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# A Geospatial Analytical Framework for Assessing Land Use and Zoning Compliance: The Case of Zamboanga City

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## Abstract

The Local Government Code of 1991 (RA 7160) mandates Philippine local government units (LGUs) to formulate and implement Comprehensive Land Use Plans (CLUPs) and Zoning Ordinances (ZOs). However, insufficient monitoring frameworks and limited institutional capacity have resulted in widespread land use violations, including the conversion of prime agricultural lands, encroachment into protected areas, and other forms of environmental degradation. To address this gap, this study proposes a geospatial analytical framework that integrates ESRI Land Cover datasets with zoning maps, utilizing Python-based workflows and open-source Geographic Information System (GIS) tools for land use and zoning compliance assessment. Zamboanga City, characterized by a ridge-to-reef landscape and rapid urban expansion, serves as the study area. A compliance matrix was developed to classify land cover–zoning relationships into four categories: Allowed, Allowed Atypical, Conditionally Allowed, and Not Allowed. Analysis revealed that between 2017 and 2023, Not Allowed areas increased by 49.55% (429 ha), and Conditionally Allowed areas by 80.51% (1,588.53 ha), indicating growing encroachment and intensified land utilization in regulated zones. Temporal analysis further identified patterns of zoning compliance, underutilization, and persistent violations, with the overall compliance rate for the city at 85.04%. These findings underscore the moderate adherence to zoning regulations and highlight the urgent need for improved monitoring and enforcement mechanisms. The proposed framework offers a scalable, data-driven tool for spatial policy evaluation and provides valuable insights for evidence-based urban planning and governance in LGUs.

## 1. Introduction

Land use planning is the systematic allocation of land for purposes such as housing, agriculture, industry, the need for livelihood, and environmental conservation, while zoning regulates land uses to avoid conflicts and ensure orderly development (UN-Habitat, 2021). Together, they form the foundation of sustainable urban growth by balancing socio-economic demands with environmental protection. Effective land management fosters equitable resource distribution and prevents degradation. Land use planning and zoning are essential in curbing urban sprawl, protecting ecosystems, and promoting economic sustainability (FAO, 2017). In the Philippines, the proposed National Land Use Act (NLUA) aims to institutionalize an integrated land use framework aligned with the Sustainable Development Goals (SDGs)—notably SDG 11 (sustainable cities), SDG 13 (climate action), and SDG 15 (life on land) (Congress of the Philippines, 2023; United Nations, 2015). Central to this is the use of standardized monitoring tools and technological innovation to improve land governance and resilience.

Under existing laws such as Executive Order No. 72, Memorandum Circular No. 54, and Republic Act No. 11201, agencies like the Department of Human Settlements and Urban Development (DHSUD)—formerly HLURB—are already mandated to monitor land use plan implementation and land use changes. These mandates include the development of systems in coordination with other relevant agencies. Despite these legislative efforts, the Philippines lacks a standardized, technology-based system for monitoring land use changes. This limits the ability of national and local governments to track land development and enforce zoning regulations. This gap highlights the urgent need for innovative methodologies that leverage advancements in geospatial technologies to enhance land use monitoring and compliance.

Zamboanga City serves as an exemplary case for research due to its diverse ridge-to-reef geography and rapid urbanization rate (Barrios-Fabian, 2004). Though the city has integrated GIS into its Comprehensive Land Use Plan (CLUP) and Zoning Ordinance (ZO), monitoring and enforcement still rely heavily on manual, fragmented systems that are costly and inefficient. To address these limitations, this study proposes a geospatial analytical framework for assessing land use and zoning compliance in Zamboanga City. By utilizing GIS and remote sensing, the study aims to enhance monitoring, support evidence-based policymaking, and promote proactive governance.

The main objective of this study is to assess land use and zoning compliance in Zamboanga City using geospatial analysis and land cover data. Specific objectives are to: (1) develop a compliance matrix in mapping the degree of conformity of ESRI land cover classes to zoning categories; (2) generate compliance maps of Zamboanga City from 2017-2023; (3) analyze and assess zoning compliance status changes and; (4) propose actionable recommendations for zoning compliance changes.

# 2. Methodology

## 2.1 Study Area

Zamboanga City, situated in the southwestern Philippines on the Zamboanga Peninsula in Mindanao, is one of the country's largest cities by land area, encompassing approximately 1,414.6 km$^2$. As shown in Figure 1, the city's 2018 General Zoning Map outlines 32 distinct zones—including forest, agricultural, residential, industrial, coastal, and water zones—each defined by specific allowable uses and regulatory guidelines. These zoning designations reflect the city's socio-economic and environmental priorities, emphasizing the need for sustainable and regulated land use.

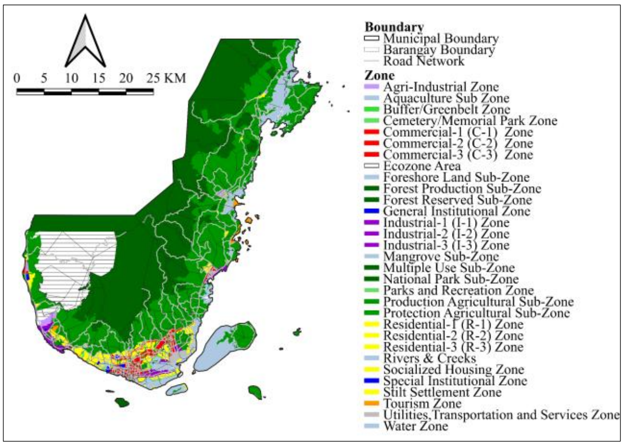


Figure 1. General Zoning Map of Zamboanga City for Planning Period 2016-2025 (Office of the City Planning and Development Coordinator of Zamboanga City, 2019)

## 2.2 Geospatial Analytical Framework

Monitoring land use and zoning compliance is essential for enforcing regulations that guide urban development, prevent environmental degradation, and ensure sustainable growth, ultimately helping to maintain a balance between development and conservation. However, traditional monitoring methods are often inefficient, time-consuming, and ineffective, enabling illegal developments and non-compliant land uses to proliferate. Geographic Information Systems (GIS) and Remote Sensing (RS) technologies offer a transformative solution by streamlining land use planning and monitoring through spatial analysis and data visualization.

Recent advancements in RS and GIS have greatly improved the ability to monitor land cover and detect illegal land use. Mehta, Baz, and Patel (2024), for example, used high-resolution satellite imagery with a deep learning segmentation model to automatically identify non-compliant urban structures with high precision. Likewise, Li and Tan (2020) developed a real-time monitoring system using stereo imagery and tilt-camera arrays to detect unauthorized buildings, significantly reducing enforcement delays. These innovations highlight how automation and spatial intelligence support proactive zoning enforcement.

Cloud-based geospatial platforms and big Earth observation datasets have also made large-scale monitoring more accessible. See, Lesiv, and Schepaschenko (2024) highlighted how platforms like Google Earth Engine and the availability of multi-temporal satellite imagery (e.g., Landsat, Sentinel) allow for the continuous generation of land cover maps and change detection analytics. In a practical application, Valdez et al. (2017) used Landsat time-series and GIS modelling to identify illegal land use conversions in Taiwan's protected areas, providing valuable insights for enforcement and policy planning.

Nazri, Muhamad Ludin, & Abdul Kadir (2012) illustrated the utility of GIS in their Land Use Monitoring System (LUMS), which assessed compliance via two models: (1) a compliance assessment matrix comparing existing and proposed land uses, and (2) an achievement assessment model measuring the area difference between planned and actual uses. However, their model depended on manually defined land uses, lacking integration with physical land characteristics.

While many of these studies focus on detecting land use and land cover changes, they often conflate the two concepts. In contrast, our study explicitly delineates land cover from land use and zoning. We define land cover as the biophysical surface features of the Earth—such as vegetation, water, or built-up areas—derived from remote sensing (Foley et al., 2005), while land use and zoning refer to the planned or regulated allocation of land for specific human purposes, as defined in local ordinances or the Comprehensive Land Use Plan (CLUP). (Housing and Land Use Regulatory Board [HLURB], 2014). This conceptual clarity is crucial when evaluating zoning compliance.

Our study introduces an innovative compliance assessment method that integrates zoning data with land cover (LC) datasets to provide a more accurate and automated evaluation of land use and zoning compliance. By comparing what is physically observed on the ground (via RS-based LC maps) against what is legally designated (zoning), this method leverages the physical characteristics of the landscape to deliver a more comprehensive and reliable compliance assessment.

Figure 2 illustrates the geospatial analytical framework developed in this study, structured into three stages: (1) Overall Landscape Description, (2) Compliance Diagnostics, and (3) Recommended Actions.

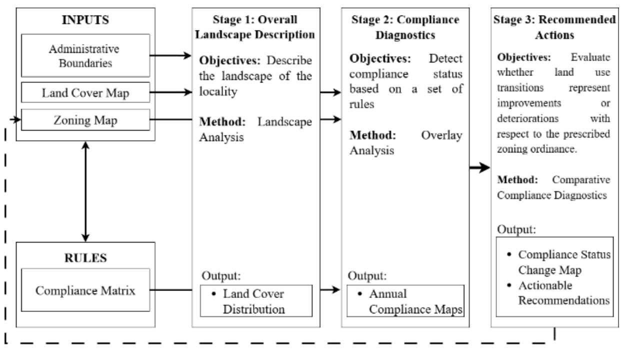


Figure 2. Geospatial Analytical Framework

It integrates four core inputs—administrative boundaries, land cover map, zoning map, and compliance matrix—where the matrix dynamically aligns with land cover and zoning classifications to ensure consistency and interoperability. Stage 1 establishes baseline land cover within administrative units. Stage 2 overlays land cover and zoning maps using the compliance matrix to generate annual compliance maps identifying compliant and non-compliant areas. Stage 3 compares baseline and assessment years to determine whether transitions reflect compliance improvements or violations, producing change maps and policy recommendations. A feedback loop allows assessment results to guide zoning updates, promoting adaptive, evidence-based land use planning. The framework is applied to Zamboanga City.

### 2.3 Geospatial Compliance Assessment Process

This study used Zamboanga City's 2016–2025 Zoning Map and annual ESRI Land Cover (LC) maps from 2017 to 2023. Zoning shapefiles were sourced from the City Planning and Development Office, while LC data—derived from Sentinel-2 imagery and processed via machine learning—were obtained from ESRI's Land Cover Explorer at 10-meter resolution. Spatial pre-processing included correcting zoning topology and masking clouds/snow in the LC data to ensure consistency and accuracy.

Figure 3 illustrates the implementation of the analytical framework using Python and open-source GIS tools. Level 1 performs the compliance diagnostic by intersecting the pre-processed zoning and LC maps and applying a compliance matrix to generate annual compliance maps. The matrix categorizes conformity into four classes—Allowed, Allowed Atypical, Conditionally Allowed, and Not Allowed (defined in Table 1)—based on the relationship between land cover and zoning regulations defined in the city's Zoning Ordinance.

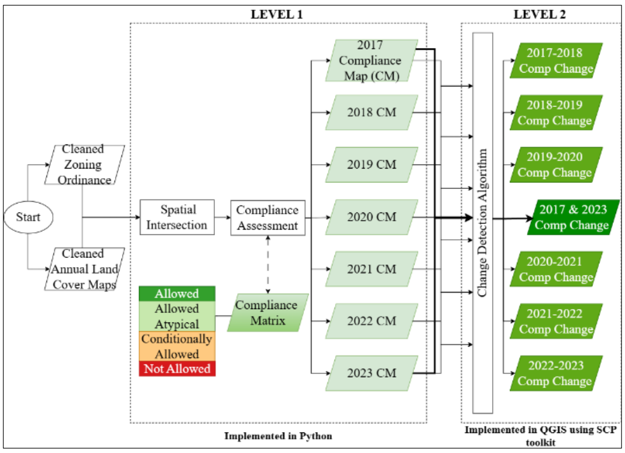

Figure 3. Geospatial Compliance Assessment Process

| Compliance Status | Definition |
|---|---|
| **Allowed (A)** | Areas where the land covers **ALIGNS** with the land use or zoning |
| **Allowed Atypical (AA)** | Areas where the land cover **DIFFERS** from the typical use for the zone but **DO NOT NECESSARILY VIOLATE** the zoning regulations |
| **Conditionally Allowed (CA)** | Areas where the land cover is **ALLOWED** for the land use or zoning but **MUST MEET SPECIFIC REGULATORY REQUIREMENTS** |
| **Not Allowed (NA)** | Areas where the land cover is **PROHIBITED** for the designated land use or zoning |

Table 1. Compliance Status Categories

Level 2 conducts temporal analysis by comparing the baseline and assessment-year compliance maps to produce a zoning compliance status change map. Using the four compliance categories (A, AA, CA, NA), the change detection algorithm identified 16 possible transition types, capturing patterns of sustained compliance, new violations, and evolving land use practices, as summarized in Table 2.

| From \ To | NA | CA | AA | A |
|---|---|---|---|---|
| **NA** | Persistent Non-compliance | Violation to Conditional Use | Violation to Atypical Use | Proper Utilization |
| **CA** | Utilization Violate Regulations | Persistent Conditional Use | Conditional Use to Atypical Use | Proper Utilization |
| **AA** | Utilization Violate Regulations | Conditional Utilization | Underutilization | Proper Utilization |
| **A** | Utilization Violate Regulations | Conditional Utilization | Utilized to Underutilized | Persistent Compliance |

Table 2. Compliance Status Transitions and Indications

## 3. Results and Discussion

### 3.1 Compliance Matrix

The Compliance Matrix was developed to evaluate the alignment between ESRI land cover classes and the zoning regulations defined in Zamboanga City's 2018 Revised Zoning Ordinance and HLURB CLUP Guidebooks. It was formulated through a review of zoning provisions, consultations with planners and policymakers, and an analysis of land cover definitions to ensure clarity and consistency. Each class was assessed for its conformity with permitted uses in each zone, providing a structured basis for spatial compliance analysis. Table 3 shows a subset of the matrix. The full compliance matrix can be accessed here: tinyurl.com/luzc-comp-mat

Land cover classes were grouped into two broad categories: human-induced (e.g., crops, built-up areas, and bare ground) and natural (e.g., trees, water, flooded vegetation, rangeland). These groupings guided the assignment of compliance values: human-induced covers are marked Not Allowed (NA) in strict protection zones but may be Conditionally Allowed (CA) in regulated zones like production forests or agricultural areas. In urban zones, built-up and bare ground are generally Allowed (A), except in zones such as Parks, Utilities, and Tourism, where stricter controls apply. Natural covers are typically classified as Allowed Atypical (AA) in urban zones, though in zones where such vegetation is mandated (e.g., forest protection), they are marked as Allowed (A). This classification provides a consistent, rule-based method for linking land cover to zoning, enabling systematic and spatially explicit compliance assessment.

| Zone/Land Cover | Water | Flooded Vegetation | Trees | Rangeland | Crops | Bare Ground | Built-up |
|---|---|---|---|---|---|---|---|
| Forest Reserve Sub-Zone | AA | AA | A | A | NA | NA | NA |
| National Park Sub-Zone | AA | AA | A | A | NA | NA | NA |
| Military Reservation Sub-Zone | AA | AA | A | A | NA | CA | CA |
| Civil Reservation Sub-Zone | AA | AA | A | A | NA | CA | CA |
| NIPAS: Strict Protection Sub-Zone | AA | AA | A | A | NA | NA | NA |
| NIPAS: Multiple Use Sub-Zone | AA | AA | A | A | A | A | CA |
| Forest Buffer Sub-Zone | AA | AA | A | A | NA | NA | NA |
| Industrial Forest Plantation Sub-Zone | AA | AA | A | A | A | CA | CA |

Table 3. Compliance Matrix Subset

### 3.2 Compliance Maps

Figure 4 illustrates the compliance map for the baseline year 2017. Areas in green indicate full compliance with zoning regulations, while red, orange, and blue areas denote varying


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degrees of non-conformity or conditional compliance based on predefined classification criteria. Gray areas represent cloud cover, which was masked during preprocessing to minimize data distortion and ensure analytical accuracy. The summary of land area (in hectares) by compliance status throughout the study period is presented in Table 4.

|  | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|
| **A** | 125,935.25 | 125,759.44 | 125,553.90 | 125,577.33 | 125,553.73 | 125,443.76 | 125,125.07 |
| **AA** | 18,369.59 | 17,774.79 | 17,159.68 | 17,198.56 | 17,322.23 | 17,542.84 | 17,162.62 |
| **CA** | 1,973.11 | 2,540.45 | 3,335.13 | 3,294.91 | 3,166.99 | 2,975.39 | 3,561.64 |
| **NA** | 865.02 | 1,068.28 | 1,094.26 | 1,072.16 | 1,100.02 | 1,180.98 | 1,293.63 |

Table 4. Compliance Status Area Summary from 2017 to 2023 (in hectares)

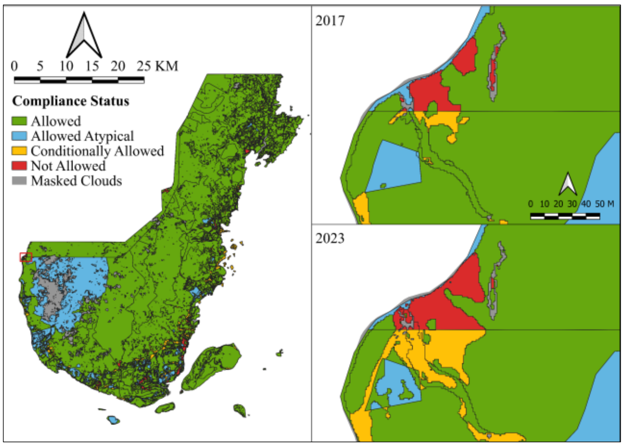


Figure 4. 2017 Zamboanga City Compliance Map

The majority of Zamboanga City's land—approximately 125,000 hectares—remains compliant with zoning regulations and is classified as Allowed, followed by around 17,000 hectares under Allowed Atypical. Although smaller in area, Conditionally Allowed and Not Allowed zones have shown notable increases, signalling emerging challenges in land use management that warrant closer monitoring.

Figure 5 shows a consistent decline in Allowed areas from 2017 to 2023, largely due to urban expansion into zones originally designated for agriculture or forest protection. Allowed Atypical areas exhibited fluctuations, reflecting natural land cover changes—such as tree growth or wetland formation—within zones where such features are not explicitly planned but do not constitute regulatory violations.

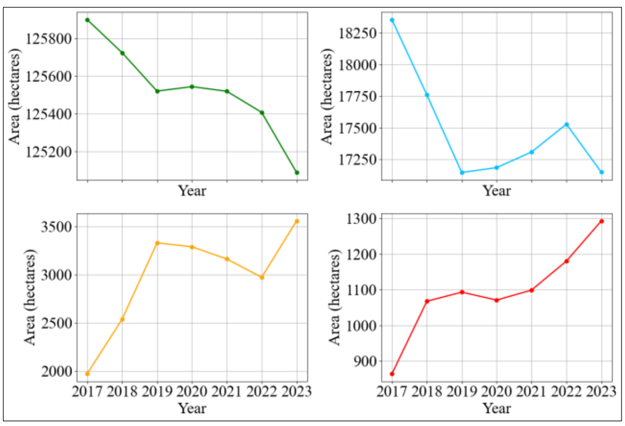


Figure 5. Land Use and Zoning Compliance Trends from 2017 to 2023 (Top-left: A, Top-right: AA, Bottom-left: CA, Bottom-right: NA)

Conditionally Allowed areas increased from 2017 to 2019, followed by year-to-year variability. These are often linked to regulated human activities like farming, infrastructure development, and resource extraction. In contrast, Not Allowed areas showed a steady rise, indicating unauthorized encroachment into protected zones. Although the net increase (~400 hectares) is modest, it represents a significant land conversion that necessitates stricter regulatory enforcement.

While large-scale views of the compliance maps may obscure visible changes, closer inspection reveals notable shifts. Figure 4 illustrates this with red areas in 2017 indicating Not Allowed (NA) built-up developments within a Forest Reserve Sub-Zone. By 2023, these non-compliant areas not only persisted but expanded. This underscores the importance of granular analysis to accurately assess how specific land use activities align with zoning regulations set by the Local Government Unit (LGU).

### 3.3 Assessment of Land Use and Zoning Compliance

Zamboanga City's land use and zoning compliance was assessed by comparing compliance statuses from the baseline year (2017) to 2023. Figure 6 maps the spatial distribution of zoning compliance changes over this period. For example, Figures 6a and 6b show persistent non-compliance and conditional use in Forest Reserve and Protection Agricultural Sub-Zones; Figure 6c highlights underutilization in residential areas; and Figure 6d depicts sustained compliance in Commercial Zones. These transitions are discussed further in this section.

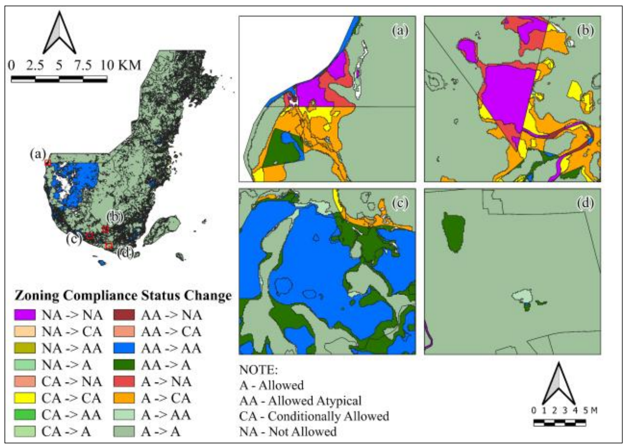


Figure 6. Zoning Compliance Status Change of Zamboanga City Between 2017 and 2023

The compliance status trends discussed in the previous section provides an overview of the compliance landscape in Zamboanga City but do not capture the specific distribution of changes over time. To address this, Sankey diagrams were utilized to effectively visualize these transitions. Figure 7 illustrates the shifts in compliance status across categories: Not Allowed (NA), Conditionally Allowed (CA), Allowed Atypical (AA), and Allowed (A). The width of the flows corresponds to the magnitude of land area transitioning from one compliance status to another, offering a clear visualization of both stability and change over the observation period. Although not immediately apparent due to the scale and absolute value of land area shown in the diagram, the transition from A to NA represents a substantial amount of land area. These diagrams provide a comprehensive overview of the dynamic changes in compliance status and show patterns of compliance improvement, degradation, or persistence.

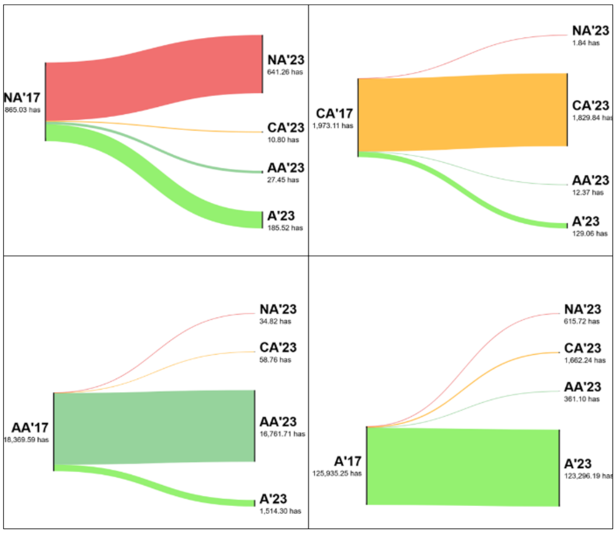

Figure 7. Zoning Compliance Status Transitions

**3.3.1 Transitions to Not Allowed**: The transitions leading to NA reveal significant patterns of non-compliance, encroachment, and degradation of regulated zones.

The NA-to-NA areas denote zones that are persistently non-compliant. The largest occurrences were found in Aquaculture (214.82 ha), Buffer/Greenbelt (117.53 ha), River/Creek (99.23 ha), Mangrove (61.01 ha), National Park (30.76 ha), and Forest Reserve Sub-Zones (17.92 ha). These areas are often affected by informal settlements, unauthorized development, and unpermitted agricultural activities. Barangays such as Mangusu, Pasonanca, Boalan, Manicahan, and Calarian recorded over 35 ha each, indicating widespread and recurring non-compliance driven by socio-economic pressures in protected zones.

The CA-to-NA transition represents a shift where areas have escalated into outright non-compliance due to the intensification of human-induced activities. The most affected zones include Aquaculture Sub-Zones (0.92 ha), Mangrove Sub-Zones (0.70 ha), and Buffer/Greenbelt Zones (0.19 ha), with the highest occurrences detected in the barangays of Mampang, Talabaan, Talon Talon, Zambowood, and Taluksangay.

AA-to-NA transitions illustrate the degradation of areas with natural vegetation—such as regrowing forests or wetlands—that were overtaken by unregulated development and encroachment. This transition was most significant in River/Creek (11.50 ha), Buffer/Greenbelt (9.35 ha), Mangrove (6.19 ha), and Forest Reserve Sub-Zones (1.65 ha). Barangays like Talon Talon, Boalan, Talabaan, Labuan, and Cabaluay experienced the highest impacts, showing the fragility of ecologically recovering areas to renewed human disturbance.

The A-to-NA transition is the most critical, indicating a breakdown of full zoning compliance. Aquaculture (344.87 ha), Mangrove (122.24 ha), Forest Reserve (82.33 ha), National Park (17.83 ha), and Buffer/Greenbelt Zones (14.43 ha) experienced the greatest losses. Notably affected barangays include Cabaluay, Talabaan, Boalan, Latuan, and Curuan, where previously regulated zones gave way to urban expansion, land conversion, and encroachment into protected areas.

Collectively, these transitions emphasize the urgent need for stronger enforcement, targeted interventions, and proactive planning to mitigate ongoing land degradation. Table 4 summarizes the total areas of transitions to NA with actionable recommendations, including cross-referencing with zoning decisions and field validation by local governments.

| Compliance Status Change | Area (has) | Area Percentage | Actionable Recommendations to LGU |
|---|---|---|---|
| NA -> NA | 641.26 | 0.4358% | • Cross-check with LGU's land use decision database<br>• If no record of issuance of Notice of Non-conformance: Issue Notice of Non-conformance<br>• If Notice of Non-conformance had been issued but still non-compliant: enforce zoning restrictions and penalties<br>• Inform the relevant National Government Agency (NGA) that has jurisdiction over the specific type of non-compliance. |
| CA -> NA | 1.84 | 0.0013% | • Conduct site inspection and cross-check with LGU's land use decision database<br>• If proved to be non-compliant: enforce zoning restrictions and penalties<br>• Inform the relevant National Government Agency (NGA) that has jurisdiction over the specific type of non-compliance. |
| AA -> NA | 34.82 | 0.0237% | |
| A -> NA | 615.72 | 0.4185% | |

Table 4. Transition to Not Allowed Summary with Actionable Recommendations

**3.3.2 Transitions to Conditionally Allowed**: These transitions reflect areas experiencing shifts in land utilization that remain within the scope of regulatory monitoring but often edge closer to non-compliance. They highlight human-induced activities occurring in regulated zones, such as farming, resource extraction, or infrastructure development, that must comply with specific conditions.

The NA-to-CA transition represents areas that have shifted from outright non-compliance to being subject to conditional monitoring. This transition was most observed in Aquaculture Sub-Zones (8.05 ha) and Mangrove Sub-Zones (2.17 ha), particularly in the barangays of Tugbungan, Mampang, and Victoria. An example of this transition is the cessation of illicit agricultural activities in Aquaculture Sub-Zones.

CA-to-CA areas reflect sustained, regulated land uses throughout the planning period, primarily in Production Agricultural, Tourism, Utilities, Parks, and Protection Agricultural zones. Concentrated in Dita, Panubigan, Manicahan, Curuan, and Calarian, these areas support ongoing activities such as agriculture, ecotourism, and infrastructure that require continuous oversight.

The AA-to-CA transition indicates a shift from natural to regulated human use, notably in the Utilities/Transportation/Services Zone (54.04 ha). This reflects expanding activities such as farming and infrastructure in Mercedes, Talabaan, San Jose Gusu, Sta. Maria, and Sangali. While signaling increased land use, it underscores the need for oversight to ensure sustainability and distinguish natural changes from human-driven modifications.

Shifting from full compliance to conditional allowance, A-to-CA transitions were most evident in Production Agricultural (1,502.20 ha) and Protection Agricultural Sub-Zones (120.13 ha), especially in Manicahan, Guisao, Patalon, Bolong, and Bunguiao. This trend reflects increasing development in regulated agricultural areas, typically tied to urban expansion or infrastructure that must remain compliant with zoning conditions to prevent future violations.

As a whole, these transitions reflect the dynamic nature of land use in conditionally regulated zones, underscoring the need for proactive monitoring, zoning enforcement, and sustainable practices. Table 5 outlines key CA transitions and recommends database cross-checking and on-site validation by local authorities.

| Compliance Status Change | Area (has) | Area Percentage | Actionable Recommendations to LGU |
|---|---|---|---|
| NA -> CA | 10.80 | 0.0073% | • Conduct site inspection to assess compliance to regulations and/or conditions<br>• Monitor compliance to regulations and/or conditions |
| CA -> CA | 1829.84 | 1.2436% | |
| AA -> CA | 58.76 | 0.0399% | |
| A -> CA | 1662.24 | 1.1297% | |

Table 5. Transition to Conditionally Allowed Summary with Actionable Recommendations

**3.3.3 Transitions to Allowed Atypical**: These transitions reflect land use shifts that deviate from intended zoning but do not constitute violations.

The NA-to-AA transition includes areas showing natural land cover changes or reduced non-compliant activity, suggesting ecological rehabilitation. Notable examples include Aquaculture Sub-Zones (14.53 ha), Mangrove Sub-Zones (5.98 ha), and River/Creek Sub-Zones (4.51 ha), mainly in barangays Mampang, Curuan, and Licomo.

CA-to-AA transitions indicate a shift from conditionally regulated areas to naturally deviating, yet compliant land cover. Found mainly in Utilities, Transportation, and Services Zones (8.71 ha) in Mercedes—particularly around sanitary landfills—these changes suggest reduced human impact and possible ecological recovery. However, they also highlight the need to distinguish between sustainable regeneration and unmanaged land cover shifts.

The AA-to-AA transitions reflect stable, atypical land uses—such as persistent vegetation in agriculture or urban zones—without further deviation. These are concentrated in Reserved Ecozone Areas (11,621.50 ha), Residential-2 (1,016.68 ha), and Industrial Ecozones (796.88 ha), notably in Labuan, Limpapa, La Paz, Patalon, and Pamucutan. While stable, these may signal underutilization or zoning mismatches, warranting further review.

A-to-AA transitions capture natural shifts such as forest or wetland expansion within zones not designated for such cover. These changes—seen in Aquaculture (128.32 ha), Mangrove (61.72 ha), and Residential-1 (26.07 ha) Sub-Zones, especially in Buenavista, Landang Laum, Mercedes, Vitali, and Zambowood—highlight the evolving nature of land cover and potential declines in agricultural use, suggesting the need for policy review and land management adjustment.

Transitions to AA emphasize the importance of distinguishing between natural and anthropogenic changes in zoning assessments. Table 6 summarizes these transitions and provides targeted recommendations for LGUs.

| Compliance Status Change | Area (has) | Area Percentage | Actionable Recommendations to LGU |
|---|---|---|---|
| NA -> AA | 27.45 | 0.0187% | • Ensure continued compliance and monitor changes<br>• Document transition of land use |
| CA -> AA | 12.37 | 0.0084% | |
| AA -> AA | 16,761.71 | 11.3914% | • Propose strategies for utilization of lands in urban, agricultural, and protection forest zones |
| A -> AA | 361.1 | 0.2454% | |

Table 6. Transition to Allowed Atypical Summary with Actionable Recommendations

**3.3.4 Transitions to Allowed**: These transitions reflect areas that fully comply with zoning regulations, indicating stability or improved land utilization.

The NA-to-A transitions signify major compliance improvements, primarily in Forest Reserve (71.14 ha), Aquaculture (63.36 ha), and Mangrove Sub-Zones (30.67 ha), notably in Vitali, Licomo, and Curuan. These gains result from halting illegal activities such as unregulated built-up development and resource extraction, alongside successful reforestation and proper agricultural use.

The CA-to-A transitions reflect compliant land use aligned with zoning regulations. Most occurred in Production Agricultural (98.45 ha) and Forest Production Sub-Zones (17.91 ha), representing either completed developments or areas where revegetation took place—particularly in Licomo, Sibulao, and Manicahan.

The AA-to-A transitions denote progress toward optimal land utilization under zoning regulations. They are concentrated in urban areas such as Commercial-2 (311.66 ha), Residential-2 (292.57 ha), Residential-1 (239.20 ha), Residential-3 (164.38 ha), Industrial-3 (132.90 ha), and Agri-Industrial Zones (97.02 ha). Predominant locations include barangays Talisayan, Boalan, Culianan, Cabaluay, and Patalon. These reflect the


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transformation of idle or atypically used lands into compliant, purpose-aligned developments.

The A-to-A transition denotes consistent adherence to zoning guidelines. Most of these areas fall within Production Agricultural (45,354.08 ha), Forest Reserve (33,392.20 ha), National Park (11,571.38 ha), Forest Production (8,135.94 ha), and Mangrove Sub-Zones (6,086.64 ha), with major concentrations in Dulian (Upper Pasonanca), Vitali, Sibulao, Limpapa, and Bunguiao. These zones collectively represent the bulk of Zamboanga City's land area—totalling 123,296.19 ha.

Overall, these transitions reflect positive trends in zoning compliance, indicating no immediate need for enforcement of zoning penalties. However, monitoring remains essential to ensure that these compliant areas do not regress to non-compliance over time. Table 7 provides a summary of areas that transitioned to A, along with recommended actions for the LGU to maintain and further support compliance.

| Compliance Status Change | Area (has) | Area Percentage | Actionable Recommendations to LGU |
|---|---|---|---|
| NA -> A | 185.52 | 0.1261% | • Document transition to compliant use |
| CA -> A | 129.06 | 0.0877% | |
| AA -> A | 1514.30 | 1.0291% | |
| A -> A | 123,296.19 | 83.7935% | • No action required |

Table 7. Transition to Allowed Summary with Actionable Recommendations

## 4. Conclusion and Recommendations

The compliance matrix proved effective for systematically identifying areas of alignment and deviation from regulatory standards. By categorizing land cover classes based on their compatibility with zoning designations, the framework enabled objective assessments and spatial monitoring of compliance. It highlighted where human-induced activities conflicted with protection zones and where natural vegetation indicated potential underutilization in urban areas. This methodology supports proactive interventions, promotes data-driven land use decisions, and strengthens zoning enforcement and environmental planning practices.

The observed decline in Allowed areas and rise in Not Allowed areas point to growing non-compliance and degradation of regulated zones. These trends—reflected in NA-to-NA, CA-to-NA, AA-to-NA, and A-to-NA transitions—highlight intensifying land use conflicts, particularly in Aquaculture Sub-Zones, Buffer/Greenbelt Zones, and Mangrove Sub-Zones. Informal settlements, unregulated infrastructure, and agricultural expansion have driven these violations, indicating weak enforcement, socio-economic pressures, and insufficient oversight. Immediate action is needed to curb further environmental degradation and encroachment.

Similarly, the increase in Conditionally Allowed areas signals more zones requiring close monitoring, especially where regulated human activities like farming, timber extraction, and infrastructure development occur. This aligns with NA-to-CA, CA-to-CA, AA-to-CA, and A-to-CA transitions, emphasizing the need for sustained regulatory attention. However, the persistence of CA-to-CA transitions may also reflect enforcement stagnation, necessitating periodic reassessment and adaptive regulation.

Conversely, transitions toward Allowed Atypical areas reveal a mix of natural land cover changes and human-driven modifications, as seen in NA-to-AA, CA-to-AA, AA-to-AA, and A-to-AA transitions. While these changes do not constitute violations, they suggest underutilization of land and mismatches between land covers and zoning categories. This highlights the need for a more nuanced approach to zoning assessments, ensuring that deviations align with broader land management goals rather than indicating inefficiencies in land utilization.

The positive compliance trends leading to Allowed areas demonstrate successful land use management and restoration efforts, particularly in NA-to-A, CA-to-A, AA-to-A, and A-to-A transitions. These shifts indicate effective enforcement, reforestation initiatives, and improved adherence to zoning regulations, particularly in Forest Reserve Sub-Zones, Agricultural Zones, and Urban Areas. While these areas do not require immediate intervention, continued documentation and monitoring remain crucial to ensuring their long-term stability and preventing regression into non-compliance.

These dynamic changes in zoning underscores the importance of a proactive, adaptive, and data-driven approach to land use planning and monitoring. The increasing trends in non-compliance and conditional regulation highlight the urgency of enhancing enforcement mechanisms, strengthening monitoring systems through geospatial technologies, and refining zoning policies to address emerging land use challenges.

The geospatial compliance assessment highlights both promising and concerning trends in Zamboanga City's land use practices between 2017 and 2023. While overall compliance remains relatively high at 85.04%, the slight decline from 85.59% in 2017, coupled with the increase in Conditionally Allowed and Not Allowed areas, signals emerging pressures on the city's long term land management plans. The doubling of Conditionally Allowed areas (+1,588.53 ha) and the 49.55% increase in Not Allowed zones (+428.61 ha) suggest a shifting landscape characterized by expanding regulated development and growing non-compliance.

Though Not Allowed and Conditionally Allowed areas comprise relatively small percentages, they represent substantial amounts of land area with 1,293.63 hectares and 3,561.64 hectares, respectively. These areas pose significant implications for zoning enforcement, environmental integrity, and development control. Their spatial distribution suggests the need for targeted monitoring and intervention, particularly in ecologically sensitive and rapidly urbanizing zones.

Despite the utility and effectiveness of the compliance matrix in identifying alignment and deviations from zoning regulations, several limitations must be acknowledged. A primary constraint lies in the accuracy of the land cover data used. ESRI's Land Cover datasets, while offering a minimum reported accuracy of 85%, may still introduce discrepancies that necessitate further validation on the ground. Moreover, the dataset's limited classification—only nine general land cover categories, with two irrelevant to the study area—reduces the specificity of features critical to zoning assessments. For instance, mangroves and fishponds are broadly categorized under "Flooded Vegetation," limiting the matrix's ability to distinguish between ecologically distinct and policy-sensitive areas.

To address these limitations, future compliance assessments should incorporate higher-resolution land cover datasets with


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more granular classifications, such as distinguishing residential from non-residential built-up areas. Ground validation and field inspections should also be integrated into the assessment process to confirm and refine spatial analysis results. Additionally, reconciling the compliance matrix outputs with the LGU's land use decision database can help verify whether some Conditionally Allowed or Not Allowed areas were, in fact, granted exceptions, thus potentially improving the actual measured compliance rate. Finally, linking compliance results with tax mapping data could enable parcel-level assessments, offering local governments more granular and actionable insights for planning, monitoring, and enforcement.

Institutionalizing the compliance matrix as part of Zamboanga City's official land use monitoring framework—through a local ordinance and integration into CLUP implementation mechanisms—would ensure its continued use and policy relevance. This system can guide both enforcement and planning decisions based on regularly updated spatial data.

Equally important is the capacity-building of local planning staff. Training local government personnel in geospatial tools, data interpretation, and evidence-based decision-making will enable autonomous, informed, and proactive land use management. These skills are essential for sustaining a responsive and adaptive planning process.

The long-term success of land use governance in Zamboanga City is anchored on the LGU's ability to leverage geospatial technologies, strengthen policy enforcement, and institutionalize adaptive planning mechanisms. By implementing these recommendations, the city can enhance its zoning compliance, support sustainable development, and serve as a replicable model for other local government units in the Philippines.

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