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Transformation of the Situ Cikaret Landscape (1901-2025): Spatial Change Analysis Based on Colonial Maps and Satellite Imagery

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Abstract

Urban water bodies such as situ play a crucial role in maintaining hydrological, ecological, and spatial balance in the region, yet their existence is increasingly threatened by urbanization, settlement expansion, and uncontrolled land conversion. Situ Cikaret is one of the water bodies in Bogor Regency experiencing high development pressure amid the growth of the Cibinong area. This study aims to analyze the landscape transformation of Situ Cikaret over the period 1901–2025 using a spatial-historical approach to identify changes in water body area, morphological changes, and surrounding land use dynamics. The research employs descriptive-quantitative methods based on spatial-temporal analysis, integrating 1901 colonial maps, multitemporal Landsat imagery, high-resolution imagery, and Geographic Information Systems. Historical maps were georeferenced using four control points, achieving a Root Mean Square Error of ±2.11 meters. Classification accuracy tests yielded an overall accuracy of 89% and a Kappa coefficient of 86.26%, indicating high data accuracy. The results show that the water body area of Situ Cikaret shrank from 49.97 hectares in 1901 to 21.08 hectares in 2025, a reduction of 57.82%. Additionally, the settlement area increased significantly from 14.78 hectares to 205.61 hectares, accompanied by morphological changes such as narrowing, loss of water body branches, and fragmentation due to landfilling activities. This study concludes that long-term urbanization is the dominant factor in the landscape transformation of Situ Cikaret and underscores the importance of protecting situ buffer zones in sustainable spatial planning.

Keyword: landscape transformation, urban situ, remote sensing, GIS, colonial maps, land use

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change.

INTRODUCTION

Lakes and situ (small artificial lakes) function as critical components within terrestrial hydrological systems, maintaining ecological, hydrological, and spatial equilibrium. These water bodies serve multiple purposes, acting as natural reservoirs, flood mitigation mechanisms, ecosystem buffers, and regulators of microclimates, all of which are essential for urban landscape sustainability. However, anthropogenic pressure often leads to uncontrolled land-use changes, which degrade hydrological functions and diminish ecosystem quality, as observed in the reduction of vegetation cover within the Citarum Watershed (Husodo et al., 2021). In an era characterized by rapid urbanization, terrestrial water bodies are increasingly vulnerable to human-induced pressures, such as land-use transformation, residential expansion, and infrastructure development. These activities contribute to the loss of water surface area and the encroachment of situ buffer zones; for instance, Situ Ciledug has shrunk from 32 hectares to 20.52 hectares due to conversion for housing, commerce, and industrial use (CHOIRIYYAH et al., 2023). Consequently, examining the spatial dynamics of lakes and situ is imperative to understanding landscape transformation driven by the interplay between human activity and natural factors, particularly regarding trends in surface water reduction and land-use shifts in buffer zones (Adi et al., 2022).

Within the urban environment, water landscape transformation is inextricably linked to urban expansion and the shifting structures of land utilization. These cumulative, gradual changes trigger the fragmentation and reduction of urban water bodies, which in turn disrupts hydrological cycles and degrades regional ecosystem functions (Ali et al., 2019). Research in Wuhan, China, highlights how the conversion of lake fringe wetlands and vegetation into built-up areas directly impairs water retention capacity and urban temperature regulation (Maheng et al., 2021). Such findings are vital for analyzing development pressures on urban water systems, where urbanization marked by the proliferation of impermeable surfaces and the loss of vegetation alters natural hydrology, accelerates surface runoff, and lowers water quality via non-point source pollution (Manjunath & Jagadeesh, 2025).

Spatial landscape transformations are influenced by complex interactions between natural dynamics and anthropogenic activity. Studies in the Bohai coastal region demonstrate that ecosystem alteration is driven by a synergy of economic growth, land-use policy, and environmental dynamics (Surya et al., 2023). This holistic perspective is crucial, as urbanization and industrialization frequently trigger land-use conversion that encroaches upon urban green

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spaces, increasing building density and fostering environmental issues such as resource scarcity and pollution (Aryastana et al., 2023). Remote sensing technology has emerged as a robust tool for monitoring and evaluating land-cover and land-use dynamics over the past decade, providing high-resolution, multitemporal satellite data essential for characterizing environmental change (Rakuasa, 2022).

Advances in remote sensing and spatial computing have significantly enhanced the precision and efficiency of environmental change analysis through the integration of multitemporal satellite imagery and Geographic Information Systems to detect land-cover dynamics (Wijaya, 2015). High-resolution remote sensing allows for the accurate detection of spatial variations in water bodies, including boundary shifts in buffer zones and surface area reductions caused by anthropogenic factors (Zhu et al., 2016). Multitemporal satellite imagery, combined with GIS, serves as an essential instrument for monitoring and evaluating spatiotemporal land-cover changes (Latuamury et al., 2016). This multitemporal approach is widely utilized in large scale lake studies; for example, research on Lake Volta demonstrates the effectiveness of such data in identifying land-use trends and water surface fluctuations over specific periods (Ali et al., 2019).

In Indonesia, remote sensing-based studies on lakes, such as Lake Limboto, show that degradation is observable through surface area loss, siltation, and surrounding land-cover shifts (Yao et al., 2022). These studies underscore the necessity of long-term spatial monitoring to comprehend the cumulative and ongoing nature of environmental degradation (Wiggers et al., 2020). While existing literature has extensively examined the spatial transformation of lakes and situ across diverse geographical settings, research that integrates historical colonial maps with contemporary satellite imagery for long-term analysis remains scarce, especially within Indonesian urban areas. Most prior studies rely solely on recent satellite data over brief periods, with few combining colonial cartographic archives and modern imagery to reconstruct century-long lake changes in rapidly urbanizing regions. Colonial maps provide critical spatial data on pre-development landscape conditions, offering strategic insights into the history of regional spatial transformation. In this context, Situ Cikaret was selected as a case study due to its status as an urban water body subject to intense anthropogenic pressure amidst rapid development in the Bogor region, making it an ideal subject for analyzing landscape transformation over a century (Andini et al., 2023). Similar studies indicate that situ in the Jabodetabek area, including Situ Cikaret, often undergo rapid changes in area and depth driven by seasonal and anthropogenic impacts, necessitating diligent oversight of surrounding land use (Ekasari, 2019). Furthermore, Situ Cikaret's location in a high urbanization zone makes it representative for

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studying terrestrial water landscape dynamics in developing urban areas that require sustainable spatial management and routine monitoring (Tranggono, 2021).

Situ Cikaret, recorded in early 20th-century colonial maps, offers a representative case for analyzing the geospatial transformation of urban situ due to urbanization and land-use changes. This study aims to analyze the spatial transformation of the Situ Cikaret landscape over the past century by integrating colonial maps with multitemporal satellite imagery. This methodology facilitates a comprehensive reconstruction of spatial changes—from initial landscape conditions to current dynamics thereby providing a holistic view of the evolution of land-cover patterns and water body boundaries over a long duration. This integrative approach seeks to identify critical periods of change, quantify spatial transformation, and analyze the drivers of Situ Cikaret's geospatial dynamics, particularly concerning land-use modifications and zoning adjustments resulting from urban expansion (Kartikakirana & Neritarani, 2022).

This research employs a combination of quantitative geospatial and thematic historical analysis to reconstruct the spatial evolution of Situ Cikaret, focusing on transformations in area, morphology, and surrounding land-cover patterns (Albulescu et al., 2023). This approach is essential for understanding the progressive impacts of land conversion specifically the transition from natural areas to residential and urban infrastructure on the hydrology and ecology of the water body (Kusumaningrum & Rosyidy, 2024). Satellite imagery and historical maps can be effectively utilized to detect rapid land-use shifts around lakes, such as the conversion into residential areas (Tranggono, 2021), while simultaneously analyzing the development impacts on the aquatic ecosystem. Ultimately, this integration is expected to provide deeper insights into the dynamics of urban situ transformation, providing a scientific foundation for adaptive, sustainable management policies and spatial planning. By comparing multitemporal spatial data, this study has the potential to reveal historical patterns of landscape transformation, which are critical for tracking change phenomena and verifying field conditions (Adi et al., 2022).

METHOD

This study employs a descriptive-quantitative methodology focused on spatial-temporal analysis to investigate the century-long landscape transformation of Situ Cikaret (1901–2025). This framework enables the integration of spatial and longitudinal datasets, facilitating the characterization of patterns, rates, and trajectories of land use and land cover modifications within the lake's buffer zone (Herlawati et al., 2021). The methodology utilizes remote sensing and Geographic Information Systems to synthesize landscape conditions from the 1901 colonial map with those derived from contemporary multitemporal satellite imagery, aligning with

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established practices in urban land change studies that integrate historical and modern spatial records (‘Ulya et al., 2023).

The research utilizes both historical and contemporary spatial datasets to reconstruct the evolution of Situ Cikaret between 1901 and 2025. The foundational dataset comprises the 1901 Situ Cikaret colonial map sourced from oldmapsonline.org which captures pre-intensive urbanization landscape conditions, specifically baseline water body configurations and land use patterns essential for assessing spatial dynamics prior to modern developmental interventions (Pahleviannur, 2019). Complementing this, a time series of high-resolution satellite imagery covering the post-colonial era through 2025 is incorporated. This imagery provides the necessary consistency in long-term temporal records and spatial resolution required to detect LULC change patterns at a regional scale (Cahyono et al., 2021).

To ensure spatial homogeneity across temporal datasets, all data underwent rigorous pre-processing, including georeferencing the colonial map to the national coordinate system, alongside geometric and radiometric correction of the satellite imagery (Sriartha et al., 2019). Establishing geometric alignment between historical maps and modern imagery is imperative to differentiate genuine environmental shifts from projection-induced distortions (Amalia et al., 2024). Georeferencing of the 1901 map was achieved using four Ground Control Points anchored to stable geographic features such as major road intersections, river junctions, and permanent topographical markers discernible in both historical and modern data. These GCPs were strategically distributed across the study area to mitigate geometric distortion and enhance the reliability of spatial transformation assessments (Bayusukmara et al., 2019). The use of only four GCPs was deemed appropriate given the limited feature correspondence between historical and contemporary datasets; relying on a higher density of control points within colonial maps which often possess significant intrinsic distortion risks introducing erroneous spatial artifacts, particularly in areas lacking fine topographical detail (Mazumder et al., 2021).

The precision of the georeferencing process was evaluated using the Root Mean Square Error, calculated as the coordinate discrepancy between control points on the source map and their corresponding reference points on the target imagery (Kartikakirana & Neritarani, 2022). This metric was subsequently assessed to confirm that the spatial accuracy of the referenced historical map adhered to the quality standards required for valid land cover change analysis (Febriani & Ahyuni, 2023). The calculation of the RMSE is expressed by the following equation:

$$RMS = \sqrt{\left(\Sigma_{i=1}^{n} (dx_i^2 + dy_i^2)\right) / n} \quad \text{.....(1)}$$

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Where dx_i and dy_i denote the coordinate disparities between the source and reference maps at each control point, and represents the aggregate number of control points (Medyńska-Gulij et al., 2024). This transformation model is utilized to rectify historical map sheets, thereby establishing a consistent coordinate reference system across all spatial datasets to support subsequent change detection (Sobala et al., 2017). Standardized RMSE thresholds for historical map georeferencing via affine transformation are generally below 5 meters; for instance, thresholds of 1.23–1.51 m have been noted in land change studies (Kratochvílová & Cajthaml, 2024), while values below 4.91 m are common in forest landscape reconstructions (Sobala et al., 2017), collectively ensuring sufficient spatial accuracy to detect land cover modifications without introducing geometric distortion. Furthermore, GCP validation is performed through visual and statistical inspection to confirm geometric integrity prior to interpretation and classification, with a uniform distribution of control points across the study area being critical to mitigate transformation bias (Schlegel, 2023).

The validation of interpretation results is conducted through field surveys and sample point verification to confirm the correspondence between satellite image classification and actual ground conditions (Tyagi et al., 2023). These samples are distributed using a stratified random sampling method to represent every identified land cover class, ensuring that the accuracy assessment objectively reflects the entire study area (Wulansari, 2017). Additionally, an overall accuracy test and Kappa coefficient calculation are performed using a confusion matrix to measure the level of classification agreement beyond random chance, thereby ensuring the reliability of the interpretation (Derajat et al., 2020). A generally accepted benchmark for overall accuracy in satellite-based land cover classification is at least 85%. This value is determined by the ratio of correctly classified samples to total samples multiplied by 100% (Ndofah & Santosa, 2023), with samples obtained via stratified random sampling to represent each land cover class (Rahmani & Sukojo, 2023). Meanwhile, a minimum Kappa coefficient of 0.8 indicates a strong to near-perfect level of agreement, as frequently cited according to the Anderson standard and the Landis & Koch interpretation in various remote sensing studies (Rwanga & Ndambuki, 2017). The Kappa value is defined by the following equation:

$$Kappa = (N \Sigma_{i1} k P_{ii} - \Sigma_{i1} k (P_{i+} P_{+i})) / (N^2 - \Sigma_{i1} k (P_{i+} P_{+i})) \quad (2)$$

where:

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N = total number of samples
k = number of classification classes
P_{ii} = number of correctly classified samples in class i
P_{i+} = total number of rows in class i
P_{+i} = total number of columns in class i

Supplementary field surveys were conducted to acquire current ground-truth data, employing handheld GPS at specific sample points representing dynamic land cover classes. This process served as a final verification of the supervised classification accuracy, mitigating potential interpretation errors stemming from temporal changes in field conditions (Husodo et al., 2021).

The water body extraction method for Situ Cikaret employed an on-screen digitizing approach based on visual interpretation of high resolution imagery. This technique was selected to address the challenges posed by the situ's small and complex morphology, as well as confounding factors such as riparian vegetation, sedimentation, and shadows, which typically diminish the efficacy of automated spectral index-based extraction (e.g., NDWI or MNDWI). For water bodies of this scale within urban environments, manual visual interpretation effectively delineated the boundaries between water surfaces, swamp vegetation, open ground, and built-up areas, avoiding the mixed-pixel limitations inherent in medium-resolution imagery (Kartikakirana & Neritarani, 2022). The extraction workflow involved compiling multitemporal data, integrating the georeferenced 1901 colonial map with contemporary high-resolution imagery for visual validation. Pre-processing procedures included radiometric and geometric correction, area-specific clipping, and projection alignment to the WGS 84 UTM Zone 48S datum to ensure spatial consistency (Sriartha et al., 2019). Visual interpretation subsequently identified water bodies based on spectral and spatial attributes, including low-reflectance tones, distinct textures, concave morphologies, and connectivity with drainage networks.

Manual digitization was executed using ArcGIS or QGIS software, generating boundary polygons directly on the digital display. To minimize interpretation bias across different temporal datasets, a consistent display scale was maintained. Water body boundaries were delineated along the outermost perimeter of permanent inundation observed in the imagery; seasonal swamps, floating vegetation, and muddy margins were excluded unless consistently present across the time series. This rigorous methodology enables a precise reconstruction of morphological evolution and surface area fluctuations, particularly along shorelines susceptible to sedimentation and land conversion (Amalia et al., 2024).

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The scarcity of transitional data between 1901 and the onset of the satellite era necessitated reliance on historical documentation. Significant landscape evolution coincided with the establishment of the Bogor Regency government center, which catalyzed the conversion of open land to urbanized areas. The relocation of the government center to Cibinong in 1976 served as the primary driver for large-scale infrastructure and residential development surrounding Situ Cikaret (Bayusukmara et al., 2019). During the 1976–1990 interval, technological and archival constraints on Landsat imagery availability required that landscape transformation assessments be synthesized from written historical records and governmental infrastructure development archives that precipitated extensive land conversion in Cibinong (Zahrotunisa, 2017).

This era represented a pivotal juncture in regional development, as Cibinong's spatial transformation was orchestrated as part of a national demographic redistribution strategy. Guided by the 1966 Regional Metropolitan Master Plan, Cibinong and Citeureup were designated as emerging growth centers to alleviate demographic pressure on the capital (Pratama & Wasino, 2023). Owing to its high accessibility within the Jakarta–Bogor corridor, Cibinong was classified as a First Order area in the spatial structure, incentivizing substantial growth in industrial and residential sectors (Amanullah & Haryanto, 2017). This progression was codified by Government Regulation Number 6 of 1982, formalizing the transfer of the Bogor Regency government center to Cibinong and cementing its status as a suburban extension of Jakarta (Wilza et al., 2022).

Landscape change analysis utilized a multi-temporal framework, employing spatial overlay and intersect techniques between the 1901 colonial map and the 2025 satellite imagery. This methodology facilitated the quantification of area changes and spatial transformation trends, alongside the computation of an error matrix to assess the uncertainty in land cover change mapping (Adrian et al., 2023). The overall research workflow is illustrated in Figure 1.

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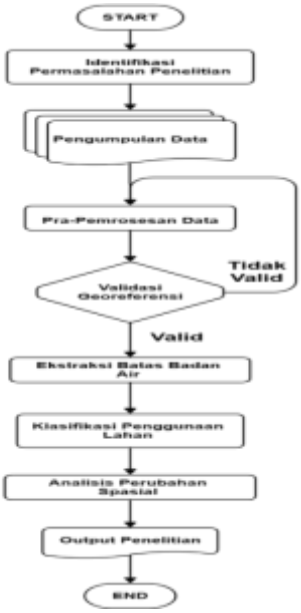


Figure 1. Research Workflow

The workflow diagram summarizes the methodological framework, beginning with historical map and satellite-image acquisition, followed by preprocessing, geospatial analysis, and spatial-validation procedures. The results are presented through thematic maps, water-body area-change tables, and spatial visualizations illustrating the dynamics of landscape transformation in Situ Cikaret. The integration of remote sensing and GIS provides a robust methodological framework for understanding the relationships among spatial change, anthropogenic pressures, and environmental sustainability within the study area (Lasaiba, 2023).

RESULTS AND DISCUSSION

Reconstruction of the Historical Landscape Conditions of Situ Cikaret in 1901

The historical landscape of Situ Cikaret in 1901 was reconstructed via the interpretation of colonial maps georeferenced to a modern coordinate system, as illustrated in Figure 2. This methodology enabled the spatial characterization of the study area prior to the onset of significant urbanization pressures. The historical map underscores a pre-transformation landscape primarily defined by natural elements and agricultural land use, establishing a baseline for evaluating subsequent environmental changes (Lasaiba, 2023).

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Figure 2. Landscape map of Situ Cikaret in 1901

Digitization analysis reveals that the primary water body of Situ Cikaret occupied 49.97 hectares, underscoring its pivotal function within the local hydrological framework of Cibinong. This suggests a significantly higher water retention capacity compared to contemporary conditions, consistent with the minimal anthropogenic pressure prevailing at the beginning of the 20th century. Morphologically, spatial interpretation indicates that the 1901 configuration of the water body exhibited greater complexity than conditions observed in 2025. The main basin featured an elongated southward orientation with natural northern branches, suggesting a seamless integration between the hydrological system and peripheral inundation zones. Furthermore, archival records identify several distinct water bodies within the central region, aggregating approximately 6 hectares, which have since undergone fragmentation due to contemporary land reclamation. These characteristics illustrate an intricate hydrological landscape structure in the colonial era that was largely devoid of significant spatial modification. Detailed attributes of this historical landscape are presented in Table 1 below:

Table 1. Landscape Characteristics of Situ Cikaret in 1901

Variable	Condition in 1901	Interpretation
Water body area	49.97 ha	Result of digitizing a colonial-era map
Morphological shape	Elongated and	Indicates a natural water body

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	branched	configuration
Settlement area (2 km radius)	14.78 ha	Settlements were still limited
Dominant land cover	Agriculture/plantations	The landscape was predominantly agrarian
Road infrastructure	Limited	Urbanization had not yet developed
Anthropogenic pressure	Low	Development-related interventions were still minimal

As illustrated in Table 1, the area surrounding Situ Cikaret in 1901 was predominantly comprised of agricultural lands, plantations, natural vegetation, and open spaces, with riparian vegetation serving as a critical ecological buffer that facilitated hydrological stability through water infiltration, erosion control, and sedimentation mitigation, thereby characterizing the rural landscape prior to extensive urbanization. Settlement development within the buffer radius was confined to 14.78 hectares, exhibiting low intensity and a dispersed pattern along existing local transport routes with minimal infrastructure, ensuring that anthropogenic pressure on the water body remained marginal. Collectively, these features demonstrate a landscape defined by high ecological equilibrium, the dominance of natural elements, and optimal water retention capacity, which establishes a foundational baseline for analyzing spatial transformations between 1901 and 2025.

Georeferencing Accuracy and Spatial Data Validation

Spatial validation is a crucial procedure for ensuring geometric and thematic accuracy when integrating the 1901 colonial map with 2025 satellite imagery, mitigating risks of positional and interpretive deviations arising from the significant temporal gap. This overarching validation protocol commences with the geometric georeferencing of the historical map, utilizing four ground control points anchored to stable landscape features, such as road intersections and river patterns, followed by the application of a first-order affine transformation to minimize linear distortion.

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Figure 3. GCP distribution map

Subsequently, the accuracy of the land cover classification was verified using a confusion matrix and the Kappa coefficient, complemented by a historical validation process based on landmark conformity. The georeferencing outcomes, detailed in Table 2, produced a total residual ranging from 1.777 to 2.400 meters and a Root Mean Square Error of ±2.11 meters, confirming that the geometric accuracy is adequate for assessing landscape transformation within the study's scope.

Table 2. Georeferencing Results of the 1901 Colonial Map.

Number of Point	Residual X (m)	Residual Y (m)	Residual Total (m)
1	-0.888	1.539	1.777
2	1.191	-2.064	2.383
3	-1.200	2.078	2.400
4	0.897	-1.554	1.794
RMS Error			±2.11 m

An RMSE value of ±2.11 m indicates the achievement of sub-pixel geometric accuracy in the correction process, which is adequate for detecting actual land cover changes without significant distortion due to spatial misalignment (Osgouei et al., 2022). Furthermore, land cover classification accuracy was evaluated using a confusion matrix and the Kappa coefficient via stratified random sampling with 55 sample points representing all land cover classes (see Figure

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4), validated against field reference data and visual interpretation of high-resolution imagery (Sabillah & Fardani, 2025).



Figure 4. Distribution Map of Sample Points

The accuracy assessment, conducted with 55 sample points, yielded an overall classification accuracy of 89.09% (49 correctly classified points). This performance exceeds the 85% benchmark generally required for reliable remote sensing classification. The confusion matrix detailing the classification performance on the 2025 imagery is presented in Table 3.

Table 3. Confusion Matrix of Land Cover Classification Accuracy Test on satellite Imagery.

Classified Result	Water Body	Vegetation	Settlement	Open Area	Road	Total Classified
Water Body	10	1	0	0	0	11
Vegetation	0	7	2	0	0	9
Settlement	0	1	16	0	0	17
Road	0	1	0	0	12	13
Open Area	0	0	0	4	1	5
Total Reference	10	10	18	4	13	55

Despite minor misclassifications observed within the vegetation-settlement and open-area-road classes—attributable to similarities in visual and spectral characteristics—the achieved overall accuracy of 89.09% demonstrates high reliability for longitudinal spatial transformation analysis. Furthermore, statistical validation using the Kappa coefficient yielded a value of 0.8626, denoting "almost perfect agreement," which confirms a high degree of

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congruence between classification results and reference data after accounting for chance agreement. The detailed calculation of this Kappa coefficient is presented in Table 4.

Table 4. Kappa Coefficient Calculation for Land Cover Classification.

No.	Class	Total Classified	Total Reference	Coefficient Value
1	Water Body	11	10	0.0364
2	Vegetation	9	10	0.0298
3	Settlement	17	18	0.1012
4	Open Area	5	4	0.0172
5	Road	13	13	0.0215
Total		55	55	0.2059

In addition to geometric and statistical validation, historical validation was conducted through a landmark conformity analysis comparing the 1901 map with 2025 field observations to identify persistent spatial elements and functional transformations over more than a century, as illustrated in Figure 5.

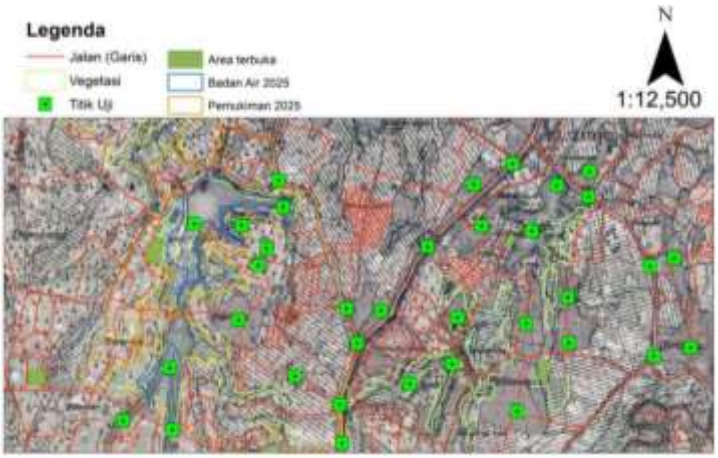


Figure 5. Distribution of landmark conformity validation points.

The findings indicate absolute stability in the road network, the conversion of some water bodies into roads/settlements, and substantial expansion of settlement areas, as detailed in Table 5.

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Table 5. Landmark Conformity Validation of the 1901 Map with 2025 Conditions.

Landmark	Points	Match	Mis match	2025 Condition	Description
Road	10	10	0	Road	Remained unchanged and serves as a stable georeferencing reference
Water Body	9	7	2	Road/Settlement	Part of the water body has undergone land-use conversion
Settlement	16	16	0	Settlement	Experienced expansion of built-up areas

Collectively, the geometric evaluation, classification performance, statistical analysis, and historical verification confirm that the datasets utilized in this study possess the requisite accuracy for analyzing long-term landscape dynamics at Situ Cikaret. This comprehensive, multi-level validation framework substantiates that the observed spatial transformations are indicative of actual phenomena—driven by urbanization and land-use conversion—rather than being artifacts resulting from data processing constraints.

Spatial Transformation of Situ Cikaret 1901–2025

Spatial overlay analysis between the 1901 colonial map and the 2025 satellite imagery reveals a substantial spatial transformation of Situ Cikaret over a period of more than a century. Based on manual delineation (on-screen digitizing), the water body area was recorded at 49.97 hectares in 1901, which shrank to 21.08 hectares in 2025 (see Figure 6), resulting in a reduction of 28.89 hectares or approximately 57.82% from the original condition.



Figure 6. Landscape condition of Situ Cikaret in 2025

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In addition to the contraction in surface area, the morphology of Situ Cikaret in 1901 exhibited an elongated configuration with natural ramifications extending into the northern, central, and southern sectors, signifying robust hydrological connectivity characteristic of an undisturbed lacustrine ecosystem (Osgouei et al., 2022). Comparative overlay analysis with 2025 satellite imagery reveals a substantial simplification of this morphology; anthropogenic encroachment has resulted in the narrowing or total loss of these natural branches, particularly in the northern, southwestern, and central zones, thereby reducing the once-complex lacustrine structure to a fragmented and constrained state. Academic literature corroborates these findings, attributing the degradation of shoreline integrity, the constriction of riparian corridors, and the reclamation-induced loss of shallow water zones to accelerated urban expansion (Sabillah & Fardani, 2025).

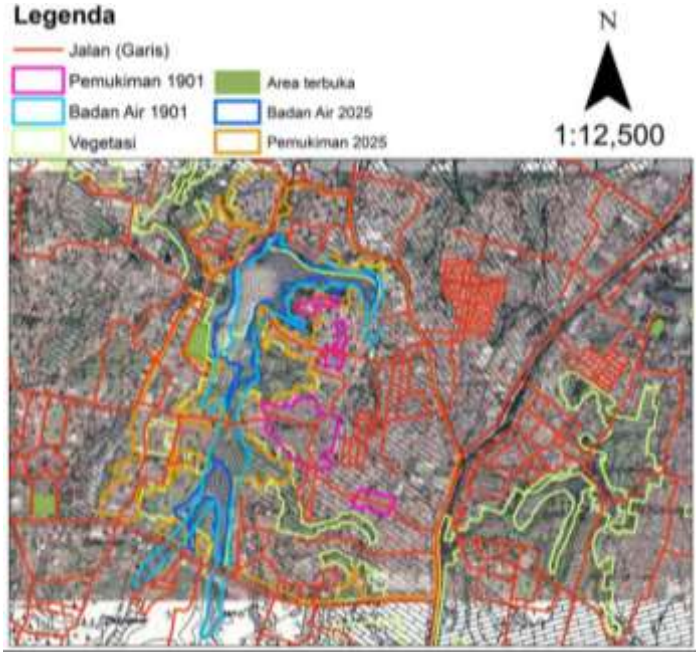


Figure 7. Comparative spatial overlay of Situ Cikaret conditions between 1901 and 2025.

Overlay analysis of the 1901 and 2025 maps further reveals spatial fragmentation within the water body, particularly in the southern and southwestern sectors of Situ Cikaret. Previously interconnected aquatic segments have been severed by land-filling activities, resulting in isolated pools that are no longer integrated with the main water body. This phenomenon signifies that the degradation of the situ encompasses not only horizontal surface area reduction but also a substantial disruption of internal hydrological connectivity. Such morphological

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transformation is primarily driven by anthropogenic pressures—evidenced by the loss of natural ramifications, the constriction of riparian zones, and the fragmentation of the water body—which collectively diminish its ecological and hydrological capacity. Regarding the developmental dynamics of the Cibinong region, the most significant alterations are estimated to have occurred following the 1976 relocation of the Bogor Regency administrative center, an event that catalyzed accelerated infrastructure development, residential expansion, and intensified economic activity surrounding the study area.

Land Use Transitions and Environmental Implications within the Situ Cikaret Landscape

The landscape evolution of Situ Cikaret is further underscored by significant shifts in surrounding land-use patterns throughout the 1901–2025 period. Spatial overlay analysis reveals that, as of 1901, the perimeter of the situ was predominantly characterized by vegetation, open land, wetlands, and low-intensity settlement, reflecting minimal developmental pressure on the aquatic ecosystem during the early 20th century. Historical documentation indicates a landscape dominated by agricultural lands, mixed plantations, castor bean cultivation, and expansive forested savannas, with minimal infrastructural development evident on colonial-era topographic maps of Java. Conversely, the 2025 condition exhibits a sharp landscape contrast, as detailed in Table 6, highlighting a substantial expansion of settlement areas to 205.61 hectares—a net increase of approximately 190.83 hectares. This trajectory reflects extensive urban development, characterized by densified settlements, road networks, and commercial infrastructure, trends that align closely with the regional development of Cibinong as the administrative center of Bogor Regency following its relocation in 1976 (Fajarini et al., 2015).

Table 6. Land Use Changes Around Situ Cikaret 1901–2025.

Variable	1901 (ha)	2025 (ha)	Change (ha)
Water body area	49.97	21.08	-28.89
Settlement area	14.78	205.61	+190.83

The observed shift in land-use patterns signifies an intensive transition from natural landscapes to urbanized environments, effectively displacing ecological buffer zones in favor of high-density settlements and infrastructure. This conversion of hydrological vegetation diminishes soil infiltration capacity, while the proliferation of impervious surfaces curtails water retention and hastens the degradation of aquatic ecosystems. Moreover, the analysis of 2025

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satellite imagery reveals significant fragmentation within Situ Cikaret, attributable to land reclamation activities; previously contiguous water bodies have been severed, resulting in isolated pools spanning approximately 6 hectares. These anthropogenic interventions disrupt the natural hydrological continuum, compromising the water body's functionality in flood attenuation and raw water supply (Supriyadi et al., 2015), as illustrated in Figure 8.

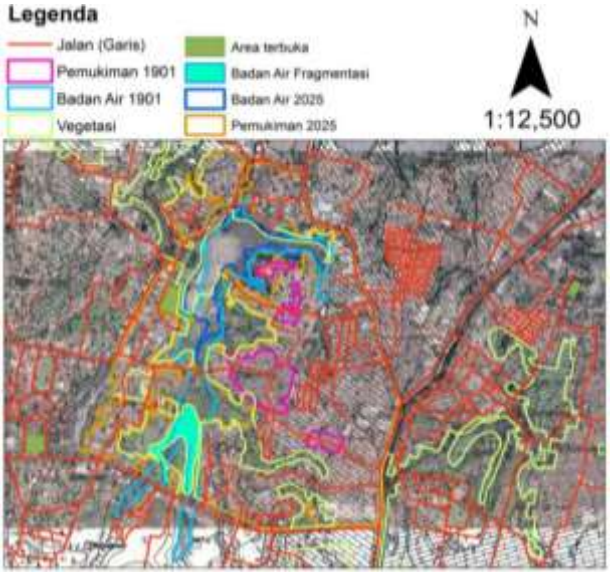


Figure 8. Land Use Change and Water Body Fragmentation Map of Situ Cikaret 1901–2025

The hydrological consequences of this fragmentation extend beyond a mere reduction in surface area. Historically, the morphology of Situ Cikaret in 1901 exhibited an elongated, integrated lacustrine system oriented north-to-south, which facilitated natural flow dynamics and sustained equilibrium among inflow, outflow, and storage capacities. Conversely, overlay analysis from 2025 indicates that the severance of distinct water segments—primarily driven by land reclamation and conversion—has disrupted internal hydrological connectivity. This degradation has diminished water retention capacity and compromised the lake's efficacy in peak discharge attenuation during extreme precipitation events. The contraction of the water body from 49.97 to 21.08 hectares, concomitant with the expansion of settlement areas from 14.78 to 205.61 hectares, highlights the proliferation of impervious surfaces. This land-use shift exacerbates surface runoff and intensifies local flood vulnerability within the Cibinong region. These findings align with prior research (Supriyadi et al., 2015), which documented the decline in Situ Cikaret's surface area and its adverse effects on flood mitigation. This trend is substantiated by empirical evidence of significant flood events: a major inundation on February 27, 2017, following over two hours of heavy precipitation in the Bogor region (Ramdhan et al.,

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2018), and the overflow of Situ Cikaret on April 17, 2024, attributed to high-intensity rainfall. The latter event resulted in the inundation of at least 11 residential properties in Kampung Keramat, Harapan Jaya Village, with flood depths reaching 80–100 cm, as documented in BPBD Bogor Regency reports.

Ecologically, the landscape transformation of Situ Cikaret has precipitated a substantial decline in hydrological capacity, primarily attributed to the reduction of the water surface area, which inherently restricts seasonal rainwater retention volumes. This contraction is exacerbated by the concomitant increase in impervious surface areas resulting from settlement expansion, which intensifies surface runoff, inhibits soil infiltration, and elevates urban flood vulnerability. Furthermore, the fragmentation of the water body—particularly within the southern and southwestern regions due to land reclamation—has severed internal hydrological connectivity, thereby undermining flood attenuation and raw water supply functions. Spatially, the study indicates that the transformation of Situ Cikaret is a consequence of long-term cumulative urbanization dynamics, notably following the 1976 relocation of the Cibinong administrative center. This process, facilitated by infrastructure expansion and insufficient protection of aquatic ecological buffers, has resulted in the attrition of natural branching and the constriction of riparian zones. This morphological transition from a natural, elongated configuration to a narrow, fragmented form has significantly degraded ecological capacity. The conversion of hydrological vegetation into built-up land diminishes water retention, accelerates the degradation of aquatic ecosystems, and compromises the long-term sustainability of the entire urban aquatic environment.

CONCLUSION

This study elucidates the significant landscape transformation of Situ Cikaret between 1901 and 2025, largely driven by progressive and cumulative urbanization. Historical reconstruction, utilizing colonial-era cartography from 1901, reveals that early 20th-century aquatic conditions featured an extensive, elongated morphology characterized by interconnected branches and a natural, vegetated perimeter. These historical conditions indicate that the lake's ecological and hydrological systems were relatively optimal prior to the intensification of anthropogenic development. Integrating historical maps with multi-temporal satellite imagery provided a reliable framework for analyzing long-term landscape dynamics. Following geometric and thematic validation, this approach achieved high precision, with an RMSE of ±2.11 meters, an overall accuracy of 89%, and a Kappa coefficient of 86.26%, confirming the efficacy of combining historical cartography with modern remote sensing techniques.

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Spatiotemporal analysis reveals a substantial contraction in Situ Cikaret's surface water area, which declined from 49.97 hectares in 1901 to 21.08 hectares by 2025, representing a net reduction of 28.89 hectares. This volumetric decline is compounded by significant morphological transformation, characterized by the attrition of natural branching networks, the constriction of riparian zones, and water body fragmentation resulting from land reclamation—subdividing previously continuous water segments into isolated pools. Consequently, this morphological evolution underscores that the degradation of Situ Cikaret extends beyond mere quantitative area loss, manifesting as structural deterioration through fundamental disruptions to its hydrological configuration.

Concurrently, residential areas surrounding Situ Cikaret expanded significantly, from 14.78 hectares in 1901 to 205.61 hectares by 2025. This escalation in built-up land identifies urbanization as the primary catalyst for landscape transformation, particularly following the 1976 relocation of the Cibinong administrative center, which accelerated infrastructure development and settlement growth in the region. In conclusion, this research highlights how the landscape transformation of Situ Cikaret exemplifies the degradation of urban aquatic ecosystems, exacerbated by protracted land conversion and insufficient protection of riparian buffers. These findings emphasize the critical need for prioritized conservation efforts and regulated perimeter development to sustain the lake's ecological and hydrological functions. Furthermore, this study validates the integration of historical cartography with modern satellite imagery as an effective methodological framework for reconstructing long-term landscape dynamics in rapidly urbanizing contexts.

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