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Spatial Prediction of Built-up Area Expansion (2007 – 2041) as a Flood Resilience Strategy in Sustainable Urban Development

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ABSTRACT

Urban land-use transformation has become one of the major drivers of environmental degradation in rapidly developing cities. This study aimed to analyze the dynamics of built-up area expansion and predict future spatial changes in Sukabumi City to support flood resilience and sustainable urban development. The research employed spatial analysis using multi-temporal satellite imagery for 2007, 2014, and 2021, supported by spatial data. The classification process used the Random Forest algorithm, while the Land Change Modeler was applied to project land-use change for 2041 based on ecological and driving-factor scenarios. The results show a significant increase in built-up land development in Sukabumi City from 2007 to 2041, with residential land expanding from 233.66 ha to 2,132.43 ha and industrial land increasing from 36.62 ha to 51.37 ha, resulting in a total built-up area increase of approximately 813%. The results showed a continuous increase in built-up areas, mainly concentrated in the city's central, southern, and western parts, replacing agricultural and green open spaces. The projected map for 2041 indicated that residential areas would continue to expand along major roads, leading to a significant decrease in non-built-up land. The study found flood susceptibility in Sukabumi City will increase by 2041, especially in the central and southern areas. A flood resilience strategy is proposed through optimized spatial policies, stronger coordination, improved drainage, and strict land-use control to achieve sustainable and flood-resilient urban development.

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1. INTRODUCTION

Land use change is a significant contributor to environmental conditions (Xie et al., 2024). Its development is accelerating due to the ever-increasing human needs (Naikoo et al., 2020). The most rapidly expanding land use type is built-up land (Ali and Nayyar, 2021). The total area of built-up land is projected to increase sharply, reaching nearly 3 million km² by 2050 (Yang et al., 2022). The development of built-up land is characterized by the conversion of agricultural land for alternative industrial uses (Xie et al., 2024). The uncontrolled expansion of built-up areas can lead to environmental degradation (Xiao et al., 2016). Based on the Regional Long-Term Development Plan (RPJPD) document for Sukabumi City for 2005–2025, the Central Bureau of Statistics (BPS) of Sukabumi City recorded several sectors experiencing significant growth, including built-up land, which increased from -1.37% in 2004 to 6.16% in 2006. Meanwhile, one sector that declined was agricultural from 8.74% in 2004 to -0.76% in 2006. This drastic change indicates the early signs of land-use conversion from agriculture to built-up land in Sukabumi City.

Land use change is also supported by the objectives of the Spatial Plan (RTRW) of Sukabumi City for 2022-2042. The demands for regional development have driven the dynamics of built-up land expansion, which are expected to continue increasing over the next 20 years due to the conversion of agricultural land for urban activities (industrial, commercial, and service sectors). In addition, the construction of various mega-projects, especially transportation infrastructure, has accelerated urbanization dynamics. Consequently, the pace of land use change is increasing, allowing further expansion of built-up land in the present and future. The increase in the number of buildings, particularly those replacing agricultural land and green open spaces, has reduced the capacity of groundwater to infiltrate (Dahlia et al., 2018). Data show that the conversion of agricultural areas into urban zones has been significant, particularly with the construction of infrastructure such as roads, residential areas, and commercial zones. Similar findings were reported by (Sugandi, 2007), who stated that land use conversion from agricultural and forest areas to built-up zones decreases infiltration capacity and increases surface runoff, thereby exacerbating urban flood risks. This has led to an increase in impervious surfaces, increasing the potential for flooding during periods of heavy rainfall. Furthermore, the Regional Disaster Management Agency (BPBD) of Sukabumi City noted that rivers considered safe from flooding in 2014 for 5, 10, or 25 year return periods became flood sources 3-4 years later. Between 2018 and 2024, the frequency, extent, and depth of floods have shown a fluctuating yet increasing trend. Sukabumi City is traversed by one main river, the Cimandiri River, and five tributaries: Cipelang, Cipanengah, Tonjong, Cisuda, and Ceger Rivers. The city's location within the Cimandiri River Basin (DAS Cimandiri) makes it highly dependent on the river system for water supply management. The existence of these five main tributaries also contributes to Sukabumi's high flood vulnerability.

The significant growth rate between 2004 and 2006, as stated in the RPJPD document, combined with Sukabumi's geographical condition, crossed by major rivers, makes the city highly prone to flooding. Moreover, the absence of spatial documentation recording past land development and flood vulnerability has become a major obstacle in predicting future trends. This lack of historical data complicates efforts to create accurate projections regarding the relationship between built-up land development and flood risk. These methods are useful for examining the dynamics of the past, present, and future development of built-up areas in Sukabumi City. They can also represent correlated datasets (Bernardini et al., 2024; da Silva et al., 2020; Chen, 2022). Therefore, in-depth research on the historical dynamics and spatial relationships between built-up land development and flood vulnerability in Sukabumi, covering the past, present, and future is urgently needed to formulate effective and

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sustainable policy measures. The purpose of this study is to analyze the development, change, and prediction of built-up land in Sukabumi City in 2007, 2014, and 2021, as well as projections for 2041, and to formulate a flood resilience strategy that supports sustainable urban development based on spatial analysis of built-up land expansion and flood vulnerability. The use of Geographic Information Systems (GIS) as an analytical and spatial technique allows for the capture, storage, manipulation, analysis, management, and interpretation of spatial data while integrating database operations such as querying and spatial analysis. Its broad intellectual foundation supports a range of economic, social, and ecological applications (Astari et al., 2021).

2. METHODS

This research was conducted in Sukabumi City, one of the cities located in West Java Province. Administratively, Sukabumi City comprises seven districts and 33 urban villages/villages. Administratively, Sukabumi City comprises 33 urban villages (villages) with varying land areas. In 2023, Lembursitu is the largest subdistrict, covering approximately 376.15 hectares, followed by Sukakarya (282.47 hectares) and Dayeuhluhur (250.12 hectares). Other villages, such as Baros (184.01 hectares), Jayaraksa (136.10 hectares), Jayamekar (129.58 hectares), and Benteng (118.20 hectares) have moderate land sizes. Meanwhile, smaller villages include Nyomplong (59.88 hectares), Warudoyong (45.49 hectares), and Sudajaya Hilir (108.35 hectares). These variations indicate differences in spatial characteristics and urban development across Sukabumi City.

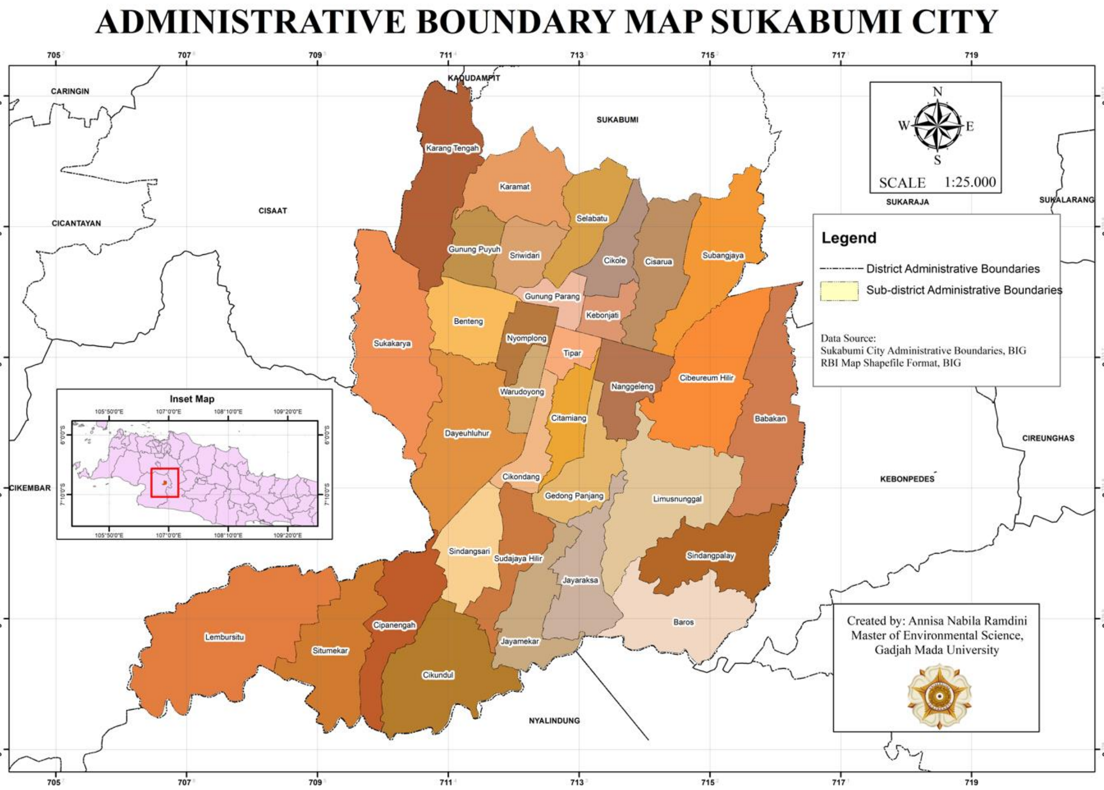

Figure 1. Sukabumi City

Based on the West Java Province Spatial Plan (RTRW) for 2009–2029, Sukabumi City holds a strategic position as a Regional Activity Center (PKW) within the Jabodetabek–Bandung Raya corridor. Moreover, the construction of several mega projects is expected to strengthen

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Sukabumi's strategic role and serve as a catalyst for urbanization and the development of built-up land, thereby contributing to the city's economic growth. The method used in this study is spatial analysis, aimed at analyzing the development of built-up land in Sukabumi City.

This research uses several datasets to analyze built-up land development and flood vulnerability in Sukabumi City. Built-up land use was derived from SPOT satellite imagery obtained from the National Research and Innovation Agency (BRIN). The imagery consists of SPOT-4 and SPOT-6 data for 2007 and 2014, and SPOT-7 data for 2021, all processed to identify and analyze changes in built-up land use over time. Topographic information was obtained from the National Digital Elevation Model (DEMNAS) provided by the Geospatial Information Agency (BIG), which was used to represent elevation and terrain characteristics. Administrative boundary data were also sourced from BIG. Population data were acquired from the Central Bureau of Statistics (BPS) of Sukabumi City. In addition, the Spatial Plan (RTRW) document of Sukabumi City 2021–2041, obtained from the Regional Development Planning Agency (BAPPEDA) of Sukabumi City, was used as supporting data for land-use prediction.

Data processing in this study was conducted using Google Earth Engine (GEE) to analyze the development of built-up land using the Random Forest algorithm for the years 2007, 2014, and 2021. GEE was selected due to its cloud-based computing environment, which enables efficient processing of large volumes of multi-temporal satellite imagery without the need for extensive local computational resources. Moreover, GEE provides access to a wide range of pre-processed geospatial datasets and scalable parallel computing capabilities, allowing rapid data analysis, visualization, and reproducibility in land-use and land-cover studies (Gorelick et al., 2017). The Random Forest Classifier (RFC) algorithm was employed, which uses multiple decision trees trained on subsets of input data and randomly selected variables. This algorithm is widely used in remote sensing applications due to its robustness in handling large datasets, missing values, and noisy data, as well as its ability to reduce overfitting and classification bias.

Built-up land classification was performed using the supervised classification method, which involves intensive analytical interaction to identify image objects (training areas) that represent specific land-cover classes (Danoedoro, 1996). Separating settlement areas, industrial buildings, and other built-up areas allows for more representative training samples in the supervised classification process, thereby minimizing classification bias and uncertainty. The final built-up map was produced by aggregating these detailed classes. The classification of land cover used ROI (Region of Interest) with the built-up land classes categorized as follows:

Table 1. Built-Up Land Classification

No	Built-Up Land Use	Definition
1.	Settlement Area	An area or land used as a living environment or settlement area, including facilities that support daily life activities.
2.	Industrial Buildings	Areas used for factories or industrial facilities, including industrial zones or company premises.
3.	Other Built-Up Areas (Health Facilities, Public Facilities)	Areas where natural or semi-natural land cover has been replaced by artificial, impervious, and relatively permanent surfaces.

Source: SNI 7645:2010 Land Use Classification with Modifications

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This study models projected land-use change in Sukabumi City for 2041 using the Land Change Modeler (TerrSet). The tested scenarios include: (i) an ecological approach, which maintains green open spaces (RTH) in accordance with the 2022–2044 Spatial Plan (RTRW), and (ii) a land-use driving factor approach, which considers the physical characteristics of Sukabumi City and distance-related factors, including proximity to primary collector roads and distance from toll roads. All assumptions rely on the quality and consistency of historical data from 2007, 2014, and 2021 for calibration and long-term prediction.

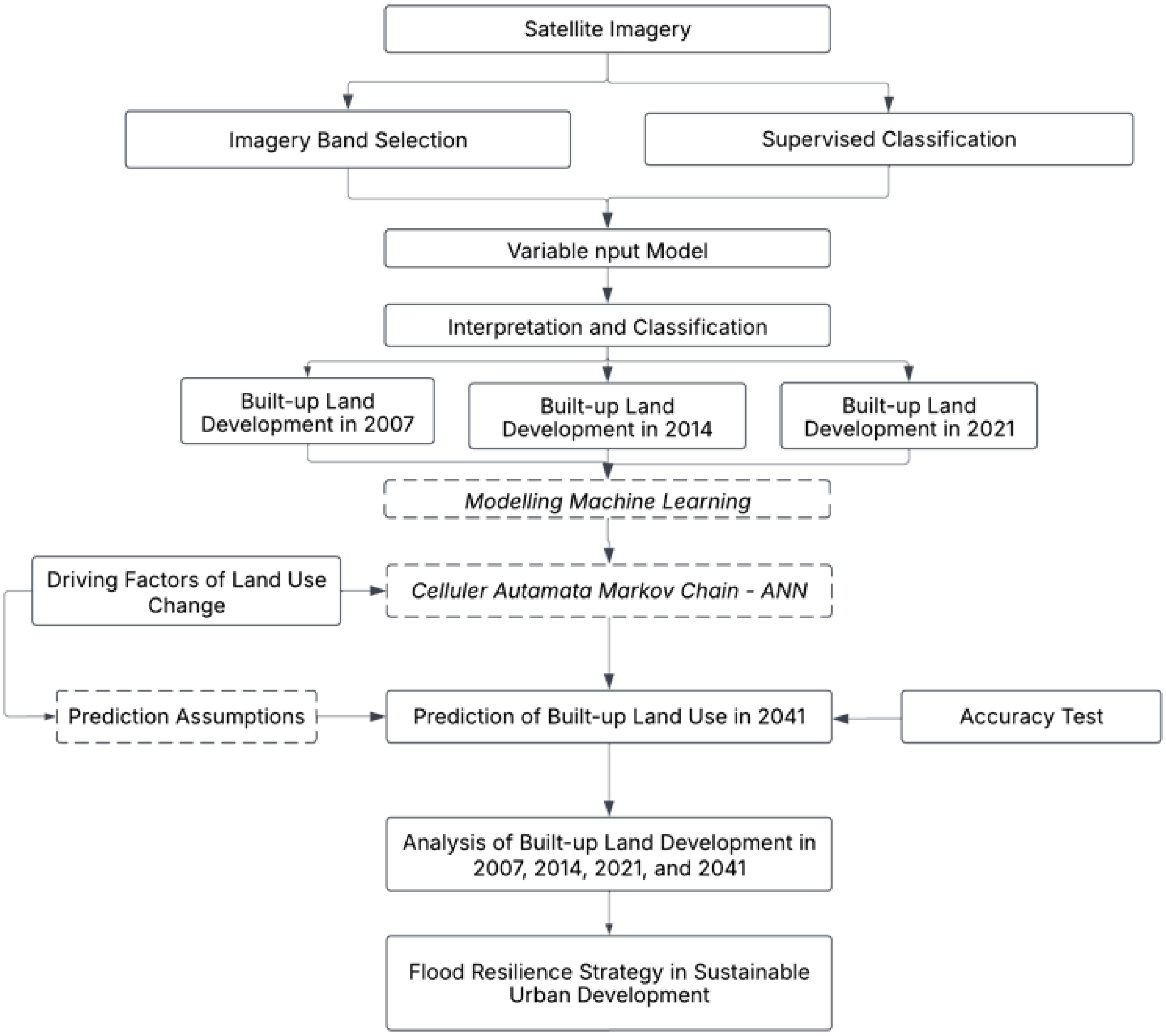


Figure 2. Flowchart Diagram

3. RESULTS AND DISCUSSION

3.1 Built-up Land Use in 2007, 2014, and 2021

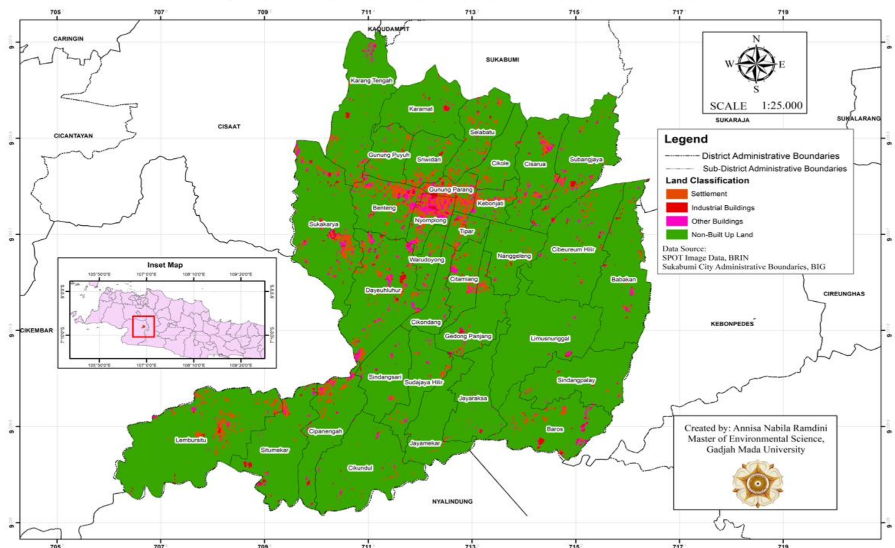
Based on the classification results using the Random Forest algorithm, there were significant changes in the built-up land area in Sukabumi City from 2007 to 2021. This increase indicates a consistent trend of regional development in line with urbanization dynamics and growing human activities. On the Google Earth Engine (GEE) platform, processing was performed in JavaScript using supervised classification techniques. Accuracy testing was performed using the Random Forest (RF) algorithm in GEE. This method works by constructing several decision trees trained from random subsets of data and input variables (image bands) (Gülci et al., 2025). Resulting in accuracy values as presented in **Table 2.**

Table 2. Accuracy Test

Year	Overall Accuracy	Kappa	Classification
2007	0,92	0,80	High
2014	0,83	0,80	High
2021	0,88	0,79	High

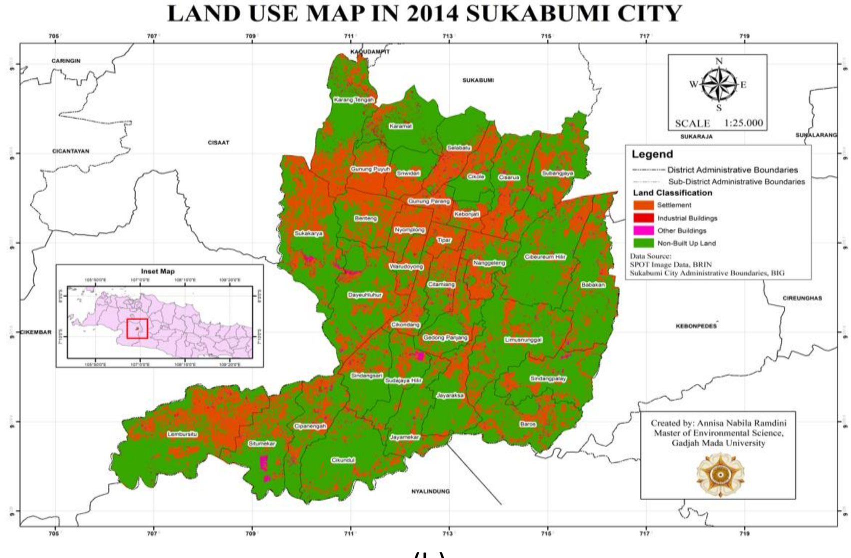
The changes in built-up land area were analyzed spatio-temporally for two periods: 2007–2014 and 2014–2021. The analysis results showed that the growth rate of built-up land tended to increase during the second period, indicating intensified development in urban areas. The distribution of these changes also revealed concentrations in several specific villages/urban neighborhoods, which can be associated with the direction of urban expansion, accessibility, and prevailing spatial planning policies. These findings reinforce the indication that urbanization in Sukabumi City has occurred gradually but consistently, with a tangible impact on spatial structure and land use.

LAND USE MAP IN 2007 SUKABUMI CITY



(a)

LAND USE MAP IN 2014 SUKABUMI CITY



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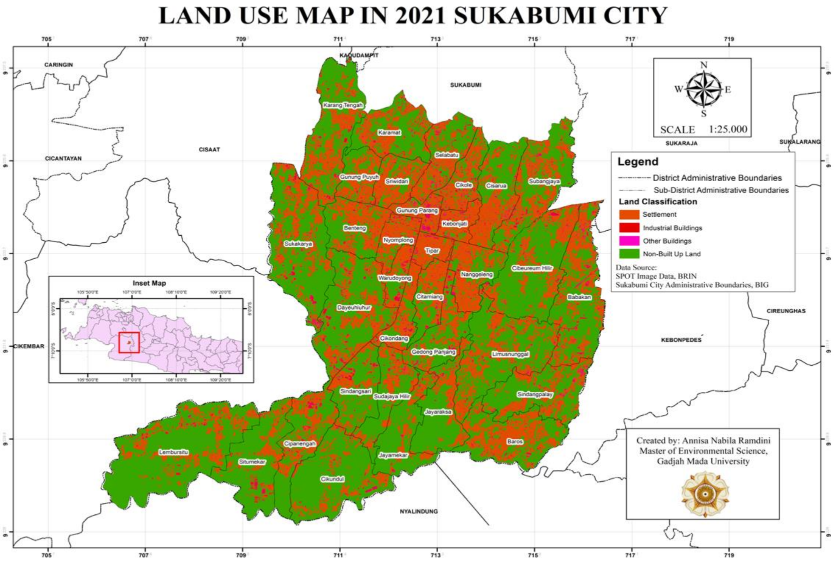

(c)

Figure 3. (a) Land Use Map 2007, (b) Land Use Map 2014, (c) Land Use Map 2021

Table 3. Built-up Land Development

No	Village/ Sub-district	2007 - 2014				2014 - 2021			
		Built-up Land (Ha)			Non-Built-up Land (Ha)	Built-up Land (Ha)			Non-Built-up Land (Ha)
		Settlement (Ha)	Industrial Buildings (Ha)	Other Buildings (Ha)		Settlement (Ha)	Industrial Buildings (Ha)	Other Buildings (Ha)	
1	Baros	42.84	-2.01	-1.72	-39.1	37.44	0.45	0.28	-38.2
2	Cikundul	24.68	-0.32	0.46	-24.83	14.29	1.07	0.16	-15.54
3	Cipanengah	39.88	0.05	0	-39.94	4.68	0.67	-0.17	-5.18
4	Lembursitu	133.26	-0.37	0.5	-133.37	-81.35	0.87	-0.1	80.54
5	Situmekar	48.47	-2.1	3.78	-50.16	-16.17	1.79	-3.94	18.31
6	Babakan	48.84	-0.45	0.6	-32.78	37.8	1.64	3.3	-42.77
7	Benteng	43.07	-1.94	-7.19	-33.94	-6.86	1.03	2.52	3.31
8	Cibeureum Hilir	50.46	-0.08	0.39	-50.78	24.48	0.92	1.5	-26.9
9	Cikondang	37.31	0.08	0.39	-37.8	1.49	0.69	1.19	-3.35
10	Citamiang	28.87	0.06	-0.49	-28.45	3.16	0.57	0.12	-3.85
11	Gunung Puyuh	52.72	0.32	-0.71	-52.34	-17.36	0.09	1.36	15.92
12	Gunung Parang	15.16	-0.54	-2.94	-11.68	-2.68	1.34	3.62	-2.27
13	Kebonjati	18.39	0.94	-1.45	-17.88	11.4	0.18	2.21	-13.78
14	Nanggeleng	51.95	0.04	1.55	-53.53	7.92	0.63	0.69	-9.24
15	Nyomplong	23.2	-2.29	-10.85	-10.05	-1.6	1.24	2.81	-2.45
16	Sriwidari	26	0.1	-0.6	-25.51	14.5	-0.19	1.86	-16.17

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No	Village/ Sub-district	2007 - 2014				2014 - 2021			
		Built-up Land (Ha)			Non-Built-up Land (Ha)	Built-up Land (Ha)			Non-Built-up Land (Ha)
		Settlement (Ha)	Industrial Buildings (Ha)	Other Buildings (Ha)		Settlement (Ha)	Industrial Buildings (Ha)	Other Buildings (Ha)	
17	Sukakarya	98.22	-1.08	-3.57	-93.56	-35.06	0.66	2.11	32.28
18	Tipar	25.38	-0.2	-0.94	-24.24	2.48	0.52	1.6	-4.6
19	Warudoyong	22.41	0.35	-0.55	-22.21	0.75	1.04	1.83	-3.63
20	Cikole	25.97	0.54	1.34	-27.85	19.97	0.6	2.57	-23.15
21	Cisarua	44.2	0.19	-0.76	-43.62	11.95	-0.46	0.5	-12.06
22	Karamat	12.07	3.69	1.04	-16.8	38.52	-3.67	1.58	-36.44
23	Karang Tengah	68.34	1.96	-0.1	-70.18	3.58	-0.82	1.08	-3.87
24	Selabatu	32.64	0.63	1.27	-34.55	14.89	0.06	1.43	-16.38
25	Subangjaya	53.85	-1.6	0.21	-52.47	18.17	1.17	1.29	-20.66
26	Dayeuhluhur	52.74	-2.32	-5.6	-44.82	7.99	1.3	1.51	-10.78
27	Gedong Panjang	33.75	0.11	0.2	-34.05	3.47	0.69	1.08	-5.23
28	Jayamekar	25.49	0.21	1.19	-26.89	3.12	0.31	-0.15	-3.28
29	Jayaraksa	35.63	-0.07	0.02	-35.59	-2.39	0.28	0.47	1.65
30	Limusnunggal	56.17	0.21	1.27	-57.63	32.49	0.6	1.1	-34.19
31	Sindangpalay	31.24	0.2	1.49	-32.93	25.98	0.56	1.45	-27.99
32	Sindangsari	28.59	0.18	0.33	-29.1	5.69	1	0.57	-7.26
33	Sudajaya Hilir	22.3	0	2.15	-24.45	11.06	0.62	-1.51	-10.18
Total		1354.09	-5.51	-19.29	-1313.08	193.8	17.45	35.92	-247.39

Source: Data Analysis (2025)

Based on the land-use change data in Sukabumi City during the 2007–2014 period, residential land increased by 1,354.09 ha, mostly resulting from the conversion of non-built-up areas such as rice fields, plantations, and shrubs. The decrease in non-built-up land by −1,313.08 ha indicates high urbanization pressure, in line with population growth and housing demand. Areas such as Lembursitu, Sukakarya, and Gunungpuyuh became the main expansion points, showing a pattern of urban sprawl toward the southern and western parts of the city, which are flat topographically and have relatively large amounts of available land. However, the industrial and commercial building sectors did not show significant development during this period. Some areas, such as Situmekar and Nyomplong, even experienced minor declines in other building categories, indicating that development remained focused on meeting basic housing needs rather than strengthening the city's economic functions.

Entering the 2014–2021 period, the intensity of land conversion declined significantly. The addition of residential land totaled 193.8 ha, accompanied by increases in industrial areas of 17.45 ha and other buildings of 35.92 ha. This development can be linked to increased activity in the service and transportation sectors post-pandemic, as well as to the push for more

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planned urban infrastructure. Areas such as Babakan, Karamat, and Sindangpalay exhibited more balanced growth between residential zones and economic-supporting facilities. This phenomenon indicates a shift in development orientation from horizontal expansion to spatial consolidation, with land use increasingly directed toward supporting economic and service activities.

These findings align with the theory of built-up land dynamics, which posits that urbanization does not occur linearly but through stages of expansion and consolidation (Liu et al., 2019). In the early stages, development tends to spread into open land, but as land pressure increases and spatial control policies are enforced, development shifts toward optimizing existing built-up areas. Sukabumi City has begun to show characteristics of more intensive development, with increasing spatial efficiency and more complex spatial functions. This development also illustrates urban spatial restructuring, namely the adjustment of land-use patterns in response to changes in economic and social functions at the regional level (Batty, 1976; Lambin and Meyfroidt, 2010).

External factors such as the construction of the Bocimi Toll Road, the National Three Million Houses Program, and the presence of IPB Sukabumi have accelerated the city's spatial transformation. According to interviews with Bappeda Sukabumi City, the Cibeureum and Baros areas have experienced significant land-use conversion, particularly for housing and supporting facilities. The revision of the Sukabumi City Spatial Plan (RTRW) 2022–2042 also accommodates this dynamic through zoning adjustments and the reinforcement of the green open space (RTH) policy to balance development needs.

3.2 Land Use Prediction in 2041

After understanding the pattern of built-up land change from 2007 to 2021, land cover prediction for 2041 was carried out to project the future development of Sukabumi City. The prediction is based on driving factors and land-use change assumptions, such as slope gradient, elevation, distance from roads and rivers, and the presence of green open spaces. The accuracy test results for the Decision Forest model **(Table 3)** showed an Out-of-Bag (OOB) accuracy of 98.89% and an OOB skill of 0.9779. A value close to 1 indicates the model's ability to recognize complex patterns without losing generalizability (Kwon and Zou, 2023). The high accuracy obtained confirms that the selected combination of input variables is relevant and able to represent real-world conditions (Panhalkar and Doye, 2022).

Table 4. Accuracy Test

Number of trees	**100**
Number of variables at split	2
Out of bag (OOB) accuracy	98.89 %
Out of bag (OOB) skill	0,9779
OOB accuracy with all variables	98.89 %
OOB accuracy holding JalanSMI	98.87 %
OOB accuracy holding KetinggianSMI	98.77 %
OOB accuracy holding SungaiSMI	98.86 %

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OOB accuracy holding KLSMI	98.68 %
OOB accuracy holding RTH	98.66 %

Based on **Figure 4**, the development of built-up land that has increased sharply is in residential areas. Land area development increased from 233.66 ha in 2007 to 2132.43 ha in 2041. This indicates that much of the non-built-up land is being converted into new residential areas. Furthermore, non-built-up land shows a downward trend, with an area of 4456.18 ha in 2007 decreasing to 2537.01 ha in 2041. This causes a decline in green ecosystems, habitat fragmentation, and a decline in the ecological function of urban areas, which play an important role in providing ecosystem services, one of which is runoff control (Senes et al., 2025).

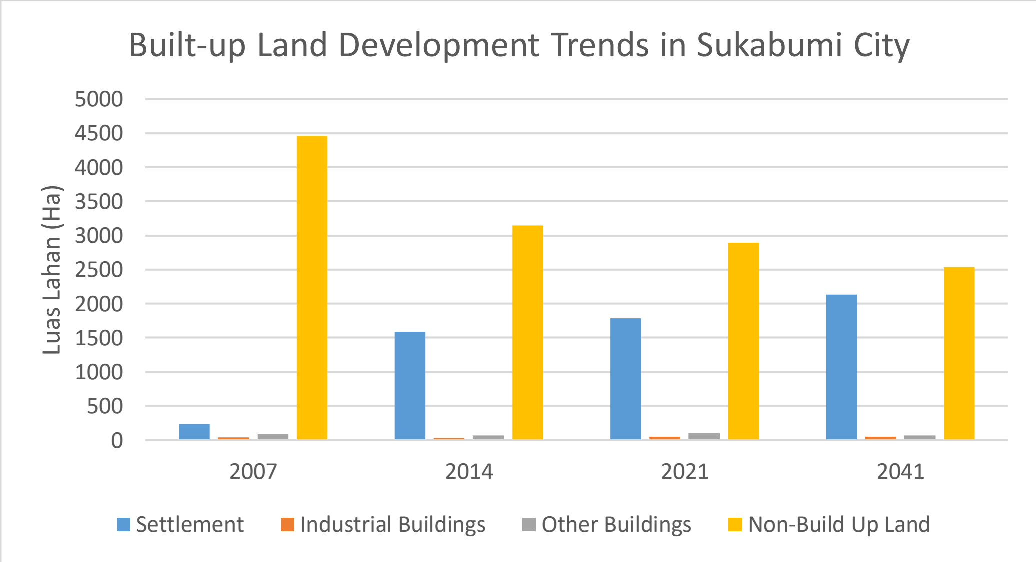

Figure 4. Built-up Land Development Trend

Based on **Figure 5**, the most dominant land use change is the conversion of non-built-up land to built-up residential land. The distribution of residential land development is most dominant in the central region, heading south to the west of Sukabumi City. Residential land development is concentrated in densely populated areas such as Cikole, Warudoyong, and Citamiang Districts. This distribution pattern indicates an increase in development intensity that follows the main road network and is associated with proximity to centers of economic and social activity. This phenomenon indicates urban sprawl around the city center, triggered by limited land in the urban core and high pressure for space in the suburbs (Zhu et al., 2024). Spatial distribution is influenced by the growing population **(Figure 4)**, resulting in increased land fragmentation, changes in urban spatial structure, and the expansion of residential areas. This spatial pattern has the potential to create landscape fragmentation and increase spatial inefficiencies, including longer travel distances between activity centers, uncontrolled land consumption, and pressure on basic infrastructure such as roads (Muhsen et al., 2023).

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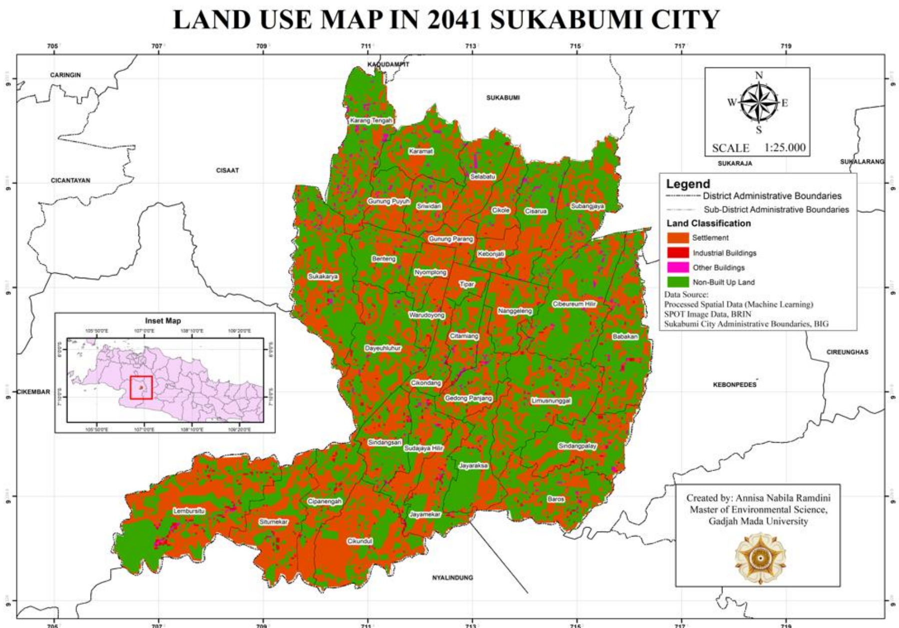

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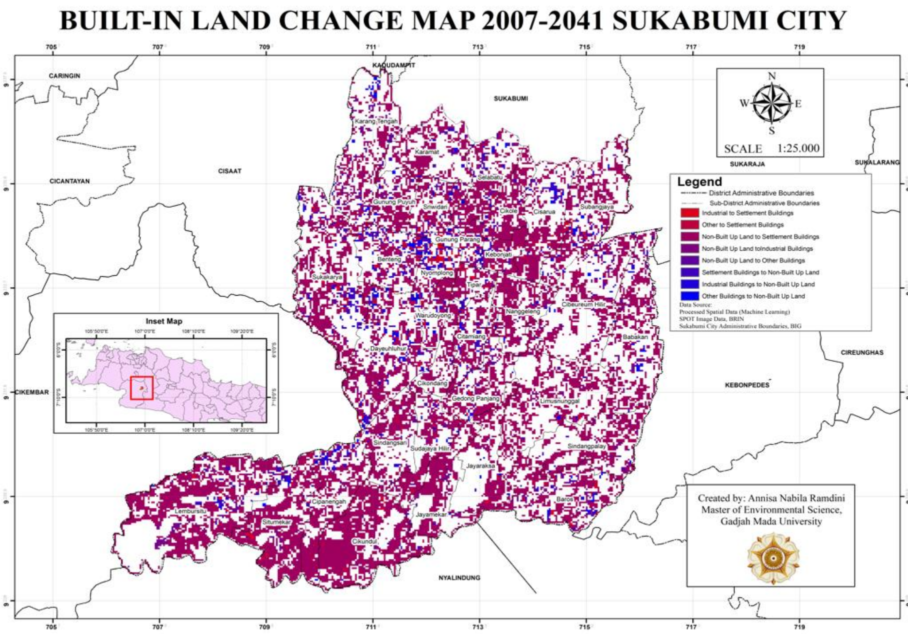

(b)

Figure 5. (a) Land Use Map 2041 (b) Built-in Land Change Map 2007–2041

Based on **Figure 5**, the most dominant land-use change in Sukabumi City is the conversion of non-built-up land into residential areas. The expansion is mainly concentrated in the central, southern, and western parts of the city, particularly in the densely populated Cikole, Warudoyong, and Citamiang Districts. The spatial pattern follows major road networks and economic centers, indicating *urban sprawl* driven by limited land availability in the city core and rising demand for space in suburban areas (Zhu et al., 2024). Furthermore, industrial development is concentrated in the northern areas (Cisarua, Gunungparang, Benteng, Nanggeleng) and the western parts of the city (Lembursitu, Sindangpalay, Cibeureum Hilir, Limusnunggal), which have higher accessibility to major transport networks, including the

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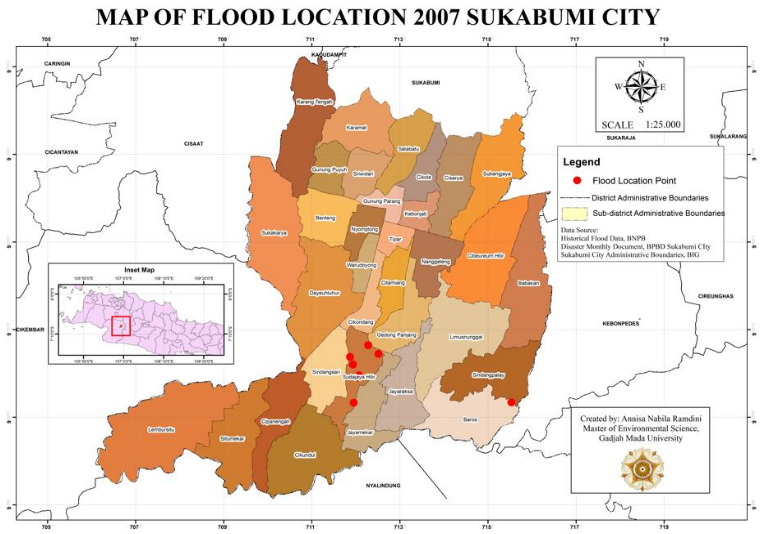
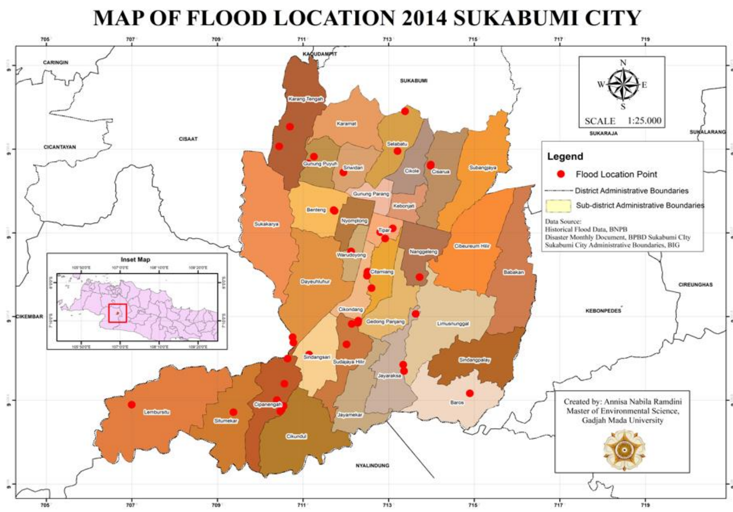
Bocimi Toll Road. This finding aligns with Surya et al. (2021), who stated that areas with high accessibility and low development pressure tend to become focal points of industrial and residential expansion, often accompanied by increasing ecological stress due to massive land conversion. Based on interviews with Bappeda, Sukabumi City is undergoing rapid growth towards becoming a service and residential city, but faces major challenges in maintaining ecological balance and spatial sustainability.

3.3 Built-up Land Sustainability Strategy

The continuous expansion of built-up areas has significantly reduced green open spaces and agricultural lands that function as natural water infiltration zones (Seto et al., 2011). This land conversion disrupts the urban hydrological balance, increasing surface runoff and reducing the capacity for water absorption, thereby intensifying flood risks in low-lying and downstream areas. The trend of flood disasters in Sukabumi City shows a fluctuating but generally increasing pattern over the years (**Figure 6**). According to the Sukabumi City Disaster Management Agency (BPBD), between 2020 and 2024, flood-affected areas have expanded to include the city center, which was previously rarely impacted.



(a)



(b)

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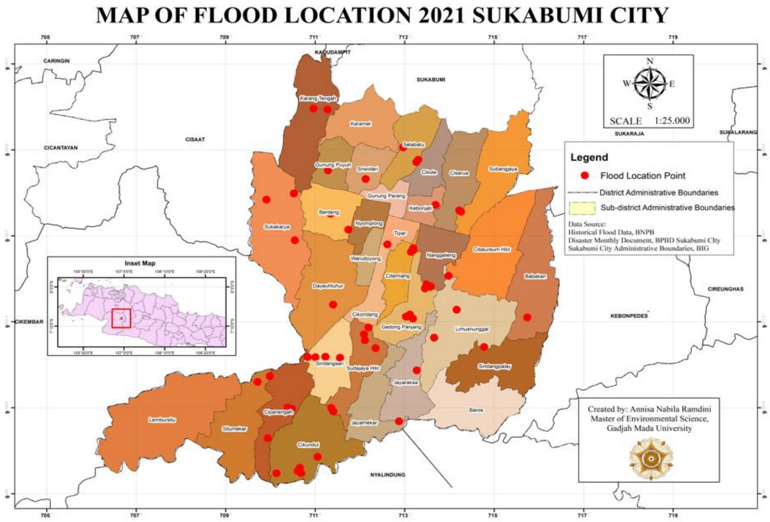

(c)

Figure 6. (a) Map of Flood Location 2007, (b) Map of Flood Location 2014, (c)) Map of Flood Location 2021

The flood resilience strategy through built-up land development is formulated using a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis, based on interviews with Bappeda and BPBD of Sukabumi City. This analysis illustrates the actual condition of built-up land development from 2007 to the 2041 projection and flood history from 2007 to 2021. **Table 5** presents the relationship between internal and external factors affecting spatial management policies and their impact on flood management in Sukabumi City. The SWOT analysis results show that internal strengths and weaknesses reflect institutional capacity and the effectiveness of policy implementation, while external opportunities and threats reflect social, economic, and environmental dynamics that shape the city's development trajectory.

Table 5. SWOT Analysis Matrix

	Strengths (S)	Weakness (W)
	• The Sukabumi City Spatial Plan (RTRW 2022–2042) adjusts built-up land development according to green open space (RTH) policies. • Cross-sectoral collaboration between Bappeda, BPBD, DLH, and DPUPR in disaster-prone area management and synchronization of flood and land-use data.	• The city government, particularly Bappeda, does not yet have an integrated and continuous spatial land-cover monitoring system. • Policy dynamics in spatial changes are still limited by economic pressures and investment demands. • The growth of built-up land

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	• Bappeda implements restrictions on construction permits in green open space zones. • The city, through DPUPR and BPBD, has disaster spatial planning and disaster risk assessment (KRB) documents that guide flood risk mitigation planning.	causes disaster management infrastructure, such as drainage, to lag behind, resulting in recurring floods in the central and southern city areas.
	S-O	**W-O**
Opportunities (O) • Development of the Bocimi Toll Road and improved connectivity can be used to promote disaster-mitigation-based spatial planning. • Bappeda plans to develop a spatial monitoring system in collaboration with universities and research institutions such as IPB. • BPBD conducts public outreach to encourage community participation in river-cleaning and drainage maintenance. • National regulations on controlling agricultural-to-nonagricultural land conversion can strengthen local spatial planning policies.	• Optimize spatial and KRB policies to support mitigation-based spatial planning in line with city development. • Utilize cross-sectoral collaboration to accelerate monitoring system implementation for land and flood development. • Use construction permit restrictions in RTH areas to strengthen regional regulations based on national land conversion control policies.	• Develop a sustainable land-use monitoring system. • Utilize public outreach to enhance education on reducing pressure on green spaces due to construction. • Formulate adaptive spatial policies referring to national agricultural land conversion regulations. • Integrate spatial planning with new infrastructure development to prevent worsening flood risk in densely built-up areas.
	S-T	**W-T**
Threat (T) • Rapid conversion of agricultural land into residential and	Strictly enforce construction permit restrictions in RTH zones to	Improve drainage and flood management infrastructure in line with

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commercial areas, especially in Cibeureum, Baros, and Warudoyong. • National housing and spatial programs may increase residential land development rates. • Rapid urbanization without infrastructure readiness can accelerate development without balanced public facilities.	curb agricultural land conversion. Use KRB and disaster spatial planning documents to anticipate rapid urbanization impacts and prevent construction in flood-prone areas. Strengthen intersectoral coordination to ensure disaster mitigation policies remain effective despite limited local funding. Use RTRW 2022–2042 as the main guideline to balance economic needs with green land conservation.	the city's development rate. Regularly revise spatial policies to anticipate investment pressures and the growth of subsidized housing areas.

The SWOT analysis reveals that Sukabumi City is supported by a relatively strong institutional arrangement and policy framework for flood risk mitigation, particularly through the integration of spatial planning instruments such as the Spatial Plan (RTRW) and disaster risk assessment (KRB), as well as cross-sectoral coordination among local agencies. These strengths provide a solid institutional foundation for incorporating flood risk considerations into spatial planning and guiding urban development toward a more resilient pattern.

However, the analysis also highlights existing constraints, including limited integration of spatial monitoring systems, and increasing pressures from rapid urban expansion and land conversion, which could weaken flood resilience if not adequately addressed. In this context, strategically leveraging available opportunities such as infrastructure development, regulatory strengthening, and public engagement through enhanced policy implementation and predictive spatial planning are crucial to mitigate emerging threats and support flood resilience within a sustainable urban development framework.

4. CONCLUSIONS

The analysis shows a significant increase in built-up land in Sukabumi City from 2007 to 2041. Residential areas expanded dramatically from 233.66 ha to 2,132.43 ha, indicating rapid urban growth and large-scale conversion of non-built-up land into settlements. Industrial areas showed moderate growth, increasing from 36.62 ha to 51.37 ha, reflecting limited economic expansion relative to residential development. Meanwhile, other built-up categories fluctuated, peaking at 105.32 ha in 2021 before declining to 64.81 ha in 2041, suggesting inconsistent use of non-residential built-up areas. Consequently, non-built-up land decreased sharply from 4,456.18 ha in 2007 to 2,537.01 ha in 2041, highlighting a significant loss of natural infiltration zones and green space. The predicted spatial pattern of flood susceptibility up to 2041 highlights the urgent need to enhance urban drainage systems and conserve water catchment areas, particularly in the city center and southern zones, which are highly vulnerable to flooding. Based on the SWOT analysis, these efforts form the foundation for formulating a comprehensive flood resilience strategy that emphasizes an integrated approach to flood resilience, combining regulatory enforcement, infrastructure adaptation, environmental conservation, and participatory governance. Furthermore, the strategy should

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focus on optimizing RTRW and KRB policies, strengthening coordination among Bappeda, DLH, DPUPR, and BPBD, improving drainage infrastructure, enforcing land-use control within RTH zones, and developing a real-time spatial monitoring system. Through these integrated efforts, Sukabumi City can advance toward sustainable and flood resilient urban development by 2041.

5. RECOMMENDATIONS

Based on the findings of this study, it is recommended that the Sukabumi City government strengthen the implementation of spatial planning by maintaining a balance between urban development and the preservation of water infiltration areas. Land-use conversion should be controlled through stricter regulations, monitoring of land use, and the application of green infrastructure concepts in flood-prone urban zones. Future researchers are encouraged to integrate land-use change analysis with hydrological parameters such as rainfall intensity, drainage capacity, and surface runoff dynamics to gain a more comprehensive understanding of the relationship between built-up area expansion and flood risk. Moreover, scenario-based spatial modeling under climate change projections can be employed to anticipate future risks and support data-driven decision-making in sustainable urban planning.

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