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A Spatial Analysis of Agricultural Land Loss Across the Urban–Rural Gradient: Applying DEGURBA in Butuan City, Philippines (2010–2020)

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ABSTRACT

Urban expansion is a major driver of agricultural land loss in rapidly developing cities. In the Philippines, urbanization is accelerating not only in metropolitan centers but also in secondary and intermediate cities, contributing to the conversion of productive agricultural land. Traditional urban–rural classifications based on administrative boundaries are often inadequate for capturing the complex, fragmented, and transitional nature of urban growth. This study addresses this limitation through a decadal (2010–2020) spatial analysis of agricultural land cover change, using Butuan City, Philippines, as an illustrative case within the Degree of Urbanisation (DEGURBA) framework. Leveraging government-produced land cover maps derived from satellite remote sensing and implementing a dasymetric DEGURBA approach based on Google Open Buildings and barangay-level census data, agricultural land change across urban centers, urban clusters, and rural areas was quantified and analyzed. Results show a total loss of approximately 49.8 km² (9.6%) of agricultural land over the decade, with the most pronounced losses occurring in urban clusters—transitional zones where high shares of remaining cropland coincide with rapid outward urban expansion. These findings highlight the relevance of urban clusters as priority areas for land-use monitoring and informed planning. While rural areas retained most of the agricultural land, they also showed signs of encroachment along expanding urban fringes. The case of Butuan City illustrates how combining standardized urban–rural typologies with fine-resolution geospatial data enables more consistent assessments of land-use transitions. This integrative framework can be applied globally to enhance monitoring of agricultural land dynamics and to support evidence-based strategies for sustainable urban and regional planning.

Keywords: *Agricultural Land Cover Change, Barangay Census Data, Dasymetric Mapping, Degree of Urbanisation (DEGURBA), Google Open Buildings, Urban-Rural Gradient, Urbanization.*

1 Introduction

Urban expansion is widely recognized as a key driver of land-use change, particularly in developing countries, where rapid urban growth often leads to the conversion of high-value agricultural land (Huang et al. 2020, Seto et al. 2012). In Southeast Asia, urbanization and population concentration in peri-urban areas have significantly disrupted traditional land-use systems (Tacoli 2003, Webster, 2002). These transitional zones, located between urban and rural areas, are particularly susceptible to agricultural land conversion, as elevated land values and development incentives lead to shifts toward residential and commercial uses (Custodio & Sombilla 2025).

In the Philippines, urbanization is intensifying not only in major metropolitan areas but also in secondary and intermediate cities (Ortega et al. 2015, Santillan & Heipke 2024). This accelerating urban expansion, often manifesting as urban sprawl, has led to the progressive loss of agricultural lands, the fragmentation of contiguous farmland, and the widespread conversion of these areas for residential, commercial, and other urban uses (Bravo 2017, Malaque & Yokohari 2007, Murakami & Palijon 2005). Recent national-scale analysis using satellite remote sensing data confirms that such agricultural land conversions to built-up areas have been widespread across the Philippines from 2000 to 2020, including within legally protected prime agricultural zones, highlighting persistent spatial and governance challenges (Araza et al., 2026). Recent evidence suggests that these challenges are further complicated by the uneven progress of institutional reforms and land-use policies, which have failed to stabilize agricultural productivity in many regions (Custodio & Sombilla, 2025). Butuan City, in northeastern Mindanao, exemplified this trend, undergoing land transformation amid national trends in decentralization and spatial expansion. Earlier studies have documented a significant increase in the spatial extent of built-up areas and other land cover changes in this city through the combined use of satellite remote sensing and geospatial analysis (Asube et al. 2021, Bentozal et al. 2024, Cacayan et al. 2022, Cloma & Asube 2020). One such study (Bentozal et al. 2024) documented the ongoing conversion of rice croplands and identified areas highly susceptible to future urban encroachment. While offering valuable insights into the characteristics and spatial distribution of vulnerable croplands, the study did not employ a standardized framework to classify and compare agricultural land transitions across the city's urban, peri-urban, and rural zones.

Urban–rural classification in the Philippines is traditionally based on barangay-level designations, where each barangay (the smallest administrative unit) is officially categorized as either urban or rural. This classification is based on criteria such as population size, the predominance of non-agricultural employment, and the presence of infrastructure and basic services (PSA, 2013). While this binary system serves administrative and statistical functions, it may fail to accurately reflect the complex, gradual transitions occurring in areas undergoing urban expansion. For instance, some barangays officially classified as rural may already exhibit urban characteristics, such as dense housing or commercial activity. In contrast, others categorized as urban may still include significant agricultural or undeveloped land. Moreover, because barangays vary widely in size and spatial configuration, treating them as the basic unit for urban–rural classification introduces inconsistencies into spatial analysis. Some barangays encompass large, heterogeneous areas that include both densely built-up and predominantly agricultural zones, while others may be small but highly urbanized. This spatial variability, combined with the binary urban–rural designation, limits the ability to map and analyze land-use/land-cover changes with sufficient geometric detail. As with other classification systems based solely on administrative boundaries, this approach fails to capture the full range of differences between areas, particularly those undergoing transition (van Eupen et al. 2012). As a result, such an approach is often inadequate for capturing the complex, fragmented, and transitional nature of urban growth, particularly in peri-urban areas where land use patterns shift rapidly and irregularly.

To better reflect these dynamics, a shift in perspective is necessary, one that moves beyond dichotomous labels and acknowledges the fluidity of land use patterns along the urban–rural continuum. Treating urban and rural areas as strictly separate entities does not reflect the complexity of real-world landscapes. Instead, these areas should be viewed as part of a continuum, with land characterized along a gradient from rural to urban, where mixed land uses often coexist (van Vliet et al. 2020). Recognizing this, several studies have highlighted the value of finer-resolution urban–rural typologies, particularly gridded approaches, for supporting spatial planning and land change assessments in the urban-rural continuum. For example, Franconi et al. (2024) used population density and land cover data to characterize communities along the urban-rural gradient, thereby capturing the relationships among human communities, their activities, and the environment.

Meanwhile, Eupen et al. (2012) introduced a rural typology in Europe that leveraged high-resolution raster data on geography, population density, and accessibility to capture regional diversity in rurality. This approach enabled the consistent identification of comparable rural areas and their transitions with urban zones, providing a spatially explicit framework for both scientific analysis and policy communication. In a similar effort to represent the urban–rural continuum, Dijkstra et al. (2021) introduced the Degree of Urbanisation (DEGURBA), a harmonized classification method developed by international organizations and endorsed by the UN Statistical Commission to support global comparisons. DEGURBA categorizes areas into urban centres (cities), urban clusters (towns), and rural areas by grouping contiguous grid cells that meet specific thresholds for population density and total population size (European Commission & Statistical Office of the European Union 2021, Van Migerode et al. 2024). The DEGURBA method has been utilized as a primary method for urban-rural delineations to support the analysis of land use change (Gibas & Majorek 2020), land use efficiency (Melchiorri et al. 2019, Schiavina et al. 2022), and population ageing (Klimanek & Filas-Przybył 2019), among others. These works emphasize the importance of moving beyond administrative boundaries tto understand better the complex dynamics of urban transformation and its effects on land resources, particularly agriculture.

Within the Philippine context, however, such approaches remain limited. Most urban growth and land conversion studies still rely on administrative boundaries as the unit of analysis (Araza et al. 2026, Bravo 2017, Murakami & Palijon 2005, Olfato-Parojinog et al. 2023, Santillan & Heipke 2024). Although satellite remote sensing data and techniques have been employed for land cover mapping and change detection, particularly to assess impacts on agriculture (Araza et al. 2026, Fargas Jr. et al. 2021, Malaque & Yokohari, 2007), these are rarely combined with urban–rural classifications to provide comparative analyses across different zones. Moreover, the integration of frameworks such as DEGURBA remains scarce in the national literature, despite its growing adoption in international urban studies. There is thus a critical gap in applying harmonized, globally recognized methods to contextualize and analyze agricultural land change in the Philippines' dynamic urban and peri-urban environments.

Global gridded datasets have emerged to provide more spatially detailed representations of the urban–rural continuum. For example, the Global Human Settlement Layer (GHSL) includes products such as the GHS Settlement Model Grid (GHS-SMOD) (Schiavina et al., 2023) and the GHS Urban Center Database (GHS-UCDB) (European Commission et al. 2024), which offer globally standardized urban–rural typologies using the DEGURBA methodology. These datasets enable spatial comparisons and analyses across different regions; however, their applicability at local scales is often limited. This limitation is primarily due to discrepancies between modeled and actual population distributions, generalization of built-up extents, and the lack of alignment with official administrative boundaries. Consequently, these global products may not fully reflect ground realities in cities like Butuan. Moreover, aside from GHSL, few efforts in the Philippines have combined barangay-level population data with detailed building footprints to classify urban and rural areas and map human presence. This gap limits our ability to analyze urbanization processes and land-use transitions at the spatial detail necessary for effective local planning and land management.

This study addresses these limitations by examining the relationship between the degree of urbanization and agricultural land cover change through a spatial typology grounded in the DEGURBA classification. Using Butuan City, Philippines, as a case study area, the analysis applies this framework in combination with official land cover maps produced by the National Mapping and Resource Information Authority (NAMRIA) for 2010 and 2020 to provide a structured assessment of where and how agricultural land conversion has occurred, as well as its implications. In doing so, the study represents one of the first applications of the DEGURBA framework in the Philippine context to systematically analyze agricultural land cover change along the urban–rural gradient, introducing a standardized, grid-based approach that complements existing administrative-boundary-based analyses.

To guide the analysis, this study aims to answer the following research questions:

- How does the distribution of agricultural land vary across DEGURBA-defined urban centers, urban clusters, and rural zones in Butuan City?
- What are the patterns and magnitudes of agricultural land cover change from 2010 to 2020 in these zones?
- How can the DEGURBA be used to anticipate areas of potential agricultural land loss?
- What are the implications of these spatially differentiated agricultural land conversion

patterns for land-use planning, agricultural land management, and food security in an urbanizing city such as Butuan?

The remainder of the paper is structured as follows. Section 2 describes the study area, data sources, and methodological framework, including the dasymetric population mapping and the implementation of the DEGURBA classification. Section 3 presents the results of the agricultural land cover analysis across urban centers, urban clusters, and rural areas, with emphasis on spatial patterns and land cover transitions between 2010 and 2020. Section 4 discusses these findings in relation to urban expansion and agricultural land conversion, their implications for land-use planning and food security, and outlines key limitations and directions for future research. Finally, Section 5 summarizes the main conclusions and highlights the broader relevance of the proposed framework for analyzing agricultural land dynamics in urbanizing cities.

2 Materials and Methods

2.1 Study Area

Butuan City (Figure 1) is a highly urbanized city located in the northeastern part of Mindanao, Philippines. Serving as the regional center of Caraga Region (Region XIII), it occupies a total land area of approximately 817 square kilometers and comprises 86 barangays (CGB 2022). The city lies within the lower Agusan River Basin and is traversed by the Agusan River, the third longest river in the Philippines. Its terrain includes riverine plains, lowland agricultural zones, and upland forested areas. Strategically situated at the intersection of several major road networks, Butuan functions as a commercial and administrative hub in northeastern Mindanao. It plays a significant role in trade, education, and government services in the region. According to the 2020 Census by the Philippine Statistics Authority (PSA), the city had a population of 372,910, up by about 20% from 309,709 in 2010 (PSA, 2022). Of the city's population in 2020, about 68.5% live in 41 barangays classified as urban (PSA, 2025).

2.2 Methodology Overview

The methodology of this study consists of four major steps. First, a gridded population map of Butuan City for the year 2020 is produced at a 1-km spatial resolution using a dasymetric mapping approach, with barangay-level population data and detailed building footprints as primary inputs. Second, the DEGURBA classification method is applied to the gridded population map to delineate urban centers, urban clusters, and rural areas. Third, a spatial overlay analysis is conducted between the DEGURBA classification and land cover maps to quantify the extent of agricultural and other land cover classes. Finally, the distribution and temporal trends of agricultural land cover are analyzed across the three DEGURBA-defined zones to assess spatial patterns and the magnitude of change.

2.3 Datasets Used

This study uses four primary datasets covering Butuan City (Figure 2): (1) a vector file of barangay boundaries, (2) population data for the year 2020, (3) building footprints that are temporally closest to the year 2020, and (4) land cover maps for the years 2010 and 2020.

2.3.1 Barangay Boundaries and Population Data

The barangay boundaries were extracted from the "Philippines–Subnational Administrative Boundaries" shapefile, available from the Humanitarian Data Exchange (UNOCHA-Philippines, 2022). The NAMRIA produced this shapefile in collaboration with the PSA. Barangay-level population data were obtained from PSA (2022, 2025) and joined as attributes of the barangay boundary shapefile.

2.3.2 Building Footprints

Building footprints were extracted from Google Open Buildings v2 (Google Research 2025, Sirko et al. 2021), a large-scale, open-access geospatial dataset derived from high-resolution satellite imagery using deep learning-based building detection. Google's Research team developed the dataset to provide precise global building footprint data, particularly for regions where such information is limited or unavailable. Each building polygon in the dataset is accompanied by a confidence score ranging from 0 to 1, representing the model's estimated likelihood that the detected footprint corresponds to an actual building. These confidence scores were used as quality indicators in subsequent analyses, with lower-confidence detections filtered out to minimize potential false positives.

In the absence of building footprints explicitly dated to 2020, the 2021 version of the dataset was used, under the assumption that changes in building stock between 2020 and 2021 are limited relative

Figure 1. Location and extent of the study area. (a) National context showing the location of Butuan City in Mindanao, Philippines. (b) Administrative boundary of Butuan City, highlighting urban and surrounding rural landscapes. (c) Close-up view of the city center, with the Agusan River flowing through the city.

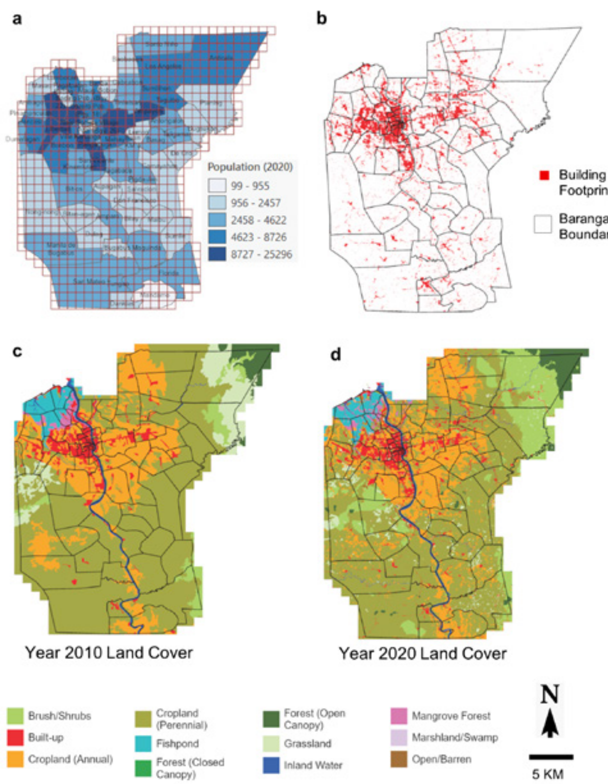

Figure 2. Overview of datasets used in the study: (a) Barangay boundaries and 2020 population data for Butuan City overlaid with 1 × 1 km grid cells used for DEGURBA classification; (b) Google Open Buildings footprint data for the year 2021; (c) 2010 land cover map; and (d) 2020 land cover map.

to the spatial scale of the 1 km DEGURBA grid. The dataset was accessed at https://sites.research.google/gr/open-buildings/, which provides building polygons in vector format along with their associated metadata (e.g., area, perimeter, and confidence). Validation studies have reported that Google Open Buildings in Southeast Asia achieves precision values above 0.80 in low-, medium-, and high-density built-up zones (Google 2025). Independent validation further indicated that approximately 79% of sampled building footprints were correctly identified at confidence thresholds of 0.65 or higher (Estrada et al. 2025), confirming the dataset's reliability.

Before analysis, building polygons with confidence scores below 0.65 and areas smaller than 6 m² were removed. The minimum area constraint followed the minimum habitable room size defined in the National Building Code of the Philippines (Republic of the Philippines 2005). After applying these criteria, a total of 145,403 building footprints were retained for analysis, with an average surface area of 76.44 m2. All retained building footprints were treated as potential residential structures for population allocation, an assumption that is later revisited in the discussion of limitations.

2.3.3 Land Cover Maps

Land cover maps of Butuan City for the years 2010 and 2020 were extracted from national land cover datasets in shapefile format, produced by NAMRIA. The 2010 land cover map was obtained from the Caraga Center for Geo-Informatics (CCGeo) at Caraga State University, based on data previously provided by NAMRIA during CCGeo's implementation of the GeoSAFER Mindanao Program (CSU 2019). The 2020 land cover map was downloaded directly from the Geoportal Philippines (https://www.geoportal.gov.ph/). The land cover maps have 12 classes, namely Annual Crop, Brush/Shrubs, Built-up, Closed Forest, Open Forest, Fishpond, Grassland, Water, Mangrove Forest, Marshland/Swamp, Open/Barren, and Perennial Crop. Both the Annual Crop and Perennial Crop are agricultural land cover classes of interest in this study. Annual crops (e.g., rice, corn) are planted and harvested within a single year, while perennial crops (e.g., coconut, banana, oil palm) live for more than two years, often requiring less frequent planting and harvesting.

According to the accompanying metadata, the 2010 land cover map was created through the visual interpretation of ALOS AVNIR-2 imagery (10-m resolution, acquired from 2007 to 2010), SPOT imagery (2.5–10 m resolution, acquired from 2006 to 2009), and Landsat imagery (30-m resolution, acquired in 2010). The 2020 land cover map was generated primarily through digital interpretation of Sentinel-2 imagery (10 m resolution) acquired from 2018 to 2019, supplemented by other high-resolution satellite imagery.

All land cover maps were rasterized at 30-meter resolution using a majority rule. Doing so ensures consistency across years, as this resolution aligns with the native resolution of the 2010 dataset and supports reliable temporal comparisons. Also, the original name of some classes was slightly modified for easier categorization and to improve clarity, e.g., Closed Forest and Open Forest were renamed as Forest (Closed Canopy) and Forest (Open Canopy), respectively; Annual Crop and Perennial Crop were renamed as Cropland (Annual) and Cropland (Perennial), respectively. The rasterized maps were converted back to vector format (polygons) to allow spatial overlay analysis with the DEGURBA classification layer.

All datasets were projected into the Universal Transverse Mercator (UTM) Zone 51, using the World Geodetic System (WGS) 1984 coordinate reference system (CRS).

2.4 Gridded Population Mapping and DEGURBA Classification

Barangay-level population counts for the year 2020 were disaggregated into a regular grid using a dasymetric population mapping approach, following the methodological guidance of the DEGURBA framework (European Commission & Statistical Office of the European Union 2021). The objective was to derive a gridded population surface that reflects the spatial distribution of inhabitants within administrative units and serves as the basis for DEGURBA classification.

The analysis employed a 1 km × 1 km grid for two reasons. First, DEGURBA explicitly defines urban centers, urban clusters, and rural areas based on population density and contiguity of 1 km² grid cells, making this resolution a methodological requirement and ensuring comparability with international applications. Second, a 1 km grid represents a practical compromise between spatial detail and data reliability when disaggregating population from heterogeneous barangays that vary widely in size, shape, and internal land-use composition. Finer grids would increase sensitivity to modeling assumptions, whereas coarser grids would obscure peri-urban gradients central to this study.

Population disaggregation was performed in two stages. First, barangay-level population totals were allocated to individual building footprints, which were used as ancillary information under the assumption that population presence is spatially associated with buildings. All retained building footprints were treated as potential residential structures. Within each barangay, the total population was proportionally distributed across its building footprints, such that each building received a share of the barangay population based on its relative presence within the barangay. This step produced a building-level population representation consistent with the PSA's total population counts.

Second, the building-level population estimates were aggregated to the 1 km × 1 km grid. For each grid cell, the populations of all buildings whose centroids fell within the cell were summed to produce an estimated population count for that cell. The resulting gridded population surface represents the spatial distribution of population across Butuan City in 2020 and serves as input for the DEGURBA classification.

Following the generation of the gridded population surface, the DEGURBA classification was applied to categorize each grid cell as part of an urban center, urban cluster, or rural area, in accordance with the DEGURBA methodological manual (European Commission & Statistical Office of the European Union 2021). The classification was based on population density thresholds, minimum cluster population requirements, and contiguity rules, as summarized in Table 1. Grid cells that did not meet the criteria for urban centers or urban clusters were classified as rural.

In this study, the term peri-urban is used descriptively to refer to areas classified as urban clusters under the DEGURBA framework, reflecting their transitional role between urban centers and rural areas.

2.5 Spatial Overlay Analysis and Temporal Trend Assessment of Agricultural Land Cover Change

Following the DEGURBA classification, a spatial overlay analysis was conducted to quantify the extent of agricultural and other land cover classes across the defined urban centre, urban cluster, and rural zones. The analysis involved intersecting the DEGURBA-classified grid with land cover maps for the years 2010 and 2020. The overlay enabled the extraction of land cover statistics for each DEGURBA category, allowing a disaggregated analysis of land cover distribution by degree of urbanization. By comparing results across the two reference years (2010 and 2020), the study quantified patterns of land conversion or persistence, highlighting the magnitude and direction of change (e.g., agricultural loss or retention) within urban, peri-urban, and rural contexts.

The 2020 DEGURBA classification was used as a static reference layer in this study to ensure consistency in spatial delineation across the analysis period. Although land cover and population distribution may change over time, using a fixed DEGURBA layer allows direct comparison of agricultural land cover dynamics across stable urban, peri-urban (urban clusters), and rural zones.

All processing and spatial analysis were conducted using Geographic Information System (GIS) software (ArcGIS Pro 3.5). It is essential to note that, while the reported area of Butuan City is approximately 817 km² (CGB 2022), the GIS-computed area of the city, based on the barangay boundaries using the UTM Zone 51N, WGS 1984 CRS, is only 649.96 km². This difference reflects variation between reported administrative-area statistics and the GIS-derived area based on the best available barangay boundary data. Moreover, the DEGURBA classification's unit of analysis is 1 × 1 km, and Butuan City is represented by 720 grid cells, some of which extend beyond the city's administrative boundaries. Additionally, the land cover maps did not fully cover the entire city, particularly areas near Butuan Bay (see Figure 1b). For this study, we retain the 1 × 1 km grid cells as the unit of analysis for DEGURBA classification. However, for reporting land cover change analysis results, we limited the analysis to the spatial extent where the required datasets (i.e., barangay boundaries, DEGURBA classification, and land cover maps) intersected. In this case, the total area coverage is 649.88 km².

3 Results

3.1 Butuan City's Degree of Urbanization

Figure 3a illustrates the DEGURBA classification of Butuan City for 2020, delineating urban centers, urban clusters, and rural areas. Approximately 6% (42 km²) of the city is classified

Table 1. Degree of Urbanisation (DEGURBA) classification criteria applied to 1 km × 1 km grid cells following the official DEGURBA methodology (European Commission & Statistical Office of the European Union, 2021).

DEGURBA Class	Population density threshold	Cluster population	Contiguity rule
Urban center	≥ 1,500 persons/km²	≥ 50,000	4-neighbor (no diagonals)
Urban cluster	≥ 300 persons/km²	≥ 5,000	4-neighbor (including diagonals)
Rural	< 300 persons/km²	Not applicable	Not applicable

as an urban center, primarily encompassing the densely populated central barangays, which have population densities exceeding 1,500 inhabitants per square kilometer. Approximately 19% (124 km²) falls under the urban cluster category, representing areas with at least 300 inhabitants per square kilometer. The remaining 75% (484 km²) is considered rural.

Urban clusters are primarily distributed around the urban center, with notable concentrations extending toward the city's eastern and southern parts. A distinct urban cluster is also visible in the southern portion of the study area. In contrast, no urban clusters are identified north of the urban center.

In comparison, Figure 3b presents the PSA urban–rural classification at the barangay level, which applies a binary scheme. Unlike DEGURBA's population-density-based grid approach, the PSA classification tends to overgeneralize by assigning entire barangays to either urban or rural categories. This results in several areas identified by DEGURBA as urban clusters, particularly in the eastern and southern parts of the city, being classified as rural under the PSA scheme.

3.2 Changes in Agricultural and Other Land Cover Types in Butuan City (2010–2020)

The land cover composition of Butuan City in 2010 (Figure 4) was predominantly agricultural, with cropland (perennial) occupying the most significant share at 376.17 km² or 58% of the total land area (649.88 km²), followed by cropland (annual) at 142.87 km² (22%). Combined, these two types of cropland accounted for 80% (519.04 km²) of the city's total area. Other significant land cover types included grasslands (6%), built-up areas (5%), and brush/shrubs (3%).

By 2020 (Figure 4), agricultural areas remained dominant but showed overall decline, with perennial cropland decreasing to 344.91 km² (53%) and annual cropland to 124.33 km² (19%). This decline represents a combined loss of 49.8 km² of agricultural land over the decade, equivalent to a 9.60% reduction in total agricultural area. There was a significant increase in brush/shrubs, expanding from 19.01 km² (3%) to 80.35 km² (12%).

Built-up areas increased from 32.75 km² (5%) to 42.78 km² (7%), accounting for only a relatively small portion (10 km²) of the total change. Grassland decreased significantly—from 38.95 km² (6%) in 2010 to just 14.68 km² (2%) in 2020. Forest (open canopy) increased slightly, while inland water and mangrove forest remained relatively stable. While the total mapped area of mangrove forest and fishponds did not show a pronounced net decline between 2010 and 2020, visual inspection of the land cover maps indicates substantial changes in their spatial configuration, including fragmentation and localized losses, particularly along coastal and riverine zones (Figure 2c & d).

3.3 Urban-Rural Gradient Land Cover Composition and Changes

Figure 5 highlights how land cover composition varies across Butuan City's urban center, urban clusters, and rural areas, and how these distributions changed between 2010 and 2020.

In the urban center, built-up areas constituted the largest single land cover class, covering 18.21 km² in 2010 and increasing slightly to 19.04 km² in 2020. Built-up land accounted for approximately 43–45% of the total urban center area (42 km²). Other land cover types remained limited in extent. Within the remaining agricultural land, a clear shift in cropland composition was observed: annual cropland declined from 14.99 km² to 10.02 km², while perennial cropland increased from 2.86 km² to 7.57 km². Grassland, brush/shrubs, and open/barren land appeared only in 2020, but each occupied relatively small areas.

In the urban clusters, land cover was more diverse but still predominantly agricultural. In 2010, annual and perennial croplands together covered approximately 108.31 km², or nearly 87% of the total urban cluster area (123.90 km²). By 2020, the area had declined slightly to 99.37 km², as the built-up area increased from 12.14 km² to 16.46 km². There

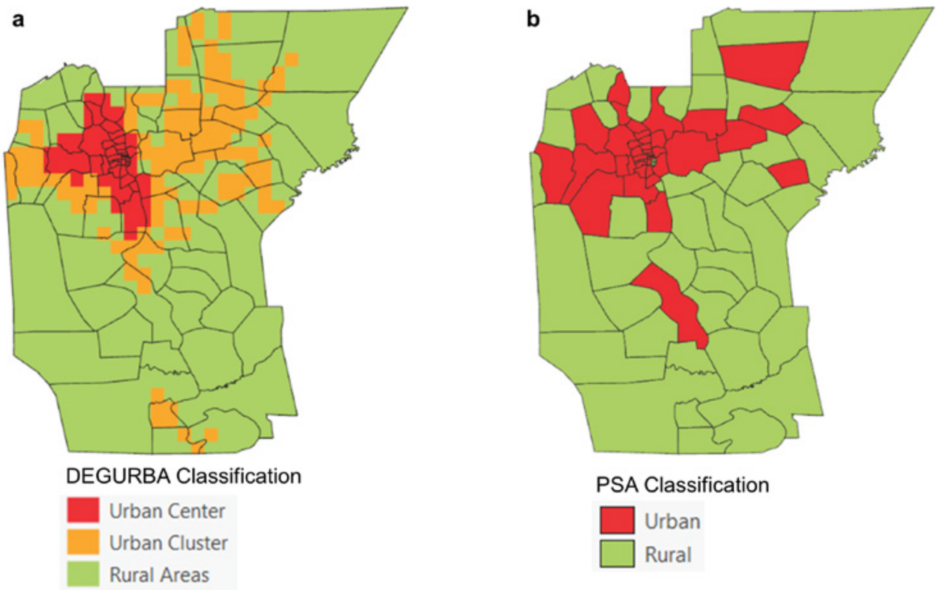

Figure 3. Comparison of urban–rural classifications in Butuan City for the year 2020: (a) Degree of Urbanisation (DEGURBA) classification based on a 1 km population grid; and (b) Philippine Statistics Authority (PSA) classification applying a binary urban–rural designation at the barangay level.

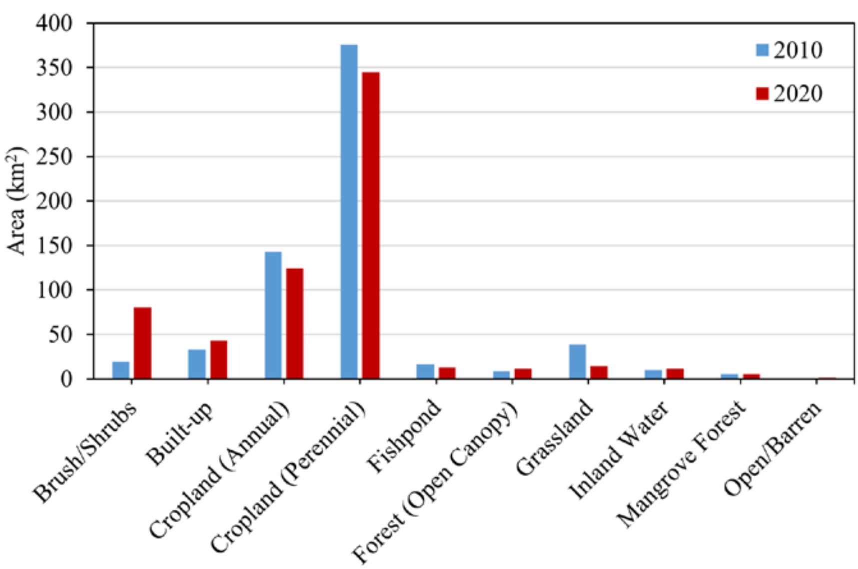

Figure 4. Land cover distribution in Butuan City for the years 2010 and 2020.

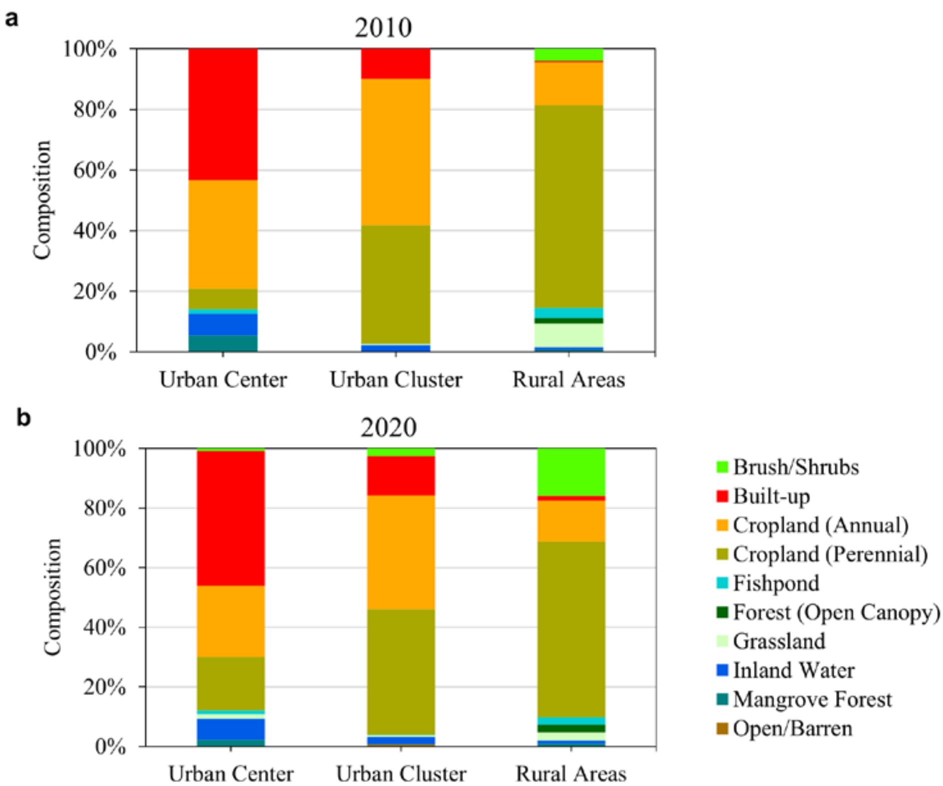

Figure 5. Land cover composition within the urban center, urban cluster, and rural areas of Butuan City for 2010 (a) and 2020 (b).

were also increases in brush/shrubs (from 0 to 3.03 km²), grassland (from 0.56 km² to 0.82 km²), and open/barren land (from 0 to 0.86 km²), indicating a trend toward land fragmentation and conversion. A small amount of forest (open canopy) also emerged in urban clusters by 2020, covering 0.06 km².

In rural areas, agriculture remained the dominant land use, though with notable changes. Perennial cropland decreased from 324.92 km² in 2010 to 285.19 km² in 2020, while annual cropland remained stable, with a slight decrease from 67.97 km² to 67.02 km². These losses were accompanied by a substantial increase in brush/shrubs, which expanded from 19.01 km² in 2010 to 77.01 km² in 2020. Built-up area in rural zones also increased significantly, from 2.40 km² to 7.27 km². Other natural land covers, including grassland, forest (open canopy), and inland water, persisted in rural areas with moderate variability over time, while mangrove forests and fishponds exhibited relatively stable aggregate extents but pronounced spatial reorganization, reflecting fragmentation and localized change as documented earlier (Section 3.2).

3.4 Land Cover Transitions Driving Agricultural Land Change

Between 2010 and 2020, agricultural land in Butuan City underwent notable transitions (Figure 6). Most of the cropland stayed the same, but there were signs of both development and land abandonment. About two-thirds (66.7%) of annual cropland remained unchanged, while nearly one-fourth (24.3%) shifted to perennial crops. However, 6.8% of annual cropland was converted to built-up areas, and a smaller portion was converted to brush or shrubs. Perennial cropland was more stable, with 78.1% remaining the same, but about 10% turned into brush/shrubs, and 2.2% became built-up.

The disaggregated results (Figure 7) reveal significant spatial variations in the transition of cropland across the urban center, urban cluster, and rural areas between 2010 and 2020.

For areas classified as Cropland (Annual) in

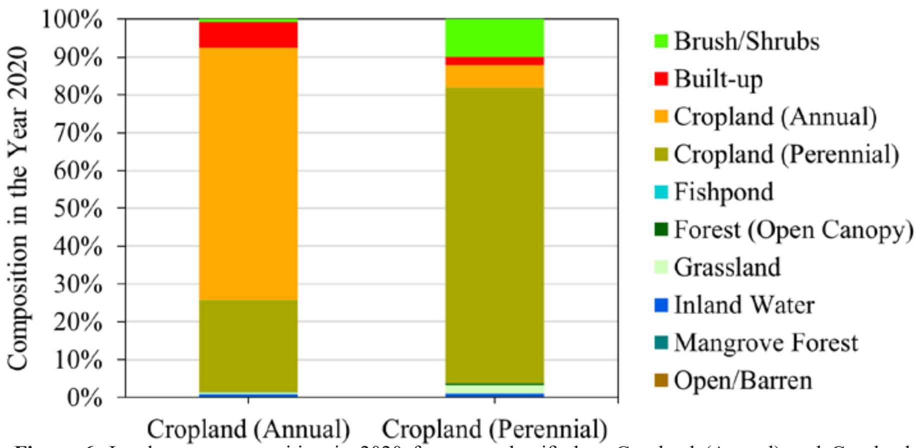

Figure 6. Land cover composition in 2020 for areas classified as Cropland (Annual) and Cropland (Perennial) in 2010, showing the types and proportions of land cover these areas transitioned into over the decade.

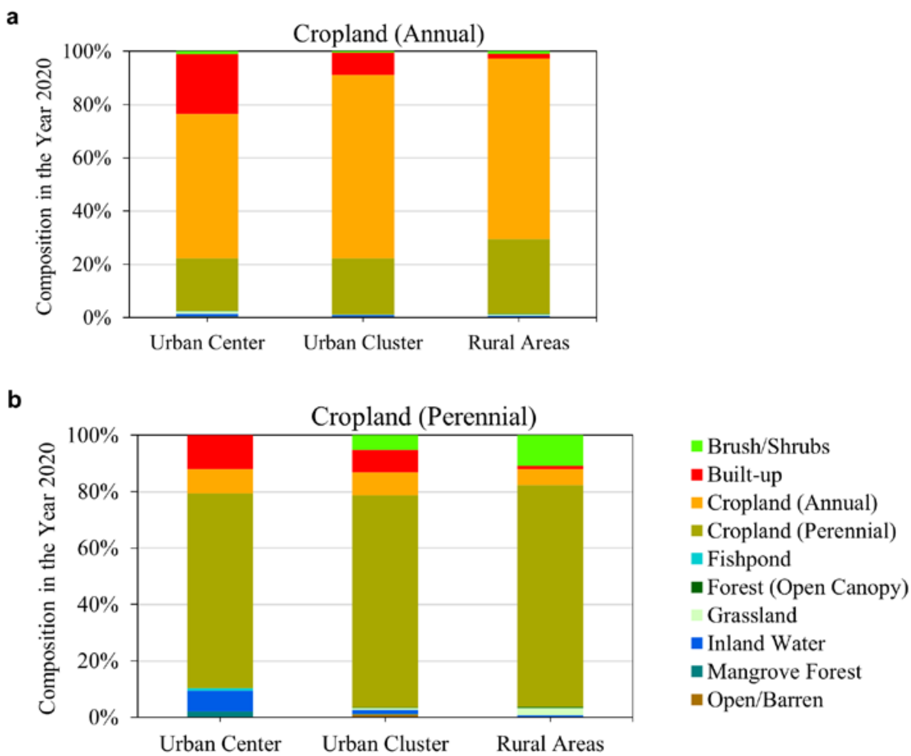

Figure 7. Land cover composition in 2020 of areas that were classified in 2010 as (a) Cropland (Annual) and (b) Cropland (Perennial), showing the types and proportions of land cover these areas transitioned into by 2020, disaggregated by urban center, urban cluster, and rural zones.

2010 (Figure 7a), the majority remained agricultural in 2020, particularly in urban clusters (68.74%) and rural areas (67.69%). A considerable portion also transitioned into Cropland (Perennial), especially in rural areas (28.11%) and urban clusters (21.11%). In the urban center, the largest share (54.24%) also remained as annual cropland, though 19.92% became perennial. It is notable that the conversion of annual cropland to built-up land is largest in the urban center (22.37%), compared to 8.37% in urban clusters and just 1.90% in rural areas. Transitions to brush/shrubs, inland water, and grassland were relatively minor but were present across all zones.

For areas classified as Cropland (Perennial) in 2010 (Figure 7b), the majority also retained their original land cover, with very high proportions retained across all zones—78.64% in rural areas, 75.33% in urban clusters, and 69.22% in the urban center. However, conversion to brush/shrubs was more pronounced in rural areas (10.70%) and urban clusters (5.23%). Conversion to built-up areas was highest in the urban center (12.00%), followed by urban clusters (8.05%) and rural areas (1.21%). A small portion of perennial cropland also shifted to annual cropland, grassland, and inland water, with rural areas showing the broadest range of transitions.

4 Discussion

This study applied the DEGURBA classification to examine the distribution and changes in land cover—particularly agricultural land—across different parts of Butuan City between 2010 and 2020. By delineating the city into urban centers, urban clusters, and rural areas based on population density and built-up presence, the analysis provides a spatially explicit perspective on agricultural land dynamics along the urban–rural gradient.

4.1 Butuan City's Urbanization Pattern

The DEGURBA classification results reveal a non-uniform spatial distribution of urbanization across Butuan City, with urban clusters forming preferentially around, but not evenly surrounding, the urban center. The concentration of urban clusters to the east and south of the city center suggests that urban expansion is occurring in a spatially selective manner rather than through radial growth.

The limited presence of urban clusters north of the urban center reflects the influence of local physical and land-use constraints on urban spatial development (Zhang et al. 2024). Coastal features, such as Butuan Bay, along with the prevalence of fishponds and other water-related land uses, appear to restrict population concentration and urban expansion in these areas. As a result, urban clustering is more pronounced in directions where larger contiguous tracts of developable land remain available.

The comparison with the PSA barangay-level urban-rural classification highlights the added spatial detail provided by DEGURBA. By relying on population density thresholds applied to a regular grid, DEGURBA identifies transitional areas of population concentration that remain masked under a binary administrative classification. This distinction is particularly evident in peri-urban areas, where population density exceeds rural thresholds but falls short of levels characteristic of the urban core. These findings illustrate how the DEGURBA framework captures the spatial structure of urban–rural transitions more explicitly than administrative classifications, providing a clearer basis for identifying zones where urbanization processes are actively unfolding.

4.2 Agricultural Land Distribution across the Urban–Rural Gradient

The results show that agricultural land is predominantly located in urban clusters and rural areas, while the urban center is predominantly built-up land. In 2020, more than 80% of both urban cluster and rural zones remained covered by cropland, including both annual and perennial types. In contrast, cropland occupied only a small fraction of the city core, reflecting the city's advanced stage of urban development. These findings confirm that agriculture continues to play a significant role in the outer parts of the city, particularly in rural areas, underscoring its continued importance for local land-based production.

4.3 Spatial Patterns and Pathways of Agricultural Land Conversion

A comparison between 2010 and 2020 reveals an apparent decline in agricultural land across all DEGURBA zones, with distinct conversion pathways that vary by degree of urbanization. At the national scale, recent satellite-based analyses have shown that agricultural land conversion to built-up areas has been widespread across the Philippines since 2000 (Araza et al. 2026). The patterns observed in Butuan City reflect broader national trends while also revealing how these processes manifest differently along the urban–rural gradient. In the urban center, the dominant transition involved converting annual cropland to built-up land, indicating that urban development has increasingly encroached on the remaining agricultural areas. Similar patterns of cropland loss near existing built-up areas have been documented in earlier studies of Butuan City, which identified rice croplands as particularly vulnerable to urban encroachment over longer time horizons (Bentozal et al. 2024). The DEGURBA-based analysis presented here refines these findings by situating such conversions explicitly within zones of high population density and built-up concentration, highlighting the heightened vulnerability of remaining cropland in already densely developed environments. This pattern mirrors broader global evidence linking urban expansion to cropland loss (Huang et al. 2020, Potapov et al. 2021).

In contrast, substantial losses of perennial cropland were observed in urban clusters and rural areas. These losses were accompanied by a pronounced expansion of brush and shrubland, particularly in rural zones. Land-cover transitions could indicate abandonment, reduced cultivation intensity, or changes in land management, potentially linked to declining agricultural profitability, limited labor availability, or land held for future development. This interpretation is consistent with broader evidence showing that the Caraga region—where Butuan City is located—exhibits the lowest agricultural labor productivity in the Philippines, making rural areas especially susceptible to labor reallocation and shifts away from active agricultural land use (Custodio & Sombilla 2025). Similar patterns of agricultural land contraction associated with labor constraints and declining production incentives have been documented at the national scale (Taer 2025).

Changes in cropland composition may also indicate shifts in farming practices. The conversion of annual cropland to perennial crops across several zones may reflect a preference for production systems that require less frequent planting and lower labor inputs. At the same time, the conversion of cropland—exceptionally annual cropland—to built-up land in the urban center and cluster zones underscores the growing pressure exerted by outward urban expansion. The conversion of perennial cropland into brush or shrubland further suggests a reduction in active land management. All these patterns are consistent with the influence of changing agricultural strategies, labor constraints, and urban development pressures on agricultural land cover change in the Philippines (Adamopoulos & Restuccia 2020, Araza et al. 2026, Huang et al. 2020, Taer 2025).

4.4 Outward Urban Expansion and Pressure on Peri-Urban and Rural Land

Built-up areas increased across all DEGURBA zones during the study period, but the most pronounced growth occurred outside the urban center. While built-up land in the urban center expanded by less than 1 km^2 between 2010 and 2020, it increased by more than 4 km^2 in urban clusters and nearly 5 km^2 in rural areas. This pattern indicates that urban expansion in Butuan City is primarily outward-oriented, extending into peri-urban and rural landscapes.

Such spatial dynamics underscore the heightened vulnerability of urban clusters and rural areas, where agricultural land remains widespread but is increasingly exposed to development pressures. They also illustrate how the DEGURBA framework helps capture the gradual and dispersed nature of urban expansion, patterns that could be missed when analyses rely solely on administrative boundaries.

Beyond retrospective assessment, the results suggest that the DEGURBA classification can also be used as a heuristic tool to anticipate areas of potential agricultural land loss, and in Butuan City, urban clusters and adjacent rural zones consistently exhibited both high shares of remaining cropland and the most pronounced increases in built-up land, indicating that these transitional areas represent priority zones of future conversion risk, by explicitly delineating functionally peri-urban areas rather than relying on static administrative labels. In these DEGURBA highlights, agricultural land is most at risk from encroaching urban development. In this sense, the degree of urbanization serves not only as a descriptive indicator of current land-use patterns but also as a spatial proxy for identifying agricultural areas likely to experience heightened development pressure in subsequent periods.

4.5 Implications for Land-Use Planning and Food Security

The spatially differentiated cropland conversion pathways identified using the DEGURBA framework have essential implications for land-use planning in Butuan City. Compared to the traditional PSA-based classification, which applies a binary urban–rural designation at the barangay level, DEGURBA provides a spatially explicit representation of transitional zones where agricultural and urban land uses coexist. This representation allows more precise differentiation between consolidated urban areas, predominantly agricultural rural areas, and urban clusters that function as transitional spaces under increasing development pressure.

As demonstrated by the results, urban clusters concentrate both substantial remaining cropland and the most pronounced recent land conversion, indicating that these areas represent critical zones where agricultural land is most exposed to urban encroachment. From a planning perspective, urban clusters are particularly well-suited for enhanced land-use monitoring, early identification of conversion hotspots, and more targeted development control measures compared to areas that are either entirely urban or predominantly rural. Incorporating DEGURBA-based spatial typologies into local land-use planning processes could therefore support more informed zoning decisions, help prioritize areas for agricultural land protection, and guide the management of urban expansion to reduce unplanned or fragmented land conversion.

Beyond land-use governance, the observed patterns also carry potential implications for food security. Research on rural–urban transitions in the Global South emphasizes that the loss and fragmentation of agricultural land at the urban periphery can weaken local food provisioning systems and increase reliance on market-based food access, often without commensurate gains in stable non-farm livelihoods (Choithani et al. 2024). Evidence from rapidly urbanizing regions in Asia similarly suggests that outward urban expansion can displace productive cropland and introduce longer-term pressures on food security by reducing local food production capacity and increasing spatial disconnects between cities and their traditional food sources (Sheng et al. 2025). In Butuan City, the conversion of cropland—exceptionally annual cropland—to built-up land in urban centers and clusters, together with land-cover patterns indicative of reduced land management in rural areas, reflects these broader rural–urban transition dynamics. These findings underscore the importance of considering potential food-system risks alongside land-use change when designing urban and regional development strategies.

4.6 Limitations and Future Research Directions

While this study demonstrates the value of applying the DEGURBA framework to analyze agricultural land cover change along the urban–rural gradient in Butuan City, several limitations should be acknowledged and point to important directions for future research.

First, the analysis was based on two temporal reference years (2010 and 2020). Although this allowed for a consistent comparison of land cover change across DEGURBA-defined urban centers, urban clusters, and rural areas, using only two time points limits the ability to capture longer-term trends and transitional dynamics. Incorporating an additional temporal reference year, such as around 2000, would enable a more comprehensive assessment of land cover trajectories, including changes in the composition of the urban–rural gradient, longer-term shifts in agricultural and non-agricultural land cover types, and more precise identification of land cover transitions driving agricultural land loss. Including a third time period would therefore strengthen the temporal robustness of the analysis and provide deeper insight into the evolution of agricultural and other land cover change in Butuan City.

The inclusion of an earlier reference year was limited by data availability. At the time of this study, no NAMRIA land cover map for 2000 was available, and the nearest available product from the agency was the 2003 land cover map. To avoid inconsistencies in decadal temporal analysis, the study therefore focused on the 2010–2020 period. Future research could address this limitation in several ways. One option is to extend the temporal coverage by incorporating earlier NAMRIA land cover maps, albeit at a non-decadal temporal scale. Alternatively, existing global or regional land cover products, such as the Global Land Analysis & Discovery (GLAD) cropland dataset used by Araza et al.(2026), could be explored, provided their accuracy is independently assessed, given their non-authoritative nature. Another promising direction is the generation of multi-temporal agricultural land cover maps using machine learning or deep learning methods (Oliphant et al. 2019, Pelletier et al. 2019, Talukdar et al. 2020) applied to freely available satellite imagery, such as Landsat and Sentinel-2, enabling the construction of consistent long-term land cover time series.

Second, the DEGURBA classification used in this study was based on population and built-up patterns derived from 2020/2021 data and remained constant throughout the analysis period. While this approach supports consistent spatial comparison, it does not explicitly capture temporal shifts in settlement structure and population distribution. Incorporating time-varying DEGURBA classifications, updated at multiple reference years, would allow future studies to examine how transitions between urban, peri-urban, and rural categories evolve and how these changes interact with agricultural land conversion processes.

Third, the analysis employed the standard DEGURBA grid resolution of 1 km × 1 km, as required by the official methodology, ensuring comparability with international applications. However, grid resolution can influence the delineation of urban clusters and the representation of peri-urban gradients, particularly in heterogeneous landscapes. Future studies could explore the sensitivity of agricultural land change patterns to alternative grid sizes (e.g., 500 m), especially for localized or intra-urban analyses. Such comparisons would help clarify the scale at which urban–rural transitions and agricultural land conversion processes are most effectively captured, while balancing spatial detail and data reliability.

Fourth, limitations of dasymetric population mapping should be considered. The analysis assumed that all mapped building footprints contributed equally to residential population distribution. Although this assumption is reasonable in the context of Butuan City, where residential structures dominate, it may introduce uncertainty in areas with mixed land use or higher concentrations of non-residential buildings. Future research would benefit from building footprint datasets that explicitly distinguish between residential and non-residential structures, allowing the population to be allocated only to residential buildings.

In addition, integrating three-dimensional (3D) building information, such as building height or floor-area data, represents a promising avenue for improving dasymetric population mapping (Maroko et al., 2019). Allocating population based on building volume or usable floor space, rather than footprint area alone, would enable a more realistic representation of population distribution, particularly in denser urban and peri-urban zones where vertical development is present.

Finally, while this study focused on the administrative boundaries of Butuan City, urbanization processes and land-use transitions often extend beyond them. Expanding future analyses to include adjacent municipalities would better reflect continuous urban development and mitigate potential edge effects in the DEGURBA classification.

5 Conclusion

This study presented a spatial analysis of agricultural land loss across the urban–rural gradient in Butuan City, Philippines, demonstrating the value of applying the DEGURBA framework in a national context where standardized urban–rural typologies remain rarely used. By integrating population density, building footprints, and authoritative satellite-derived land cover maps, the study provides one of the first applications of DEGURBA for systematically examining agricultural land distribution and conversion across urban centers, urban clusters, and rural areas in a Philippine city. This approach provides a spatially consistent alternative to traditional barangay-based classifications, enabling more precise differentiation of land-use dynamics along the urban–rural continuum.

The analysis estimated a loss of approximately 49.8 km² (9.6%) of agricultural land between 2010 and 2020, with the most pronounced reductions occurring in urban clusters—transitional zones experiencing increasing development pressure. These findings underscore the importance of urban clusters as priority areas for land-use monitoring and informed planning, particularly in cities where agricultural land and urban expansion are increasingly intersecting. By explicitly distinguishing these zones, the DEGURBA framework helps clarify where agricultural land conversion is most concentrated and where planning attention may be most effectively directed.

A key strength of the DEGURBA framework lies in its ability to transcend administrative boundaries and represent settlement patterns using a regular, grid-based system. This ability enables the identification of gradual, spatially dispersed land-use transitions, particularly in peri-urban areas, more clearly than is possible with binary urban–rural classifications at the barangay level. In this sense, DEGURBA serves not only as a descriptive tool for analyzing current land-use patterns, but also as a practical framework for anticipating areas at heightened risk of future agricultural land loss.

Overall, this study demonstrates that the

DEGURBA framework provides a scalable, standardized, and policy-relevant approach for analyzing agricultural land cover change along the urban–rural gradient in the Philippine context. By revealing how agricultural land loss varies with degrees of urbanization, the approach offers a practical tool for supporting evidence-based urban planning and sustainable land management, particularly in urbanizing cities such as Butuan.

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7 Statement of Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

8 Author Contribution

Jojene R. Santillan: Conceptualization, Methodology, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. Meriam Makinano-Santillan: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

9 Data availability statement

Barangay boundary data were obtained from the Humanitarian Data Exchange (https://data.humdata.org/dataset/cod-ab-phl). Population data were sourced from the Philippine Statistics Authority's Urban Population of Caraga (2020 Census) release (https://rssocaraga.psa.gov.ph/content/urban-population-caraga-based-2020-census-population-and-housing). Building footprint data were accessed from the Google Open Buildings dataset (https://sites.research.google/gr/open-buildings/). The 2010 and 2020 land cover maps were obtained from the Philippines' National Mapping and Resource Information Authority (NAMRIA), with the 2020 dataset accessible via Geoportal Philippines (https://www.geoportal.gov.ph/) and the 2010 dataset provided directly to the authors through a collaboration with NAMRIA. Additional supporting data are available from the corresponding author upon reasonable request.

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11 Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this manuscript, the authors utilized ChatGPT 5 to enhance the clarity and quality of the language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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