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Land-use conversion from agricultural production areas to built-up areas in the Philippines for decades 2000–2020: Spatial analysis and policy implications

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ABSTRACT

Rapid urban expansion in the Philippines has intensified the pressure on agricultural lands, raising concerns about national food security and environmental sustainability. This study presents a national-scale spatial analysis of agricultural land conversion to built-up areas between 2003 and 2019, using high-resolution Earth Observation (EO) maps. The map validation based on expert-labeled reference data yielded 81% user accuracy, while correlation and bivariate mapping revealed a strong relationship (r = 0.89) between cropland loss (ha) and built-up expansion (ha), with hotspots identified in Central and Southern Mindanao, and Central Luzon. Conversions showed a moderate association with agricultural land area (r = 0.38), which may correspond to provinces with large areas for high-value crop production with intact economic value. Around 31% (3,228 out of 10,397 ha) of converted cropland to built-up fell within legally protected zones under the Network of Protected Areas for Agriculture and Agro-Industrial Development (NPAAAD), indicating possible governance and enforcement gaps. Almost 80% of the conversions within NPAAAD are mostly agro-industrial and alluvial lands characterized as high-value and road-accessible, thus being vulnerable also to urban and industrial projects. The findings underscore the urgency of enacting the National Land Use Act (NaLUA) to institutionalize spatial planning and safeguard agricultural lands from unregulated conversion. The findings of this study alongside mapping of specific land-uses following the conversions nationwide are deemed helpful inputs for mandated local land use planning.

1. Introduction

The conversion of agricultural lands to built and urban areas has become increasingly prevalent due to rapid urbanization and population growth (Satterthwaite et al., 2010; UN, 2018). By 2050, urban expansion and sprawl is projected to significantly encroach on agricultural lands, posing challenges to food security and environmental sustainability (Grafton et al., 2015). Urban areas globally are projected to nearly triple, from 213 Mha in 2000 to 621 Mha in 2040, significantly encroaching on cropland and displacing 65 Mton of crop production (van Vliet et al., 2017). This issue is particularly pressing in the Philippines, considered as an agricultural country, with a dense and growing population at the same time (Bravo, 2017). The country has a current population of approximately 113 million in 2024 and is projected to reach 142 million by 2050 (UN, 2018). This increase has intensified pressure on the country's primary agricultural regions and affects both food security and production, especially given that 25% of the workforce depends on agriculture for their livelihood (Bravo, 2017; PSA, 2020).

Managing and monitoring agricultural conversions remains challenging as the country balances urban growth and food security, and

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this requires timely and robust data to support informed decision-making (Bagarinao, 2014; Arceo-Dumlao et al., 2021). Fargas et al. (2021) demonstrated that a spatial approach can reveal where and how fast changes unfold, moving beyond traditional analyses based on aggregate statistics (Liu et al., 2018). While national land cover maps can be an information source for analyzing agricultural land use changes, they are updated infrequently, typically every 5–7 years (Bagarinao, 2014b). Moreover, there can be inconsistencies in the land cover maps, such as the baseline year 2003 being produced using different data and methodologies compared to subsequent years (Manuel, 2014).

Earth Observation (EO) involves the collection of data about the Earth's surface and atmosphere from satellite-mounted sensors. These sensors capture imagery that can be processed to generate maps of land cover over time, allowing the detection of converted agricultural land to built and urban areas (Potapov et al., 2022). One of the key strengths of EO is the consistency of its acquisition and processing methods, which ensures comparability across both time and space (Hansen et al., 2013). This allowed studies such as Liu et al. (2018) to compare agricultural area estimates from EO land cover maps (e.g., ESA-CCI) with FAOSTAT statistics at the global scale. EO-based approaches have been effectively applied in the Philippines to detect agricultural to built-up land-use changes, such as in the study by Fargas et al. (2021), which analyzed urban sprawl from 2015 to 2019 with 76% accuracy while providing an EO-based monitoring roadmap. Similarly, Bentozal et al. (2024) conducted a two-decade assessment 2003–2023 revealing significant spatial patterns in agricultural changes in a peri-urban ecosystem. While these local studies provide methodological demonstrations, their scope is limited to specific areas, limiting the use for national-level analysis. In contrast, analysis-ready data EO products provide regional to global scales maps produced using consistent satellite data input (e.g., based on Landsat data) in mapping agriculture areas for different epochs. For instance, Han et al. (2021) produced high-resolution annual paddy rice maps for Southeast Asia from 2017 to 2019, while (Vadrevu et al., 2022) synthesized and mapped land cover change across South and Southeast Asia from the early 1990s to 2015 using multi-temporal satellite data. Potapov et al. (2022) provide a global, 30 m cropland extent multi-date dataset for cropland change analysis at >90% accuracy.

Validating the accuracy of EO products is an essential step in ensuring the reliability of any land cover change analysis, especially when used for national and sub-national level estimations (Loew et al., 2017). While EO products with high spatial resolution like the Potapov dataset demonstrate high accuracy in capturing land cover changes, independent validation especially when global maps are used for national applications remains crucial. This process involves comparing the EO-derived classifications with ground-truth reference datasets, which are mostly obtained local surveys and even very high-resolution imagery (Fritz et al., 2012). For the latter, random samples are created and labeled by multiple experts annotating the same sample to mitigate annotation errors (Dida et al., 2021). Further mitigation of the errors involves discarding samples if annotations of experts disagreed.

Furthermore, combining EO data and Geographic Information System (GIS) analysis can provide valuable insights for evidence-based decision-making related to land use planning and policy formulation (Salvacion, 2019). A study by Mehra and Swain (2024) utilized both RS and GIS analysis to assess land use and land cover changes and they indicated that by 2040, the built-up area is projected to increase is linearly correlated and would lead to leading to reductions of agricultural protected areas in an Indian province. Bagarinao (2014) found out that most converted areas being less than 1,000 m^2, located at elevations of approximately 12 m, on gentle slopes and consisting primarily of loam soil in a province in the Philippines. Analyzing land cover changes in the past decades at the provincial level offers a suitable scale for understanding and planning for agricultural land uses. This scale aligns with the administrative units for which agricultural statistics are reported by the national government and provincial land use plans, facilitating comparisons and the integration of diverse data sources (Perez et al., 2016). Furthermore, provincial-level analysis allows for a more nuanced understanding of agricultural conversions. For instance, Du et al. (2014) conducted a GIS-based analysis of land use changes and revealed significant correlations between cropland loss and built-up area expansion at the provincial level. Such an analysis can be effectively visualized such as utilizing bivariate choropleth maps to document land use and land cover changes (Calka, 2021).

The outcomes of spatial analysis should be contextualized within the framework of national agricultural policies (DA-PRDP, 2024). Policy directives such as those under Republic Act 9700 and related administrative orders, aim to restrict the conversion of prime agricultural lands, designated as highly sustainable production areas. However, no study to date has comprehensively analyzed agricultural land conversion over past decades to determine the extent of conversion within protected agricultural areas and zones, nor assessed the policy implications of such changes. The GIS datasets for the Network of Protected Areas for Agriculture and Agro-Industrial Development (NPAAAD) and Strategic Agriculture and Fisheries Development Zone (SAFDZ) and their overlay with the agricultural conversions provide an opportunity for such critical analysis. NPAAAD delineates prime and protected agricultural lands for conservation, while SAFDZ designates priority zones for agriculture and fisheries development. Both are official national datasets has recently been updated to modernize mandated land-use inventories, reflect rapid conversions and provide standardized digital basemaps for local planning as support to National Land Use Act (NaLUA) deliberations (DA-BSWM, 2022).

This study presents a spatial analysis of agricultural land conversion to built-up areas and their policy implications. The study consists all provinces, utilizing nationally validated EO data and government GIS data of NPAAAD and SAFDZ. This research serves as a situational analysis for policymakers and key stakeholders while supporting the development of evidence-based strategies for future land use planning. The study objectives include: (1) Validate EO products of cropland conversions using expert-labeled reference data; (2) Assess the correlation, patterns and hotspots of agricultural land conversion to built-up areas at the provincial level and (3) Contextualize the findings to current agricultural and food security policies while providing policy recommendations.

2. Materials and methods

2.1. Study area

The study covers all 81 provinces of the Philippines, an archipelagic country in Southeast Asia with a land area of about 300,000 km^2 (Fig. 1). The Philippines has a population exceeding 110 million, with a large share residing in rural areas where livelihoods remain heavily dependent on agriculture and fisheries. The country's biophysical setting is highly diverse, comprising fertile alluvial plains, volcanic uplands and coastal zones that support a wide range of crops including rice, corn, coconut and sugarcane. Its tropical monsoon climate, marked by distinct wet and dry seasons, combined with frequent exposure to typhoons and flooding, further shapes land-use patterns and pressures. Rapid urbanization in provinces hosting major agricultural production areas, reflects the dual challenges of sustaining food security while accommodating growing settlement demand.

2.2. The cropland and built-up dataset from EO

We utilized two EO products, specifically the Global Land Analysis & Discovery (GLAD) cropland dataset and the GLAD built-up dataset both accessible at https://stac.openlandmap.org/. These products were chosen due to their high temporal and spatial consistency, as they are both based on Landsat archive. The GLAD cropland dataset was used to

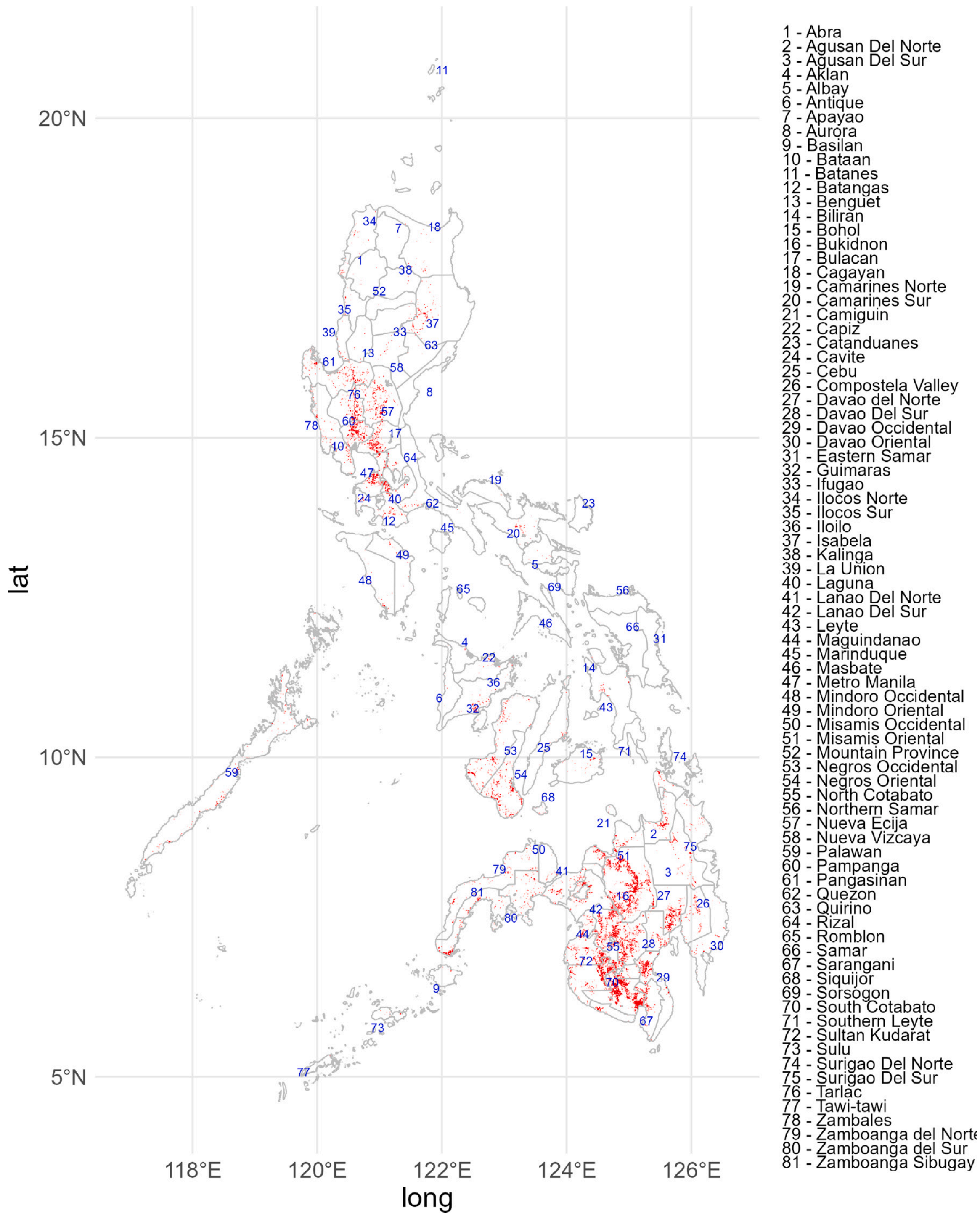

Fig. 1. Map of the Philippines with provincial boundaries and the changes in croplands from 2003 to 2019 (red).

identify areas used for annual and perennial herbaceous crops for human consumption, forage and biofuel, excluding tree crops, permanent pastures and shifting cultivation (Potapov et al., 2021). This excludes woody perennial crops such as coconut, mango, coffee, cacao and others. This dataset was produced using a locally calibrated cropland models that utilized multi-date training data from all possible regions. The final product was filtered to remove artifacts and cropland patches smaller than 0.5 ha. On the other hand, the GLAD built-up dataset was used to identify man-made land surfaces associated with infrastructure, commercial and residential land uses. This dataset was created using a Convolutional Neural Network (U-Net) algorithm calibrated with building outlines and road data from *OpenStreetMap*. The final product provides information on the extent of built-up areas for the years 2000 and 2019, but only 2003 was the earliest epoch accessible.

To identify changes in agricultural land cover, the cropland dataset for the years 2003 and 2019 were subtracted from each other. The resulting map was used to identify areas where agricultural land-use changes occurred. The stable agricultural land cover areas were also identified by removing all pixels with values of 1 or 0 in both the 2003 and 2019 datasets.

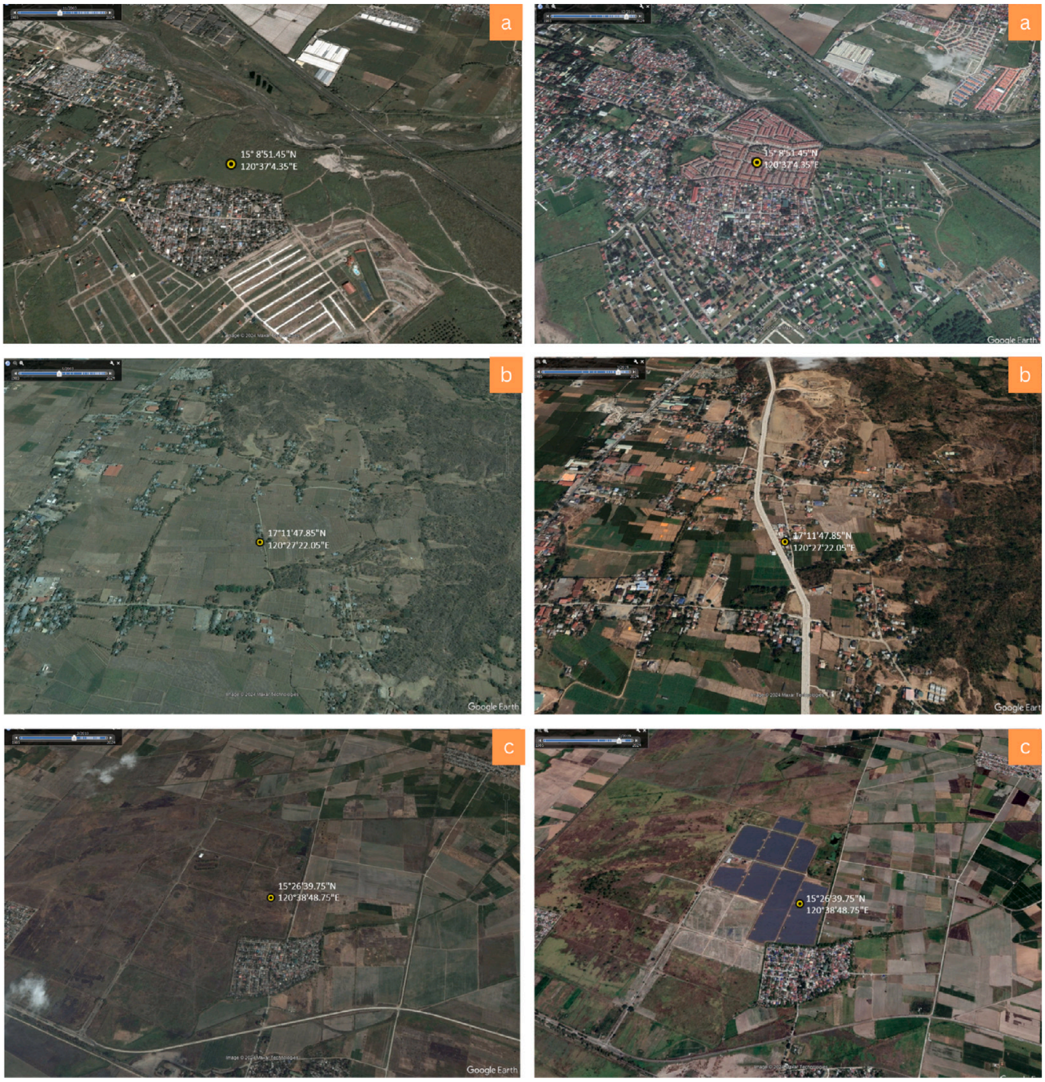

Fig. 2. Examples of the reference data for agricultural land conversions into residential area (a), road network (b) and solar farm (c).

2.3. Cropland change validation

To validate the agricultural change detection results, a random sample of 2-ha polygons were obtained from the 2020 Built-Up dataset. These points were visually checked back in time using Google Earth Pro historical basemaps and local publications to determine whether the areas were previously cropland. Two local experts facilitated the annotation. The validation results were used to estimate the accuracy of the agricultural change detection. See Fig. 2 for example agricultural land conversions into different built-up areas including the most common conversion into residential areas, and the more recent type of conversion i.e., into solar farms.

For binary classification, where the categories were defined as ‘with conversion’ (cropland converted to built-up) and ‘without conversion’ (cropland remaining unchanged), an accuracy assessment was conducted. This included calculating User’s Accuracy (UA). The UA for the ‘with conversion’ category is:

$$\mathrm{UA} = \frac{TP}{TP + FP}, \tag{1}$$

which indicates the reliability of the detected conversion areas, representing the proportion of correctly classified conversion areas to all areas classified as conversion.

2.4. Correlating built-up and cropland changes

To analyze the correlation between built-up area expansion and cropland conversion at the provincial level, Pearson correlation analysis was employed. Provincial-level data were derived including agricultural area (ha), and built-up and cropland areas over time (ha) calculated as the difference in their respective areas between two time points. The Pearson correlation coefficient (r) was used to quantify the linear relationship between these variables, with significance tested at $p < 0.05$. For instance, the formula for Pearson correlation for correlating built-up and cropland changes is:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}, \tag{2}$$

where x_i and y_i represent the changes in built-up and cropland areas for province i, $\bar{x}$ and $\bar{y}$ denote their respective means and the totals are derived from summing changes across all provinces.

2.5. GIS data of prime agricultural lands

The main agricultural data we used is the prime agricultural lands recently published by the Department of Agriculture of the Philippines (Concepcion and Nilo, 2019). Under Republic Act 8435, the

Table 1
Classification of different prime agricultural lands. Note that 'F' is defined as all agricultural lands that are ecologically fragile (not considered as a prime agricultural land).

Symbol	Description
A	All irrigated lands/areas
B	All irrigable lands already covered by irrigation projects with firm funding commitments
C	All alluvial plain lands highly suitable for agriculture, not irrigated
D	Agro-industrial croplands or lands presently planted to industrial crops that support the viability of existing agricultural infrastructure and agro-based enterprises
E	Highlands or areas located at an elevation of five hundred (500) meters or above highly suitable for growing semi-temperate and high-value crops
G	All fishery areas as defined pursuant to Fisheries Code of 1998

Bureau of Soils and Water Management delineated these lands as part of the Network of Protected Areas for Agriculture and Agro-Industrial Development (NPAAAD). These lands include irrigated and irrigable areas, highly suitable alluvial plains, agro-industrial croplands, highland areas for high-value crops, ecologically fragile lands and fishery areas (Table 1). The NPAAAD and Strategic Agriculture and Fisheries Development Zone (SAFDZ) maps, updated and released in digital form in 2022 https://www.bswm.da.gov.ph/program/updating-npaaad-safdz/. We were granted access of the dataset through the Philippines' eFOI (Electronic Freedom of Information) data request protocol. See Table S1-S2 for the full details of the NPAAAD and SAFDZ dataset and classification.

2.6. Map overlays, spatial analysis and visualization

To analyze the extent of agricultural land conversion in relation to provincial and prime agricultural lands, we utilized open-source Geographic Information System (GIS) tools and data. Provincial boundaries were obtained from the Global Administrative Areas Database (GADM) and the official names of provinces in the Philippines, as of 2020, were used. The analysis focused on areas with an 8% slope classified as Alienable and Disposable (A&D) lands in the Philippines, utilizing geospatial slope data to delineate these areas.

Rasters of converted croplands to built-up areas were converted into polygons. Then, we performed bivariate analysis to visualize the relationships between agricultural land conversion and selected variables, such as % change in agricultural lands and % built-up areas from these changes. This is to analyze the relationship between the percentage of total agricultural lands in 2003 and the percentage change in agricultural lands from 2003 to 2019, as well as the percentage change in agricultural lands and the percentage of built-up areas resulting from these changes.

For the classification of the bivariate maps, we used quantiles to partition the data and ensure parity in class contributions, mitigating dominance by skewed distributions. Quantile classification divides sorted data into q intervals containing equal numbers of observations. For sorted data $X = \{x_{(1)}, x_{(2)}, \dots, x_{(n)}\}$, the kth quantile break is:

$$Q_k = x_{\left\lceil \frac{k}{q}\cdot n \right\rceil} \quad \text{for } k = 1, 2, \dots, q-1 \tag{3}$$

where n = total observations and $\lceil\cdot\rceil$ denotes the ceiling function. This ensures each class contains n/q observations. We partitioned into nine categories based on the distribution of two variables, X (e.g., percentage change in agricultural land) and Y (e.g., percentage change in built-up areas). The classification is defined as:

$$\text{Category} = \begin{cases} \text{Low-Low}, & \text{if } X \le Q_{33}(X) \text{ and } Y \le Q_{33}(Y), \\ \text{Low-Med}, & \text{if } X \le Q_{33}(X) \text{ and } Q_{33}(Y) < Y \le Q_{66}(Y), \\ \text{Low-High}, & \text{if } X \le Q_{33}(X) \text{ and } Y > Q_{66}(Y), \\ \text{Med-Low}, & \text{if } Q_{33}(X) < X \le Q_{66}(X) \text{ and } Y \le Q_{33}(Y), \\ \text{Med-Med}, & \text{if } Q_{33}(X) < X \le Q_{66}(X) \text{ and } Q_{33}(Y) < Y \le Q_{66}(Y), \\ \text{Med-High}, & \text{if } Q_{33}(X) < X \le Q_{66}(X) \text{ and } Y > Q_{66}(Y), \\ \text{High-Low}, & \text{if } X > Q_{66}(X) \text{ and } Y \le Q_{33}(Y), \\ \text{High-Med}, & \text{if } X > Q_{66}(X) \text{ and } Q_{33}(Y) < Y \le Q_{66}(Y), \\ \text{High-High}, & \text{if } X > Q_{66}(X) \text{ and } Y > Q_{66}(Y), \end{cases} \tag{4}$$

where Q_{33} and Q_{66} represent the 33rd and 66th percentiles of the distributions of X and Y, respectively. This classification provides a detailed representation of the bivariate relationship across nine categories.

While the bivariate maps provided a visual representation of the relationship between these variables in each province, we supported the maps with bar graphs of the conversions that disaggregate between NPAAAD and non-NPAAAD conversions. The provincial summaries with NPAAAD information were also summed per region. The aggregated scale also minimizes the effect of random errors and reduces the impact of pixel counting bias, ensuring more reliable spatial comparisons and trend analyses.

The last spatial analysis was proximity analysis using OSM road network data (primary roads) and the converted cropland. All geospatial data preprocessing, spatial analyses and visualization were performed using *R* software, particularly using 'sf' and 'terra' packages and 'biscale' package.

3. Results

3.1. Validation of the agricultural change data

The user accuracy for the cropland change data to built-up was calculated to be 81%. This indicates that 81% of the areas identified as exhibiting agricultural change in the dataset were correctly classified as such when compared to reference data and suggests a reasonably reliable cropland classifications of the EO dataset within the local context. Those commission errors (maps detected conversion but the reference data did not) are those areas that remained crop lands but without evident vegetation yet i.e., land preparation, fallow and post-harvests especially when they are rice paddies with burned rice straws.

3.2. Province-level correlations and spatial analysis

Fig. 3 shows the relationship between cropland decrease and built-up expansion, particularly the high positive correlation (r = 0.89). The figure also shows some relationship between total agricultural area and built-up expansion (r = 0.38). While a positive trend exists, the spread of data points suggests that built-up expansion is less dependent on the total agricultural area, implying other influencing factors might be at play e.g., provinces with large areas for high-value crop production with intact economic value.

Fig. 4 shows bivariate maps capturing agricultural land conversions into built-up areas from 2003 to 2019 across Philippine provinces. The left panel cross-references the percentage reduction in agricultural area with the proportion of that land converted to built-up use, while the right panel compares baseline agricultural area in 2003 with subsequent conversions. The spatial patterns are uneven, with high-conversion provinces clustered across Luzon (e.g., Bulacan, Pampanga, Nueva Ecija), Mindanao (e.g., South Cotabato, Sultan Kudarat, Maguindanao) and select areas in the Visayas (e.g., Cebu, Negros Occidental). These provinces often fall in the upper-right quadrant of the bivariate grid, reflecting both large agricultural land bases and significant conversion rates. In contrast, low-conversion provinces such as Ifugao, Mountain Province, Palawan and Eastern Samar show limited built-up

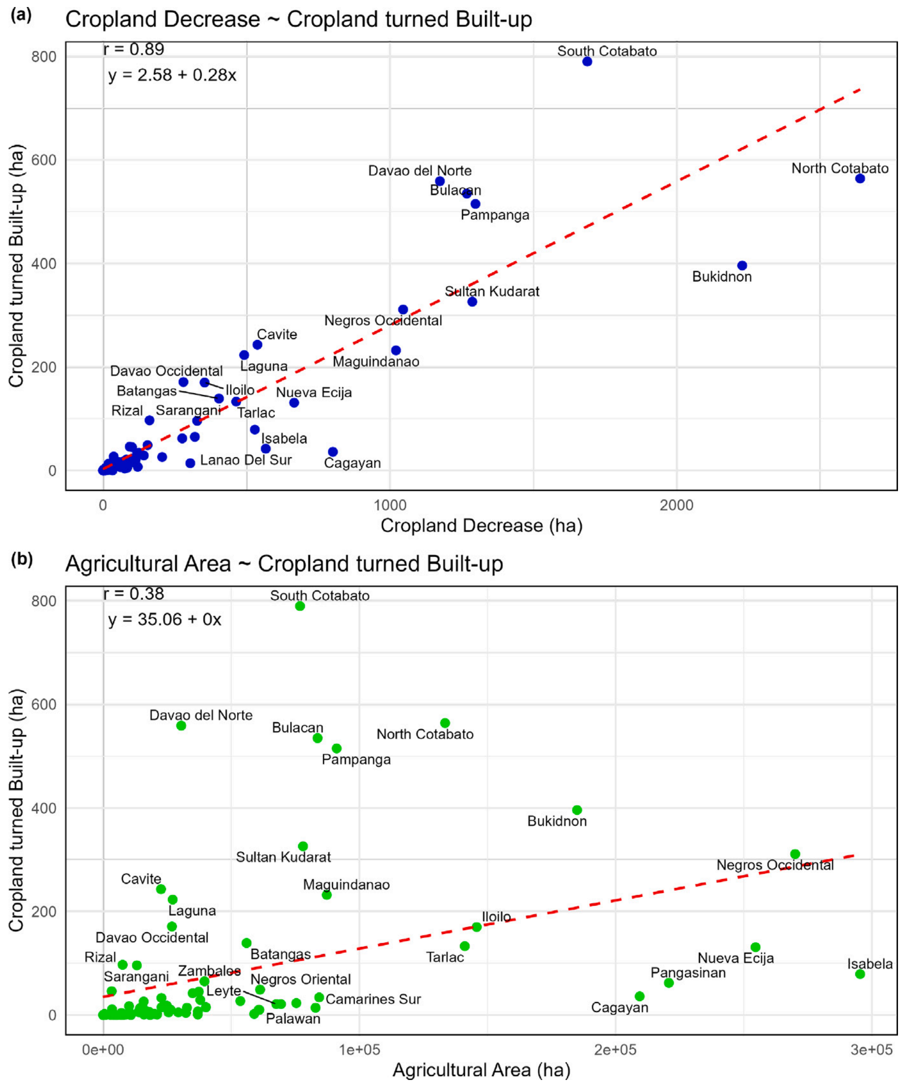

Fig. 3. Correlation between agricultural land area, decrease in croplands and increase in built-up areas.

encroachment, likely due to physical constraints or lower development pressure. These results reveal that agricultural land conversion is highly stratified, often following urbanization corridors, peri-urban zones and regions with emerging infrastructure.

Fig. 5 shows conversions to built-up categorized as within and outside NPAAAD areas. The numbers are 3,228 ha and 7,169 ha or 31% and 69% of the total conversions, respectively. While distinct spatial patterns across provinces can be observed, the proportion of conversion within NPAAAD stands out. South Cotabato recorded the highest total conversion area, with approximately 1,700 ha converted, of which over 470 ha fell within protected NPAAAD zones. Bukidnon followed with a total of roughly 1,450 ha converted, including 430 ha under NPAAAD. Other top provinces in terms of absolute converted areas included North Cotabato, Sultan Kudarat and Maguindanao, each reporting more than 600 ha of land use change, with substantial portions also coming from NPAAAD-designated lands. See Table S2 for further details.

Overall, among the top 15 provinces with the highest conversion, at least 8 exceeded 200 ha of conversions within NPAAAD zones indicating significant encroachment into legally protected agricultural lands. Central Luzon provinces such as Tarlac and Nueva Ecija appeared prominently in the list, reinforcing regional concerns over land conversion pressures in food production zones. Notably, most of these conversions were observed in Central and Southern Mindanao and select parts of Central and Northern Luzon, aligning with known hotspots of urban and industrial expansion.

Regionally, NPAAAD conversions are concentrated in SOCCSKSARGEN (largest by far), followed by Northern Mindanao, Davao Region, and BARMM, with Central Luzon next at a smaller magnitude (Fig. 6). Across these hotspots, conversions are dominated by agro-industrial zones, with alluvial plains second; nationally this mirrors a composition of 41.2% agro-industrial and 37.2% alluvial. Irrigated NPAAAD lands contribute 13.1%, while highlands (6.6%) and fishery (1.8%) make up the remainder. The bulk of encroachment occurs on agro-industrial and alluvial lands in Southern Mindanao, with additional though smaller losses of irrigated areas in Central Luzon and select parts of the Visayas and Mindanao.

4. Discussion

4.1. Utility of EO dataset for monitoring agriculture to built-up conversions

Achieving an 81% user accuracy in validating agricultural land changes using GLAD dataset underscores the utility of EO data for monitoring agriculture to built-up conversions. User accuracy reflects

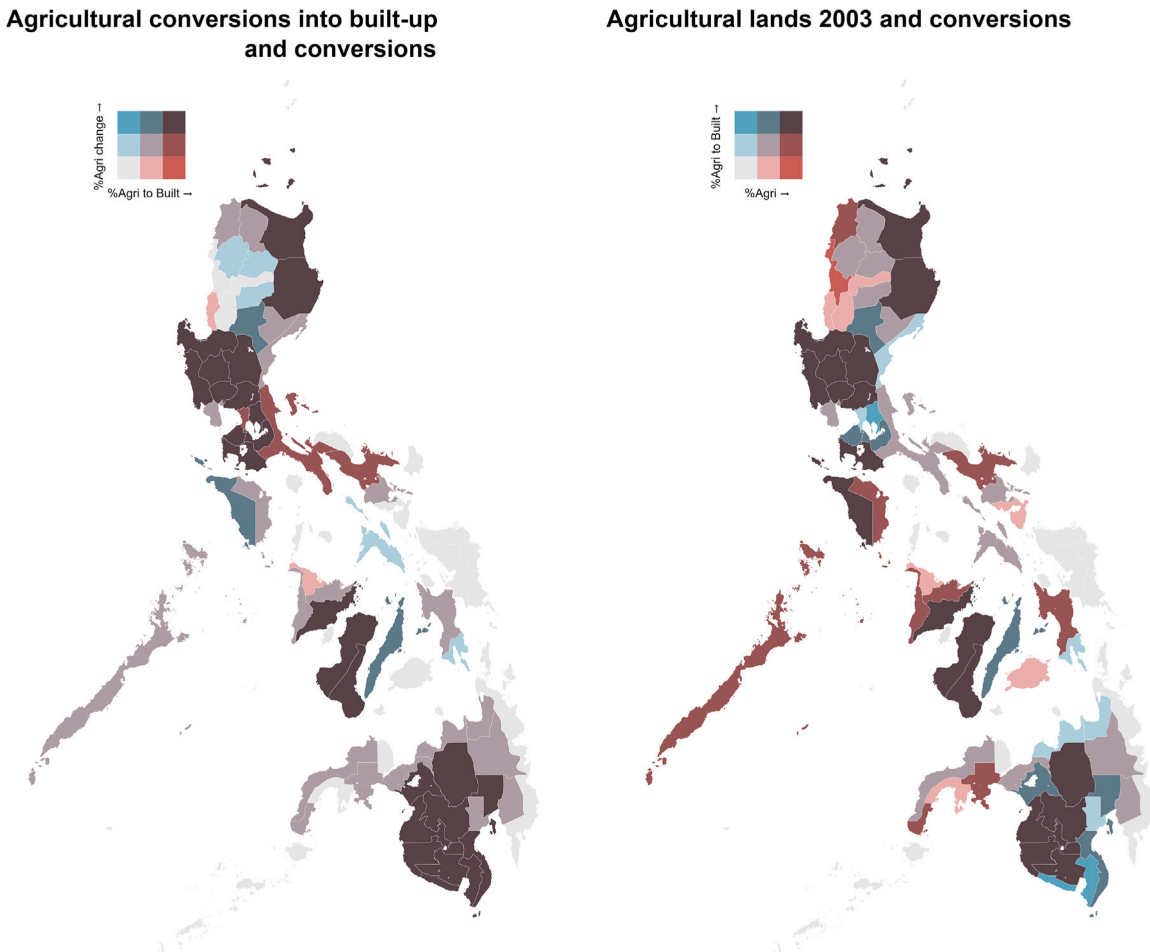

Fig. 4. Bivariate maps of % agricultural changes and % agriculture converted built up from 2003 to 2019 (left) and % agricultural lands in 2003 and % agriculture converted built up from 2003 to 2019 (right). Note that the color matrix can be interpreted from 'low' to 'high' (left to right and bottom to top).

the reliability of the classification from the perspective of the user of the data, emphasizing the proportion of true positives among the classified instances. Remote sensing (RS) techniques are particularly effective in detecting such conversions due to the distinct spectral signatures of agricultural and built-up areas, which simplifies classification compared to more subtle transitions such as forest to grassland (Sam Navin and Agilandeeswari, 2020). High-resolution imagery further enhances this capability by providing detailed spatial information, allowing for precise identification of land-use changes.

While much built-up area is residential (Angel et al., 2016), finer land-use classification is feasible using building-footprint datasets (e.g., Google Buildings). Peri-urban zones (interfaces of urban and rural areas) are dynamic hotspots of conversion driven by proximity to cities and infrastructure (Mulya et al., 2024). Complementary reference sources, such as Google Street View for fine-scale roadside land use (Li et al., 2015); crowdsourced data of land uses e.g., via *Geo-Wiki* (Fritz et al., 2012); drone data open repositories; and local farmer apps (e.g., *Digisaka*), can populate a geodatabase of agricultural land-change evidence. These reference datasets can be further validated and updated by participatory community mapping. Visualizing these datasets through interactive web dashboards and story maps translates GIS outputs into policy-ready insights. Finally, AI-enabled systems when coupled with participatory governance can strengthen agricultural planning and policy by bridging data gaps and enhancing transparency in land use decision (Osorio et al., 2024). For instance, Mehra and Swain (2024) followed an AI-based workflow to provide comparative benchmarks for how EO-driven projections can be systematically embedded into GIS-based land use policies and scenario building.

While EO datasets can provide analysis-ready data, limitations remain especially for analysis at higher temporal resolution. For example, Li et al. (2022) highlight how frequent cloud cover especially in tropical regions like the Philippines can hamper reliable detection, while temporal mismatches between EO updates and rapid urban and peri-urban expansion can delay detection of conversions. Similar constraints have been observed in other insular Southeast Asian countries such as Indonesia and Malaysia, where reliance on EO monitoring without consistent and adequate validation has resulted in gaps, higher omission errors and underestimating land use changes (Wang et al., 2023). Other limitations of EO for agricultural monitoring are elaborated in Whitcraft et al. (2015).

4.2. Associations between decreasing croplands and increasing built-up areas

We found a strong positive correlation ($r = 0.89$) between cropland decrease and built-up expansion at the province level, suggesting that urbanization and population growth are significant drivers of agricultural land conversion. This is consistent with global findings that urban sprawl and infrastructure development, particularly near roadsides and strategic locations, often come at the expense of agricultural

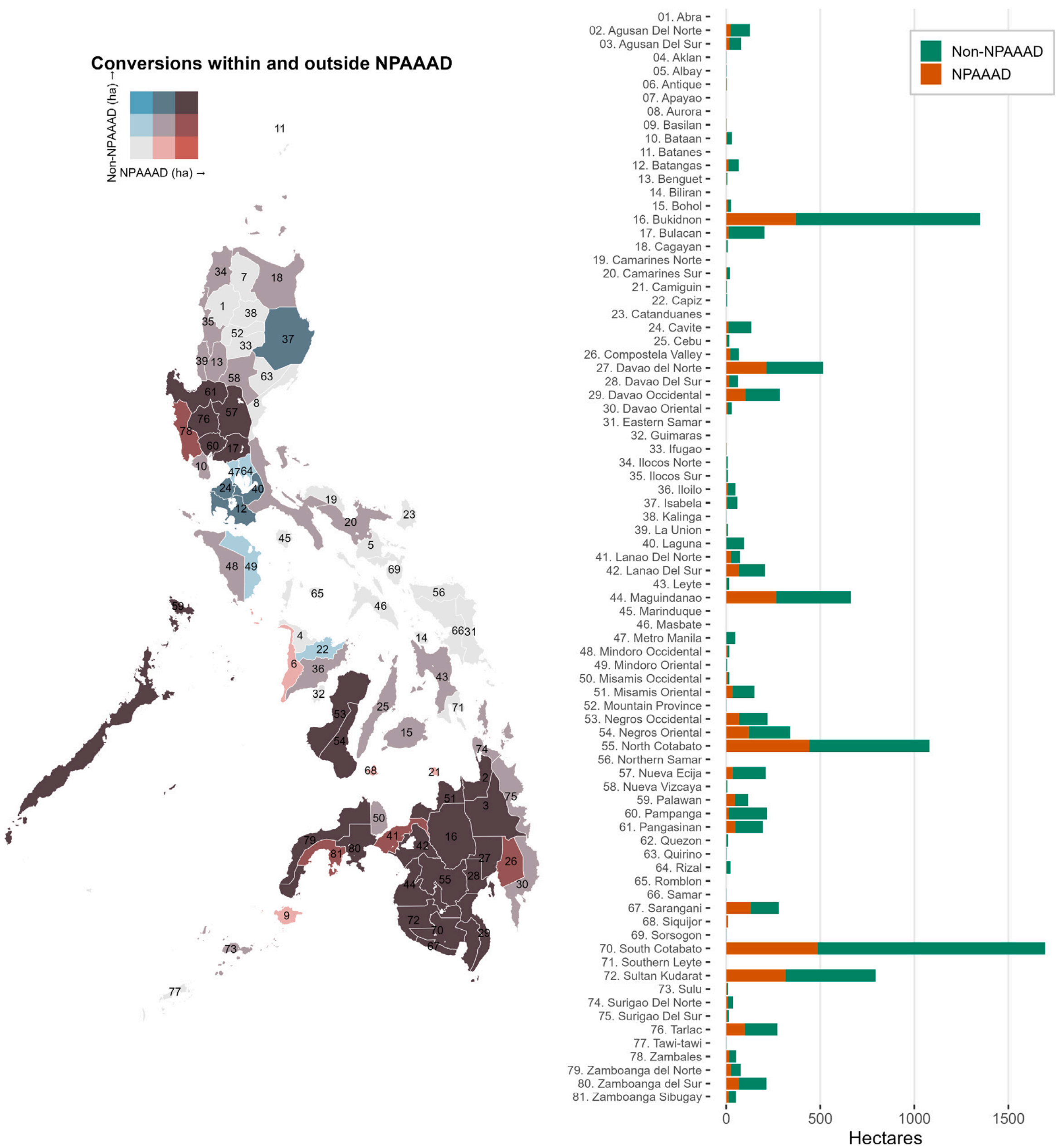

Fig. 5. Bivariate maps of converted croplands into built-up inside and outside NPAAAD, including summary statistics per province.

lands (McManamay et al., 2024; Linh et al., 2024; Mao et al., 2025). Same findings were found in several local studies with the same study areas as the hostpots provinces identified in this study. In Southern Philippines, Janiola and Puno (2018) and Masancay et al. (2025) both reported decreasing agricultural years 2002–2023 are caused by rapid population increase and accumulation of different industrial plantations. In Central Luzon, Taer (2024) compiled all studies driving the decline in rice areas over the past 30 years. He mentioned rapid urbanization and sprawl have directly converted 30%–50% of rice lands near cities displacing farmers and threatening food security. Alberto et al. (2019) conducted a 1989–2019 investigation in the rice granary of the Philippines (Nueva Ecija) and found out that built-up area has increased at a much higher rate than any land uses.

The less prominent correlation between total agricultural area and built-up expansion ($r = 0.38$) implies that other factors, such as land use policies or localized urban planning practices, may moderate the extent of agricultural conversion to built-up areas. Moreover, provinces with vast agricultural lands dedicate production of high-value crops and these are less susceptible to conversions given their economic value (see Figure S2). At least 12 high-value crops are identified by Philippine Statistics Authority in these provinces. On the other hand, there existed some provinces with larger agricultural areas that also exhibited larger cropland conversions e.g., Bukidnon, Negros Occidental. These regions are often more vulnerable to conversion due to their strategic proximity to urban centers and infrastructure projects.

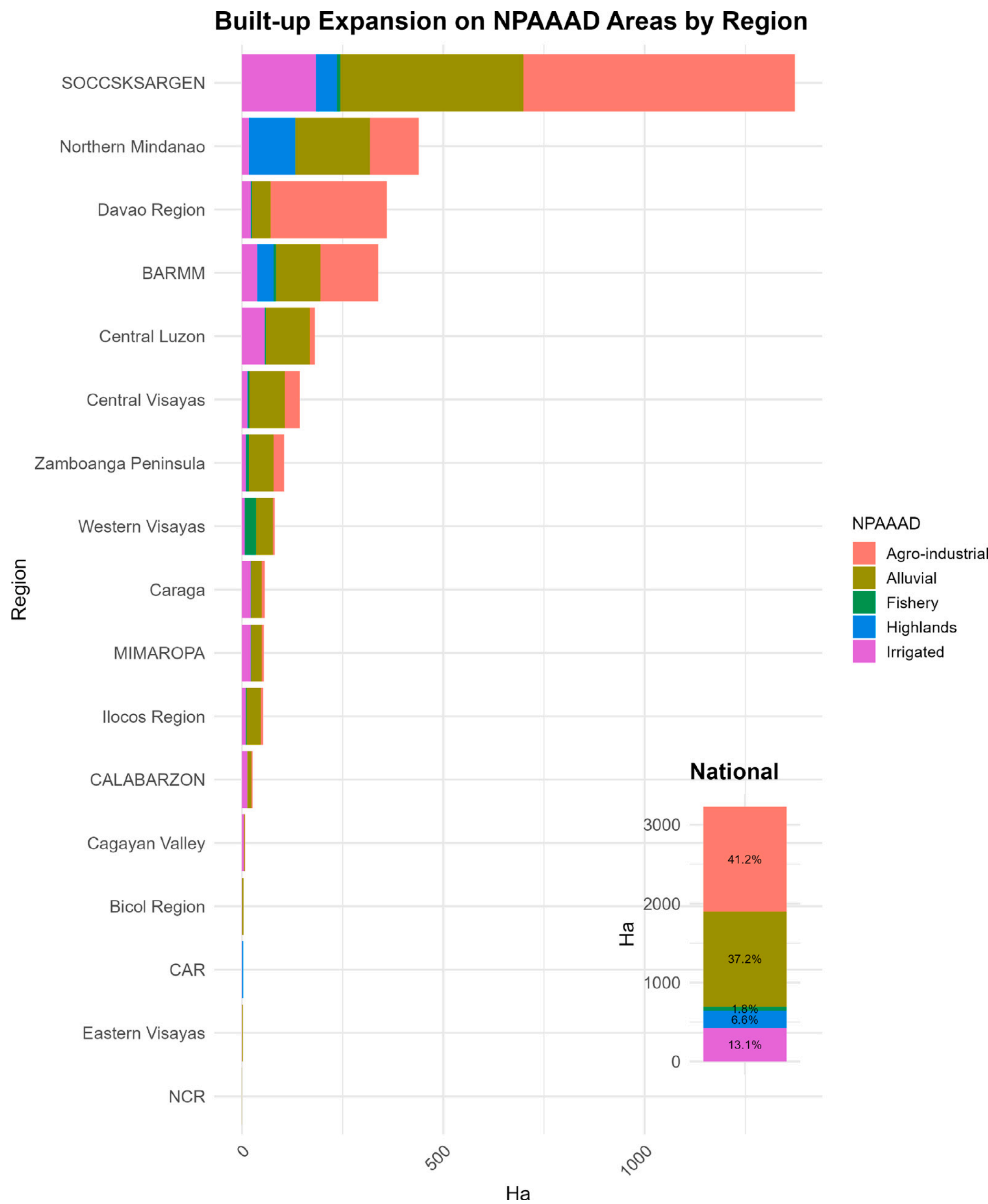

Fig. 6. Regional and national breakdown of croplands converted into built-up under NPAAAD areas.

We further investigated and found that agricultural land conversions in Luzon predominantly occurred near primary roads, with a mean distance of just 3.5 km, indicating strong road-induced development pressure. In contrast, Visayas exhibited a wider spatial spread, with a mean distance of 19.6 km, suggesting conversions are occurring even in relatively remote areas. Mindanao falls in between, with a mean of 8.5 km, highlighting mixed patterns of peri-urban expansion and accessibility-driven change (See Figure S1).

4.3. Long-term implications of the conversions

Cropland conversion to built-up areas is often irreversible, as urbanized lands rarely revert to agricultural use. This phenomenon has been well-documented in remote sensing-based studies, emphasizing the alarming pace of agricultural land loss in rapidly urbanizing regions (Wen et al., 2024; Assennato et al., 2022). The combination of increasing population density and strategic urbanization of agricultural lands in the Philippines paints a worrying picture of the country's future food security. Moreover, an increase in financial loan schemes targeting low to middle-income households, particularly for studio-type apartments. This trend reflects efforts to address housing affordability challenges by enabling access to smaller, more affordable unit (Ballesteros and Ancheta, 2022). Aside from the residential lands pressure, a progressing industry that are expanding in the past years are solar farms. Recall that we noticed areas flagged as conversions (see Fig. 2) but these should be subject to further validation given that solar panels can coincide with agricultural lands i.e., agrivoltaics.

Landscape fragmentation, a concept frequently analyzed in forest landscapes but rarely applied to agricultural land-use change, could provide valuable insights into the spatial structure and continuity of cropland amid urban expansion. Metrics such as patch size, edge density and connectivity could be explored in future studies to assess how built-up encroachment disrupts agricultural land continuity (Foley et al., 2005).

4.4. Policy implications of conversions within NPAAAD

The encroachment of urban development into agricultural lands poses a significant threat to the Philippines' agricultural productivity. Urban expansion, driven by population growth and infrastructure development, often occurs at the expense of fertile croplands, leading to a measurable decline in food production capacity (van Vliet et al., 2017). Despite the existence of legal frameworks such as Republic Act No. 9700 (Comprehensive Agrarian Reform Program Extension with Reforms) and Republic Act No. 8435 (Agriculture and Fisheries Modernization Act), enforcement challenges persist, undermining efforts to protect prime agricultural lands (Briones, 2022).

Our geospatial analysis revealed that large portions of land converted to built-up use between 2003 and 2019 occurred within zones designated as non-negotiable for conversion under the NPAAAD. The policy instrument of NPAAAD is the DOA ADMINISTRATIVE ORDER NO. 38, S. 1999, October 04, 1999. Provinces such as Bukidnon, South Cotabato, Nueva Ecija and Misamis Oriental alone accounted for over 3228 ha of NPAAAD lands lost to mostly to urban expansion and even industrialization (Pelicano and Pelicano, 2013; Taer, 2024). These areas are among the most agriculturally productive in the country and their conversion threatens both local and national food security targets. Such trends suggest systemic governance gaps and insufficient monitoring of protected areas. At the local level, Comprehensive Land Use Plans (CLUPs) and local zoning ordinances must be reviewed and rectified to reflect the non-negotiable for conversion and SAFDZ guidelines (BSWM, 2020). Strengthening regulatory instruments should be complemented by digital integration of parcel-level cadastral maps and satellite-based change detection, enabling near real-time monitoring and rapid enforcement of land-use restrictions. In addition, trend cost–benefit analysis can help local governments weigh the economic gains of conversion against long-term agricultural productivity losses and food security implications. Identified conversion hotspots can undergo policy compliance audits to countercheck potential land grabbing, speculative conversion, and zoning irregularities.

The patterns of conversions within NPAAAD are policy-relevant because agro-industrial and alluvial lands (almost 80% of conversions within NPAAAD) are exactly the high-value and road-accessible areas that urban and industrial projects target; their large, contiguous parcels in Central and Southern Mindanao make conversion administratively and financially attractive (Kelly, 2018). The smaller but notable losses of irrigated NPAAAD in Central Luzon are likely driven by proximity to expressway and industrial estate corridors. Recall that the conversions nearest to primary roads occurred mostly in Luzon, with an average distance of 3.51 km (Figure S1).

4.5. Outlooks and possible pathways in the upcoming years

The findings of this study reinforce long-standing concerns over the unregulated conversion of agricultural land in the Philippines and offer robust spatial evidence to support ongoing legislative reforms. One of the most critical policy gaps is the absence of a National Land Use Act (NaLUA), a comprehensive bill that would guide the allocation, protection and utilization of land resources nationwide. Despite nearly three decades of advocacy since the 9th Congress in 1994, the bill only made substantive progress recently, when House Bill No. 8162 was passed by the House of Representatives and referred to the Senate in May 2023 (Senate, 2023) https://web.senate.gov.ph/lis/bill_res.aspx?congress=19&q=HBN-8162. As documented by Navarro (2023), the lack of a unified land use framework has led to ad hoc, uncoordinated land conversion, particularly in prime agricultural zones. This discussion paper has detailed the reasons and urgency for the NaLUA.

Public consultations and multi-stakeholder dialogues, particularly involving local farmers and landowners, are essential to strengthen decision-making processes and promote community engagement in safeguarding agricultural lands. These participatory processes can also support a more inclusive approach to zoning and land-use planning i.e., considering Shared Socioeconomic Pathways (SSPs). For instance, Lasko and Vadrevu (2024) highlighted spatial monitoring variations in Southeast Asia and their implications for how EO data, when combined with local-led GIS overlay and hotspot mapping, can inform environmental policy strategies. Such local participation can ease the investigation of underlying drivers of agricultural land conversions we are studying in parallel to this study. When presenting information to the public, an effective online medium for such has been through story maps, allowing GIS data to be understood easier even by local stakeholders (Walshe, 2016).

At the national scale, aligning both legislation and implementation mechanisms with international commitments such as the Sustainable Development Goals (notably SDG 2 and SDG 11) and the Paris Agreement can reinforce long-term agricultural resilience and attract climate-aligned investments. A practical and timely intervention would be the application of low carbon farming particularly in paddy rice (e.g., Alternate Wetting and Drying) not only to preserve the lands, but also provides additional income from carbon credits (Evangelista et al., 2026).

5. Conclusion

This study demonstrated the effectiveness of Earth Observation in mapping and understanding the conversion of agricultural land to built-up areas in the Philippines from 2003–2019 (cropland change map = 81% accuracy). Cropland decrease and built-up expansion were highly correlated (r = 0.89), while spatial analysis further confirmed that a substantial portion (around 3,228 ha) of conversions falls within areas designated as non-negotiable areas for conversion under the NPAAAD. The updating of the NPAAAD and SAFDZ datasets by the national government is timely, coinciding with the growing availability of analysis-ready EO data for integrated spatial analysis. Thanks to the eFOI portal, streamlining public access to these national data is made efficient.

The findings reinforce long-standing concerns over the unregulated conversion of agricultural land and highlight the urgency of institutional reforms, particularly the passage of the National Land Use Act (NaLUA), to guide the allocation, protection, and utilization of land resources nationwide. Providing the needed spatial information are satellite-based near-real-time monitoring systems and digital agriculture mobile apps (e.g., crowdsourcing apps) capable of detecting non-compliant land-use changes. These systems should eventually be embedded within the operational framework of the NaLUA to ensure that spatial data inform land allocation decisions and regulatory enforcement. Lastly, AI-based innovations e.g., efficient scenario building, cost–benefit analysis decision-support and mapping of specific land-uses following the conversions nationwide are all deemed helpful inputs for mandated local land use planning.

CRediT authorship contribution statement

Arnan B. Araza: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Wesley Gagarin:** Writing – review & editing, Visualization, Data curation. **Ma. Christina Corales:** Writing – review & editing, Data curation. **Chad Patrick Osorio:** Writing – review & editing. **Marlo D. Mendoza:** Writing – review & editing, Investigation. **Rico Ancog:** Investigation.

Declarations

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors. During the preparation of this work the author(s) used ChatGPT+ in order check text consistency, and debug and optimize codes used. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.landusepol.2025.107874.

Data availability

Data will be made available on request.

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