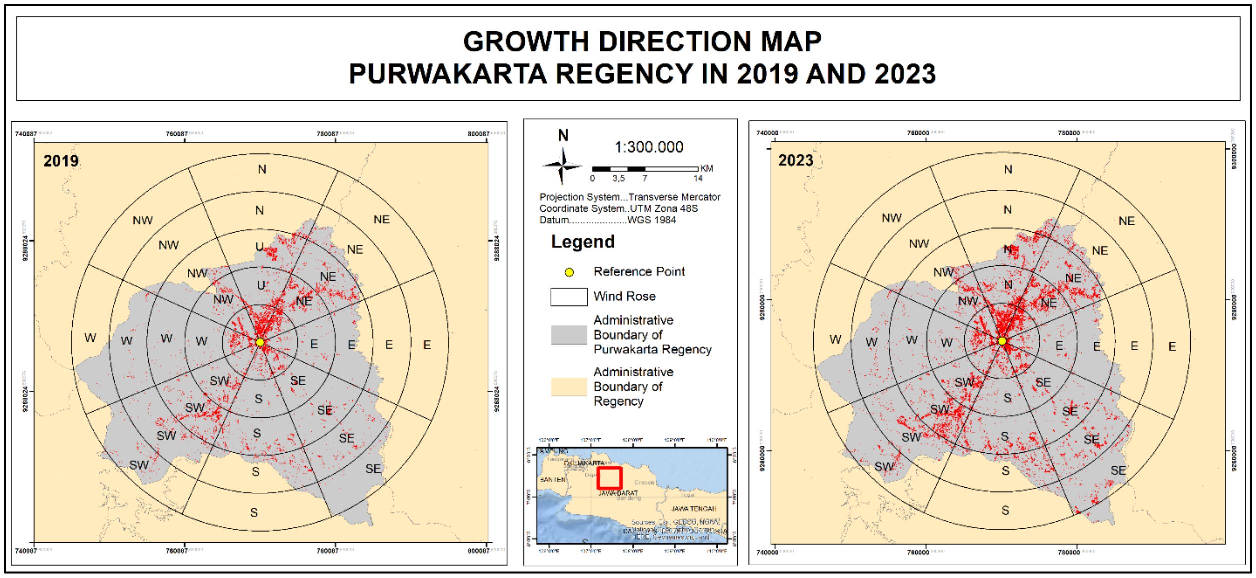

Figure 5. Growth Direction Maps for Purwakarta Regency in 2019 and 2023
(Source: Data Processing, 2025).

Table 3 shows a significant increase in almost all directions between 2019 and 2023. In 2019, the total urban area was 42.88 hectares; in 2023, it increased to 77.06 hectares, an increase of 34.19 hectares. The most significant growth occurred in the south-west direction, accounting for 7.72 hectares (22.57%) of the total change, confirming that the south-west region is the dominant direction of urban development. In addition, the northeast direction also showed a significant increase of 5.74 hectares (16.78%), followed by the southeast direction with 5.58 hectares (16.34%), and the north direction with 5.12 hectares (14.98%). Meanwhile, the south direction experienced an increase of 4.82 hectares (14.10%), and the west direction increased by 1.60 hectares (4.68%). Smaller-scale growth occurred in the northwest direction, with an addition of 2.62 hectares (7.67%), and in the east direction, with an increase of 0.92 hectares (2.89%). By percentage distribution, in 2019 the northeast direction had the highest share (24.05%), whereas in 2023 the southwest direction was dominant (20.78%). Overall, these results indicate that Purwakarta's urban development is concentrated in areas with high accessibility, particularly along transport routes to the southwest, followed by the northeast and southeast (Figure 6). These findings indicate an uneven growth pattern, with development concentrated in specific strategically located corridors.

Table 3. Area of Urban Development.

Direction	2019 (ha)	2019 (%)	2023 (ha)	2023 (%)	Difference (ha)	Difference (%)
North	8.91	20.78	14.03	18.21	5.12 (+)	14.98
Northeast	10.31	24.05	16.05	20.83	5.74 (+)	16.78
East	1.18	2.75	2.17	2.81	0.92 (+)	2.89
Southeast	4.16	9.71	9.75	12.65	5.58 (+)	16.34
South	4.53	10.57	9.35	12.14	4.82 (+)	14.10
Northwest	3.04	7.09	5.66	7.35	2.62 (+)	7.67
Southwest	8.30	19.36	16.02	20.78	7.72 (+)	22.57
West	2.44	5.68	4.03	5.24	1.60 (+)	4.68
Total	42.88	100.00	77.06	100.00	34.19 (+)	100.00

(Source: Data Processing, 2025)

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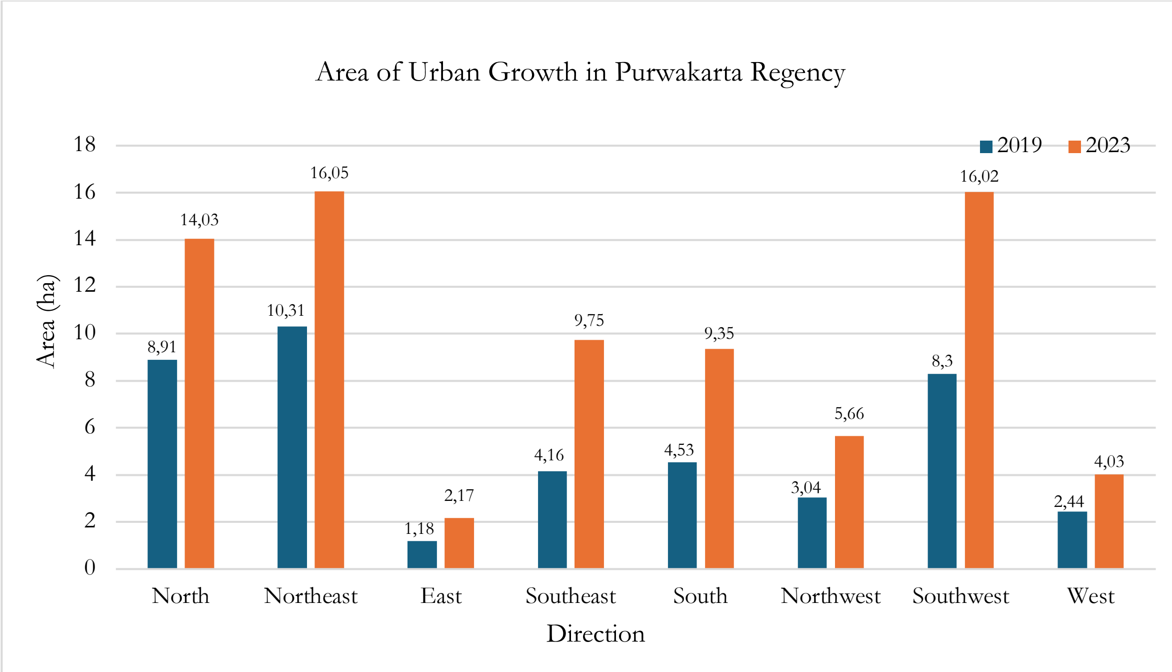

Figure 6. Area of Urban Growth in Purwakarta Regency (Source: Data Processing, 2025)

Further analysis of urban growth patterns in Purwakarta Regency was conducted by integrating the results of remote sensing analysis with spatial policy documents, particularly the Purwakarta Regency Spatial Plan Map (RTRW) presented in Figure 7 and the regulations established under Purwakarta Regency Regulation No. 3 of 2021 concerning the spatial plan for the period 2011–2031 (Pemerintah Kabupaten Purwakarta, 2021). The integration of spatial data with policy frameworks is essential for understanding not only where urban expansion occurs but also why specific directions exhibit faster growth than others. The spatial plan designates the western and eastern sectors as conservation and cultivation areas, respectively, comprising protected forests, plantations, and croplands. These areas serve as ecological buffers that sustain the regency's environmental carrying capacity, support biodiversity, and secure water-catchment functions critical to long-term sustainability. Consequently, both development and urbanization in these directions are deliberately restricted in accordance with local spatial policies. The strict enforcement of conservation zoning aims to minimize environmental degradation, prevent natural hazards such as flooding and landslides, and mitigate the negative impacts of global warming, which could otherwise threaten the ecological stability of the regency.

In contrast, the southwestern and northeastern quadrants of Purwakarta exhibit markedly different development trajectories. These areas have been strategically designated for residential expansion and industrial development within the regional government's long-term planning framework. The Purwakarta Regency Government has adopted a cluster-based industrial development model that concentrates economic activities in specific zones, particularly in the northern part of the regency and in areas surrounding toll road interchanges. This strategy is closely aligned with the regency's advantageous location at the intersection of three major transportation corridors: Jakarta, Bandung, and Cirebon, which provides high levels of accessibility and connectivity to regional and national markets. The southwestern corridor, in particular, benefits significantly from toll road access points that serve as gateways for logistics and mobility. This accessibility fostered industrial and residential growth, explaining why most expansion between 2019 and 2023 occurred in this direction.

Similarly, the northeastern part of Purwakarta has become another growth pole due to its proximity to rapidly developing industrial regions such as Karawang and Subang. These areas are integrated into broader economic corridors in West Java, and their designation for industrial and residential purposes has attracted considerable investment and population inflows. The spatial plan explicitly supports this by promoting industrial clustering to enhance competitiveness, create employment opportunities, and stimulate local

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economic growth. Thus, urban expansion in the northeast reflects both demographic pressures and policy-driven allocation.

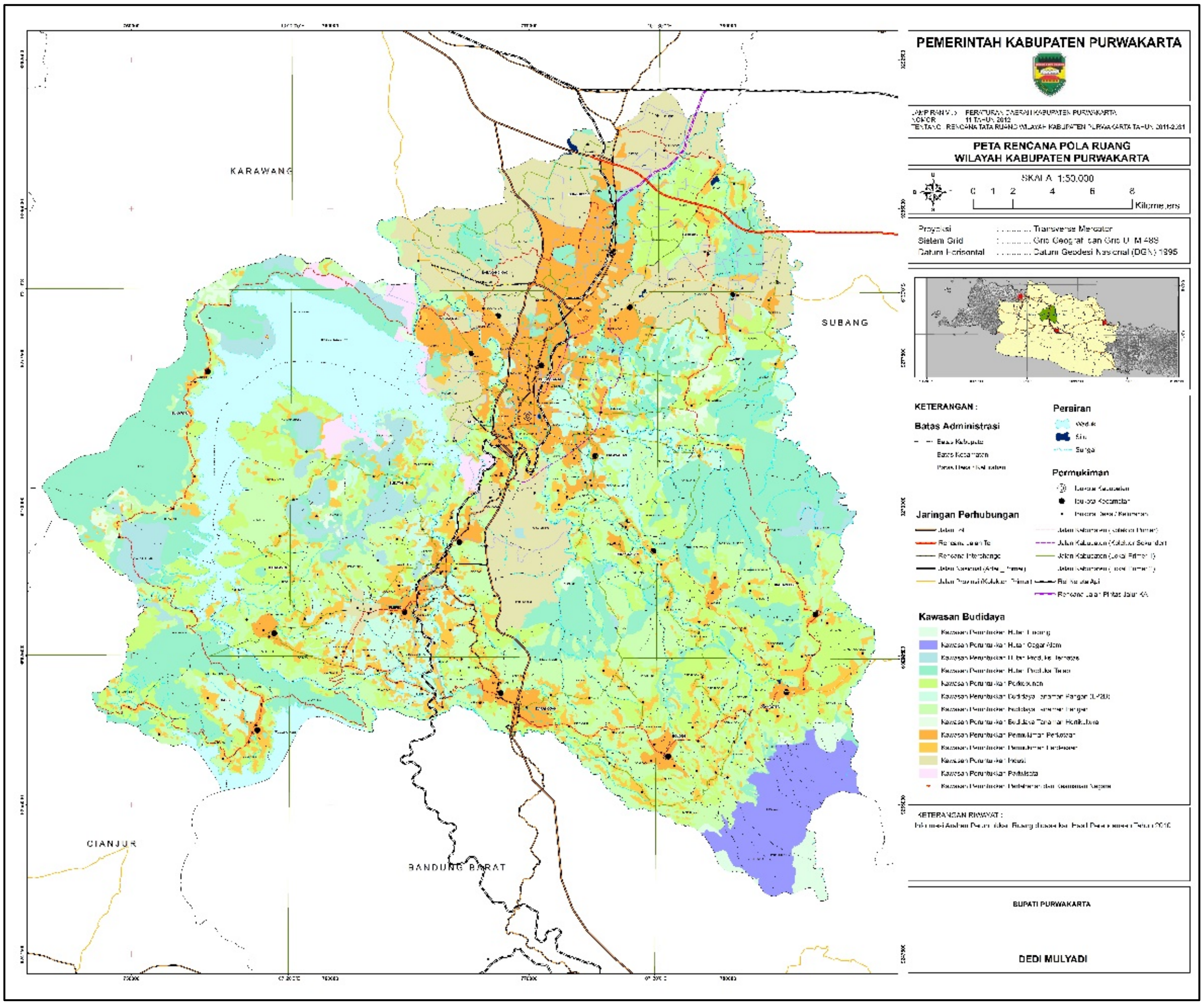

Figure 7. Purwakarta Regency Spatial Planning Map (Source: Pemerintah Kabupaten Purwakarta, 2021).

Overall, the analysis highlights a spatially differentiated pattern of urban development in Purwakarta Regency. At the same time, conservation-oriented zones in the west and east limit urban encroachment to preserve environmental sustainability, development-oriented corridors in the southwest and northeast act as focal points for urban and economic growth. This contrast reflects the balancing act embedded in regional spatial planning: on the one hand, protecting ecologically sensitive landscapes to ensure long-term resilience, and on the other, facilitating strategic economic and infrastructural development to meet growing demands for housing, industry, and services. The findings underscore the critical role of spatial planning regulations in shaping the trajectory of urban growth, ensuring that development remains concentrated in accessible and economically viable zones while safeguarding ecological assets in designated conservation areas. Such integration between geospatial analysis and policy documents provides a comprehensive framework for understanding and managing urban expansion in rapidly growing regions such as Purwakarta.

Urban expansion in Purwakarta Regency was validated using Google Earth imagery. High-resolution imagery can be utilized to collect reference data and validate classifications using visual interpretation sampling. In this study, the validation test for the Purwakarta Regency urban growth direction map in 2019 yielded an accuracy of 92%, whereas in 2023, the accuracy decreased slightly but remained high at 90%. However, several potential difficulties and risks must be considered. First, there is a risk of overfitting if the model is overly

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tailored to the training data, resulting in reduced accuracy on new data. Second, validation faces challenges, including the availability of images that are not always up to date, the selection of representative sample points, and the difficulty of distinguishing similar land-cover classes, such as mixed vegetation and settlements, or shallow-water areas covered by vegetation. These factors are important to consider when interpreting classification results.

The consistency of the accuracy values across the two study years further demonstrates that the methodological framework, including Sentinel-2 imagery and a Random Forest classification algorithm, was robust in capturing the spatial dynamics of urban expansion. Moreover, the high accuracy indicates that the classification outputs align well with ground conditions, thereby strengthening the validity of subsequent spatial analyses, such as the quadrant-based assessment of urban growth directions. Thus, the validation results not only provide statistical evidence of the quality of the classification process but also ensure that the findings of this study can be used with confidence to inform spatial planning and policymaking in Purwakarta Regency.

4. CONCLUSION

Purwakarta Regency experienced significant urban expansion between 2019 and 2023, with an estimated 34.19 hectares of non-urban land converted to urban areas. The spatial distribution of this growth was irregular, exhibiting notable concentrations in the southwestern and northeastern quadrants, which aligns with the development trajectory specified in the Purwakarta Regency Spatial Plan (RTRW) and policies that facilitate industrial and residential expansion near the toll interchange. The primary catalysts of this urbanization were population growth, the expansion of transportation infrastructure, and increased economic activity. The implementation of the Random Forest (RF) algorithm on the Google Earth Engine (GEE) platform yielded land-cover classifications with overall accuracies of 92% and 90%, thereby affirming its reliability for spatial analysis and urban growth verification. These findings highlight the need to implement remote sensing and data-driven methodologies in spatial planning, particularly to ensure ecological sustainability in the comparatively stable protected areas in the regency's western and eastern regions. Furthermore, the results of this study provide a substantial empirical basis for policymakers to develop cohesive and flexible spatial planning methods that reconcile social, economic, and environmental dimensions. Future research should enhance urban growth modeling by integrating machine-learning predictive techniques and cellular automata simulations, thereby facilitating more anticipatory and evidence-based spatial planning in response to the challenges of accelerating urbanization.

5. REFERENCE LIST

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