Semi-Automated Land Use Monitoring Prioritization Scheme Based on Forest Loss, Cropland Loss, and Built-up Gain from 2000-2020 of Philippine Local Government Units

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Keywords: Land Cover Land Use Change, Forest Loss, Cropland Loss, Built-up Gain, Hotspot Analysis, Monitoring Prioritization

Abstract

Local Government Units (LGUs) in the Philippines are mandated to craft and enforce Comprehensive Land Use Plans (CLUPs) and Zoning Ordinances to guide sustainable land use. However, limited resources hinder effective monitoring and enforcement, leading to issues such as environmental degradation and urban sprawl. To support LGUs, the Environmental, Land Use, and Urban Planning and Development Bureau of the Department of Human Settlements and Urban Development (DHSUD-ELUPDB) seeks a data-driven approach to identify and prioritize areas most affected by cropland loss, forest degradation, and urban expansion. Leveraging global geospatial datasets from the GLAD Laboratory, this study proposes a semi-automated land use monitoring prioritization workflow based on LCLUC indicators. This approach enables national agencies to efficiently assess over 1,600 LGUs, target technical support, and optimize resource allocation for improved land use governance. Principal Component Analysis (PCA) was employed to derive indicator weights at the provincial level, allowing for the assessment of each factor's contribution to overall LCLUC. Using these weighted scores, high-priority LGUs were identified at both national and regional scales, with Dumaguete City in Negros Oriental, Bongao in Tawi-Tawi, and Mercedes in Eastern Samar ranking the highest overall. PCA-weighted scores aligned high-scoring LGUs with provincial development goals, while provincial weights improved consistency with the national urban settlement hierarchy. Notably, high-scoring LGUs were situated within land use change hotspots clusters. Distance correlation analysis showed stronger interactions among LCLUC indicators at the provincial scale, revealing regional land use dynamics that may be masked nationally.

1. Introduction

Land use planning is a critical process that shapes the physical layout of human settlements. It involves the systematic assessment of land and its uses to guide the development and conservation of resources in a sustainable, equitable, and efficient manner (Metternich, 2017). Effective comprehensive land use planning (CLUP) ensures that the current and future needs of the population are met.

However, an often overlooked but crucial step in the CLUP process is implementation and monitoring. Planners and local government units (LGUs) frequently struggle with this due to limited financial and human resources. Although nationwide tools for land use monitoring and assessment are being developed, they face similar resource constraints. Thus, identifying pilot sites is necessary before a full-scale rollout. Prioritizing key areas provides a more efficient approach to monitoring regions with the following indicators: high conservation value and increased human activity. These indicators can be quantified by areas that have experienced extensive land cover and land use changes (LCLUC), specifically, forest cover and cropland loss, as well as built-up gain (Potapov et al., 2022).

In land use planning, one method for identifying priority areas is through stakeholder consultations to determine which LGUs require technical assistance. Another method is the climate and disaster risk assessment process, which identifies areas within an LGU that have high exposure and vulnerability; these areas are then prioritized for hazard mitigation measures (HLURB, 2014). However, these existing methods are not comprehensive and often fail to address the complexity of stakeholder interests and competing land use demands (Leppert & Lech, 2018). Geographic Information Systems (GIS) are tools used to map and analyze geospatial data (USGS, 2023). Using a GIS-based prioritization scheme offers a robust and data-driven approach to identifying priority areas for land use monitoring and sustainable development.

This study proposes a land use monitoring prioritization scheme to identify key areas for land use monitoring in the Philippines, focusing on three factors: forest cover loss, cropland loss, and built-up area gain. The researchers also aim to identify LGUs with significant land use change and analyze the correlation and interdependency among these variables to determine their optimal weights in calculating a priority score for each LGU.

The proposed scheme is intended to support national government agencies in selecting pilot sites for land use zoning monitoring projects through data-driven methods. It also aims to provide a framework for deploying other systems that promote sustainable human settlements. Analyses were conducted at both regional and national levels, with the city or municipality serving as the minimum mapping unit. The analysis period of land cover changes was limited from 2000 to 2020. The municipality of Kalayaan in the province of Palawan was excluded in the study due to the lack of land cover data.

2. Materials and Methods

2.1 Global Land Analysis & Discovery Data Preparation

This study utilized datasets provided by the Global Land Analysis and Discovery (GLAD) laboratory at the University of Maryland, which is renowned for monitoring global land surface change using Earth Observation data. Specifically, the study utilized GLAD's datasets on Forest Height Loss, Cropland Loss, and Built-up Area Change to examine land use dynamics between 2000 and 2020. GLAD's LCLUC datasets have a spatial resolution of 30 meters, having been derived from Landsat imagery. The user's accuracy varies across the three datasets: 88.5% for forest loss, 73.3% for cropland loss, and 74.1% for built-up, with only the forest loss dataset meeting the 85% acceptability threshold (Potapov et al., 2022). Nevertheless, the datasets were considered suitable for this study due to their unique long temporal coverage and their applicability at the LGU level of analysis.

The LCLUC datasets, originally in raster format with 1 arc-sec spatial resolution, were subsequently converted into vector format and pre-processed to ensure compatibility. These processed datasets were then uploaded into a spatial database, facilitating efficient management and analysis.

2.2 Semi-Automated Monitoring Prioritization Scheme

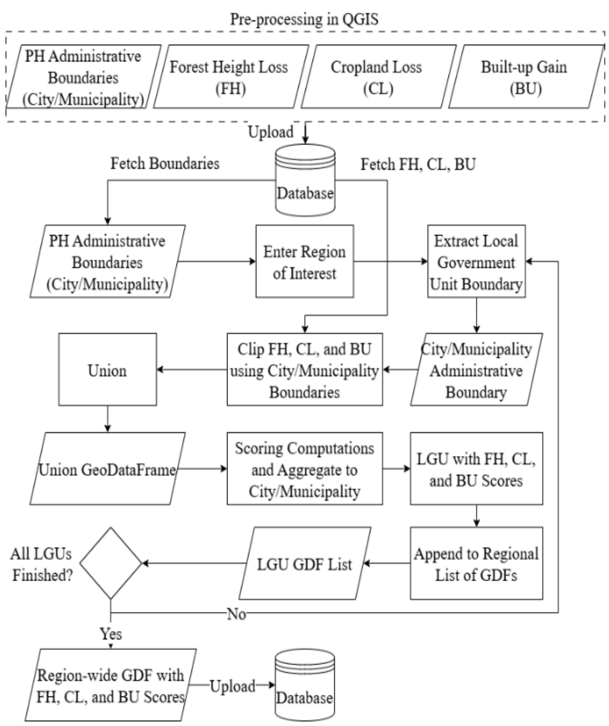

Figure 1. Semi-Automated Prioritization Workflow

The prioritization workflow centers on three key indicators to assess, analyze, and score environmental changes across Local Government Units (LGUs) in the Philippines. The process integrates multiple tools and technologies, utilizing QGIS for pre-processing, PostgreSQL with the PostGIS extension for geospatial data management, and Jupyter Lab, along with GeoPandas and Pandas libraries, for automation. Figure 1 illustrates the semi-automated workflow. Due to hardware limitations, the conversion of LCLUC areas from the datasets into LGU-level scores was performed manually. In contrast, the computation of the final prioritization scores was automated using Python.

The pre-processed geospatial datasets are uploaded to the spatial database to ensure efficient access and management. Given the high resource demands of conducting a nationwide assessment, pre-processing of the datasets was done manually in QGIS at the regional level. Specifically, the boundary of each LGU within a region is extracted and used to clip the nationwide datasets for Forest Height Loss (FH), Cropland Loss (CL), and Built-up Area (BU) changes, thereby reducing computational complexity and optimizing processing efficiency.

Scores for FH, CL, and BU changes were calculated by dividing the total area affected by each indicator by the overall area of the corresponding LGU. The initial prioritization score for each LGU was derived by averaging the three individual scores, with the assumption of equal weighting across the indicators. This approach is further elaborated upon in subsequent sections, where varying weights are computed using Principal Component Analysis at the province level.

The output of the prioritization workflow (Figure 1) is an automated nationwide list of LGUs, ranked by province according to their priority for land use monitoring. However, human input remains necessary to incorporate existing policies and development objectives.

2.3 Distance Correlation and Land Use Change Hotspot Analysis

Distance correlation was used to assess the dependence among the three land cover change variables across varying LGU land cover distributions. Compared to Pearson correlation which examines linear relationships between two variables, distance correlations also account for non-linear associations (Edelmann et. Al, 2021). This was ultimately chosen to examine the relationships between the LCLUC variables since LCLUC often has effects on its surrounding environments that may not be directly attributed to it. Provincial analysis was conducted to examine whether differing levels of urbanization influenced correlation values and to see if clearer trends could be seen if aggregations were made at the provincial level instead of the national level. Distance correlation matrices at both national and provincial levels were computed using the distance_correlation function from the dcor Python module. Based on Cohen (1992), coefficients between 0.3 and 0.5 were interpreted as moderate, while values above 0.5 were assumed to indicate a strong correlation.

For hotspot analysis, the Hotspot Analysis plugin in QGIS was utilized, employing the Getis-Ord Gi* statistic and assessing the spatial relationship defined by Contiguity Edges Corners. The objective was to examine whether the LGUs with the highest prioritization scores also coincide with LCLUC hotspots. The aim is to prioritize LGUs within identified hotspot clusters, allowing neighboring LGUs experiencing similar development pressures to adopt relevant strategies. This approach facilitates the dissemination of effective measures without the need to include more LGUs than is feasible under existing financial constraints.

Additionally, the classification of each LGU according to the 2021 Hierarchy of Urban Settlements was cross-referenced to determine whether LGUs with high prioritization scores based on LCLUC also serve as regional or provincial centers.

2.4 Adjustment of Variable Weights in Prioritization Scoring using PCA

To better capture varying land cover dynamics, Principal Component Analysis (PCA) from the sklearn module was conducted at national and regional levels to determine each variable's contribution. Weights were derived from the absolute loadings of the first principal component, normalized by the sum of all absolute loadings. These PCA-based weights (Appendix A) were then applied to account for the different land cover change dynamics for each province. The LGU prioritization rankings were then reassessed and evaluated in comparison to the equal-weighted approach.

Despite PCA having a more targeted approach in applying weights per province due to the consideration of each variable's contribution to over LCLUC compared to applying equal weights for all LGUs across the country, it is limited by its assumption of linear relationships between the variables. To account for this, other indicators for development, such as whether it is placed highly in the hierarchy of urban settlements, were considered. Another limitation is PCA's sensitivity to outliers and varying data ranges, accounted for by measuring LCLUC extent in terms of percentage rate.

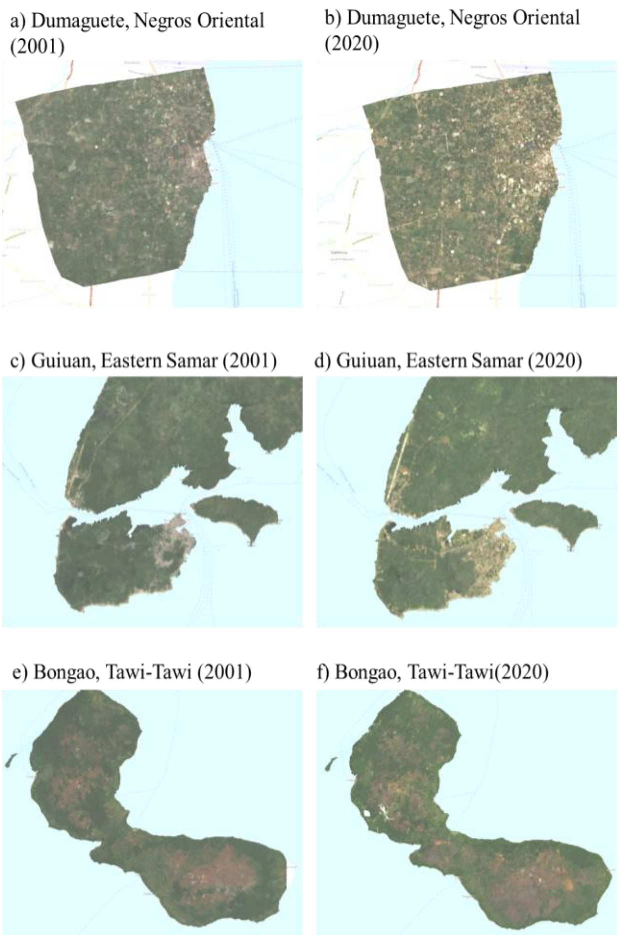

Figure 2. Landsat annual natural color composites; 2001 and 2020

3. Results and Discussion

3.1 LGU Prioritization Scoring and Variable Weight Adjustment using PCA

Top LGUs based on Provincial-weighted Score					
No.	Region	LGU, Province	Prio. Score by Weight		HUS Center
			Equal	Prov. PCA	
1	7	Dumaguete City (Capital), Negros Oriental	8.5	11.01	Sub-Regional
2	BARMM	Bongao (Capital), Tawi-Tawi	7.45	9.92	Sub-Regional
3	8	Mercedes, Eastern Samar	8.29	9.87	Local
4	8	Guiuan, Eastern Samar	7.19	8.55	Provincial
5	10	Tagoloan, Misamis Oriental	8.36	8.41	Local
6	BARMM	Paglat, Maguindanao del Sur	7.66	8.08	Local
7	BARMM	Ditsaan-Ramain, Lanao del Sur	6.38	7.66	Local
8	11	Laak (San Vicente), Davao de Oro (Compostela Valley)	5.98	7.54	Provincial
9	BARMM	Marawi City (Capital), Lanao del Sur	6.69	7.52	Sub-Regional
10	11	Compostela, Davao de Oro (Compostela Valley)	5.96	7.33	Provincial

Table 1. Top 10 LGUs nationwide based on provincial-weighted LCLUC prioritization scores.

Top LGUs based on Equal-weighted Score					
No.	Region	LGU, Province	Prio. Score by Weight		HUS Center
			Equal	Prov. PCA	
1	7	Dumaguete City (Capital), Negros Oriental	8.5	11.01	Sub-Regional
2	8	Julita, Leyte	8.41	1.56	Local
3	10	Tagoloan, Misamis Oriental	8.36	8.41	Local
4	8	Mercedes, Eastern Samar	8.29	9.87	Local
5	8	Pastrana, Leyte	8.21	1.51	Local
6	8	Dagami, Leyte	7.89	1.49	Local
7	BARMM	Paglat, Maguindanao del Sur	7.66	8.08	Local
8	BARMM	Bongao (Capital), Tawi-Tawi	7.45	9.92	Sub-Regional
9	11	Cateel, Davao Oriental	7.41	6.00	Local
10	8	Jaro, Leyte	7.32	1.26	Local

Table 2. Top 10 LGUs nationwide based on equal-weighted LCLUC prioritization scores.

Incorporating the provincial-level weights derived from PCA (Table 1) improved the alignment between high-scoring Local Government Units (LGUs) and those designated as provincial or

https://doi.org/10.5194/isprs-annals-X-5-W4-2025-393-2026

sub-regional centers from the hierarchy of urban settlements, compared to when equal weights were used (Table 2). This indicates that the identified priority LGUs are also assumed to have higher levels of human activity compared to other neighboring LGUs. Figure 2 shows the before and after images of notable priority LGUs that experienced significant LCLUC from 2000 to 2020. Dumaguete consistently emerged with the highest activity scores, attributed to sustained urban expansion since the early 2000s. Other notable LGUs include Guiuan, due to extensive mining activities on Homonhon Island; Marawi City, which underwent large-scale land cover and land use change (LCLUC) as a result of armed conflict; and both Bongao and Mercedes, which recorded significant deforestation over the analysis period.

The identification of Dumaguete as a priority LGU for monitoring is consistent with its designation as a strategic growth center in the 2014–2019 Provincial Development and Physical Framework Plan (PDPFP) of Negros Oriental (Province of Negros Oriental, 2016). The PDPFP outlines the province's intention to transition Dumaguete's primary economic growth driver from agriculture to industry and services in an effort to improve overall provincial economic performance and reduce poverty incidence. Selecting Dumaguete as a pilot site for LCLUC monitoring would support evidence-based decision-making by allowing stakeholders to assess whether ongoing urban development patterns are aligned with the PDPFP's development goals.

The identification of Guiuan as a high-scoring LGU is consistent with the long-term urbanization trajectory outlined in the 2001–2010 Provincial Physical Framework Plan (PPFP) of Eastern Samar (Province of Eastern Samar, 2002). As early as the planning period, Guiuan had already been designated as a marketing and processing hub for surrounding satellite settlements, positioning it as a potential urban center. The PPFP also highlights the province's development strategy to promote the establishment of resource-based industries. This underscores the importance of monitoring land cover and land use changes in the area to assess whether such developments are being implemented sustainably and in alignment with the province's development goals.

Meanwhile, while there are no provincial plans available from the 2000s for Misamis Oriental, their 1975-1995 Provincial Comprehensive Plan (PCP) includes the facilitation of capital investments and development of alienable and disposable lands within the province (Misamis Oriental Provincial Development Staff, 1975). The selection of Tagoloan, ranked 5th, as a pilot site will be beneficial in assessing the implementation of the province's PCP.

To support regional planning, the analysis also identified top-scoring LGUs per region (Tables 1 and 2), which may serve as candidates for pilot implementation by regional offices. When PCA-derived provincial weights were applied, the top-ranked LGUs closely matched those officially recognized as provincial or sub-regional centers, suggesting strong correlation between quantified LCLUC and development-induced population growth.

Regional LCLUC patterns also varied in terms of dominant drivers. In Regions I, III, V, VI, IX, and CAR, built-up area expansion and cropland loss were the most influential variables. Meanwhile, Regions II, VII, VIII, and IV-B showed stronger influence from built-up area gain and forest loss. In Regions IV-A, X, XII, XIII, and NCR, LCLUC drivers exhibited relatively balanced contributions. In contrast, Regions XI and BARMM were primarily influenced by forest and crop loss. Notably, BARMM displayed distinct provincial-level weight variations, indicating localized development dynamics and heterogeneous LCLUC trends across its provinces.

3.2 Land Use Change Hotspot and Distance Correlation Analysis

Strong to moderate distance correlations between built-up area gain and cropland loss were observed in all regions (Table 2). In particular, CAR exhibited the highest correlation, aligning with its significant conversion of agricultural lands for urban development, such as the construction of subdivisions and commercial districts in areas like Tabuk City in Kalinga (See, 2022). This underscores the potential of distance correlation analysis for monitoring agricultural land conversion and reclassification in the absence of land cover maps for a specific area.

	Average Distance Correlation		
Region	**BU Gain – CL Loss**	**BU Gain - FH Loss**	**CL Loss – FH Loss**
1	**0.64**	0.37	0.50
2	0.48	**0.51**	0.31
3	**0.63**	0.45	0.47
4A	**0.64**	0.49	0.43
4B	0.47	0.38	**0.55**
5	**0.65**	0.45	0.45
6	**0.62**	0.41	0.41
7	0.40	**0.52**	0.37
8	0.40	0.46	0.37
9	0.43	0.33	0.28
10	**0.59**	0.48	0.42
11	**0.57**	**0.58**	**0.58**
12	**0.53**	0.47	**0.52**
13	**0.52**	**0.51**	0.41
BARMM	0.45	0.46	0.42
CAR	**0.68**	0.36	0.47
NCR	**0.61**	**0.55**	**0.58**
National	0.19	0.21	0.27

Table 2. Averaged provincial distance correlation values per region between LCLUC variables.

Additionally, strong to moderate correlation between built-up gain and forest loss was also found in all regions, indicating associations between urban expansion and deforestation nationwide (Table 2). Notably, Davao Region had the highest correlation. This is consistent with the clearing of forests and the construction of built-up structures in watersheds such as the Panigan-Tamugan watershed (Colina, 2021).

Meanwhile, the same trends of having moderate to strong correlations across the regions were also found between crop loss and forest loss, with the exception of the Zamboanga Peninsula having weak average values (Table 2). NCR and the Davao region had the highest provincial correlation values, suggesting possible transitions from forested areas to agricultural use.

Overall, urban expansion shows stronger associations with cropland loss than with forest height loss. This is consistent with typical land conversion trajectories, where non-cropland areas such as forests are often cleared for agriculture before being developed into built-up areas. The generally low national distance correlation values highlight the importance of provincial-scale analysis and the influence of localized urbanization patterns and land-use drivers in LGU-level LCLUC.

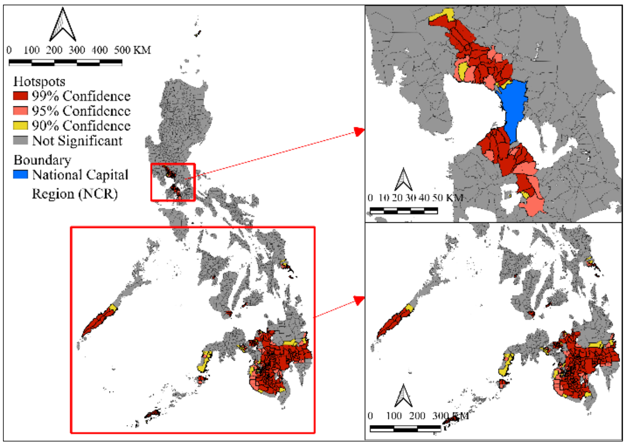

Figure 3. Nationwide LCLUC Indicators Hotspots

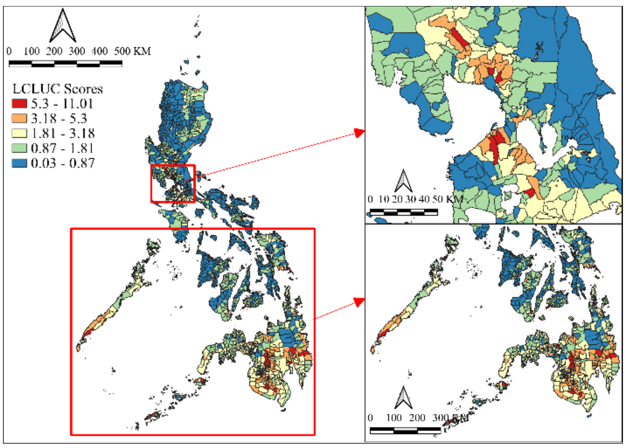

Figure 4. Nationwide LCLUC Indicators Weighted Scores

Hotspot analysis of land use change revealed concentrated areas of significant activity in Central Luzon, CALABARZON, southern Palawan, and mainland Mindanao (Figure 3). Spatial clustering of LGU-level hotspots closely aligned with the locations of priority LGUs identified through LCLUC indicators (Figure 4). Notably, while LGUs within the National Capital Region (NCR) were not identified as hotspots, adjacent LGUs in Central Luzon and CALABARZON exhibited pronounced hotspot activity (Figure 3). This discrepancy may be attributed to the high degree of built-up areas already within NCR even before the 2000s, where ongoing urban growth has shifted towards vertical development, which is less detectable in satellite-based LCLUC analyses. In contrast, surrounding LGUs are experiencing horizontal expansion driven by increasing housing demand, due to the economic opportunities and spillover effects from NCR. In highly urbanized areas like NCR where vertical development is now more prevalent, both prioritization and monitoring become more difficult, Prioritization requires an additional level of analysis since what needs to be monitored shifts into more specific built-up land uses such as residential, commercial, and industrial uses, as compared to the initial monitoring scheme for urbanization.

4. Conclusion and Recommendations

4.1 Conclusion

This study proposed a semi-automated prioritization scheme based on built-up gain, forest loss, and crop loss to identify candidate LGUs for the implementation of development monitoring initiatives. PCA was used to identify appropriate weights for each LCLUC indicator at the provincial level, using the loadings to determine the influence of each indicator to the overall LCLUC of an area. High-priority LGUs at both national and regional levels were identified and found to align with development-oriented objectives outlined in provincial comprehensive land use and development plans. The integration of provincial-level weights, derived from PCA loadings, improved the correspondence between identified LGUs and the established urban settlement hierarchy. LGUs with the highest LCLUC scores were also located within clusters of land use change hotspots. Results from distance correlation analysis indicated that interactions among built-up gain, forest loss, and crop loss are more clearly observed at the provincial scale, reflecting the variability in land use development priorities across provinces that may be obscured when looking from a national lens.

4.2 Recommendations

The researchers recommend exploring a policy-based approach in determining variable weights for the LCLUC indicators and threshold critical values in the selection of priority areas. Policies such the Memorandum Circular 54 of 1993 where maximum limits for how much agricultural land in a city or municipality can be reclassified into other uses are stated can be used to determine the extent of crop loss that should be monitored. Having set threshold values depending on the LGU class (e.g. only 15% of agricultural land can be reclassified for highly urbanized and independent component cities) can create different levels of prioritization based on the LGU class.

Service value estimations from ecosystem degradation due to specific land cover transitions may be explored when looking for thresholds on how much forest loss and crop loss are sustainable for an area's ecosystem. The study also urges decision makers to propose policies outlining critical values for forest loss and uncontrolled urban development to serve as basis for LCLUC score thresholds.

Given that the study only looks at the LCLUC indicators in determining the prioritization levels for monitoring LGUs, further levels of prioritization based on hazard risks through a climate and disaster risk assessment may be considered. A tertiary level of prioritization based on population density to account for vertical urban development for monitoring rapidly urbanizing areas may also be explored.

Acknowledgements

The researchers would like to thank the Department of Human Settlements and Urban Development (DHSUD) and the Department of Science and Technology - Philippine Council for Industry, Energy, and Emerging Technology Research and Development (DOST-PCIEERD) for providing funding to the team.

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Appendix

An interactive map showing the priority LGUs per region can be accessed here: https://ajdccarrido.github.io/nationwide-prioritization-map/

Appendix A: PCA-based LCLUC score weights per province.

Region	Province	Weight		
		BU Gain	Crop Loss	Forest Loss
1	Ilocos Norte	0.377	0.456	0.167
	Ilocos Sur	0.356	0.354	0.289
	La Union	0.327	0.349	0.324
	Pangasinan	0.308	0.412	0.280
2	Batanes	0.500	0.000	0.500
	Cagayan	0.340	0.349	0.311
	Isabela	0.428	0.237	0.334
	Nueva Vizcaya	0.362	0.311	0.327
	Quirino	0.424	0.450	0.125
3	Bataan	0.315	0.258	0.427
	Bulacan	0.289	0.379	0.332
	Nueva Ecija	0.479	0.478	0.043
	Pampanga	0.404	0.383	0.213
	Tarlac	0.348	0.343	0.310
	Zambales	0.368	0.433	0.198
	Aurora	0.352	0.362	0.286
4A	Batangas	0.370	0.238	0.392
	Cavite	0.330	0.367	0.303
	Laguna	0.385	0.389	0.226
	Quezon	0.392	0.375	0.232
	Rizal	0.354	0.342	0.304
5	Albay	0.429	0.161	0.410
	Camarines Norte	0.457	0.451	0.092
	Camarines Sur	0.459	0.476	0.065
	Catanduanes	0.384	0.344	0.273
	Masbate	0.043	0.479	0.477
	Sorsogon	0.335	0.351	0.314
6	Aklan	0.401	0.406	0.194
	Antique	0.422	0.439	0.139
	Capiz	0.423	0.388	0.189
	Iloilo	0.393	0.404	0.204
	Negros Occidental	0.004	0.498	0.498

	Guimaras	0.460	0.289	0.252
7	Bohol	0.313	0.324	0.363
	Cebu	0.383	0.291	0.327
	Negros Oriental	0.443	0.144	0.413
	Siquijor	0.367	0.342	0.291
8	Eastern Samar	0.371	0.232	0.397
	Leyte	0.487	0.459	0.055
	Northern Samar	0.432	0.193	0.375
	Samar (Western Samar)	0.356	0.367	0.277
	Southern Leyte	0.379	0.238	0.383
	Biliran	0.372	0.347	0.281
9	Zamboanga del Norte	0.394	0.396	0.210
	Zamboanga del Sur	0.352	0.371	0.277
	Zamboanga Sibugay	0.439	0.307	0.254
10	Bukidnon	0.385	0.461	0.153
	Camiguin	0.425	0.222	0.354
	Lanao del Norte	0.363	0.286	0.351
	Misamis Occidental	0.376	0.355	0.269
	Misamis Oriental	0.346	0.340	0.313
11	Davao del Norte	0.162	0.431	0.407
	Davao del Sur	0.397	0.293	0.310
	Davao Oriental	0.357	0.379	0.264
	Davao de Oro (Compostela Valley)	0.228	0.332	0.440
	Davao Occidental	0.340	0.330	0.330
12	Cotabato (North Cotabato)	0.314	0.329	0.357
	South Cotabato	0.334	0.321	0.345
	Sultan Kudarat	0.307	0.353	0.340
	Sarangani	0.412	0.303	0.285
NCR	Metropolitan Manila First District	0.413	0.193	0.393
	Metropolitan Manila Third District	0.372	0.380	0.248
	Metropolitan Manila Fourth District	0.146	0.436	0.417
CAR	Abra	0.459	0.462	0.080
	Benguet	0.186	0.403	0.411
	Ifugao	0.476	0.472	0.053
	Kalinga	0.289	0.380	0.331
	Mountain Province	0.383	0.435	0.182
	Apayao	0.438	0.434	0.128
13	Agusan del Norte	0.406	0.403	0.191
	Agusan del Sur	0.494	0.489	0.017
	Surigao del Norte	0.496	0.069	0.435
	Surigao del Sur	0.338	0.319	0.343
	Dinagat Islands	0.340	0.283	0.376
4B	Marinduque	0.127	0.429	0.443
	Occidental Mindoro	0.357	0.367	0.275
	Oriental Mindoro	0.355	0.390	0.255
	Palawan	0.133	0.402	0.465
	Romblon	0.036	0.473	0.492
BARMM	Basilan	0.262	0.367	0.371
	Lanao del Sur	0.464	0.460	0.076
	Sulu	0.382	0.343	0.275
	Tawi-Tawi	0.447	0.111	0.442
	Maguindanao del Norte	0.363	0.329	0.308
	Maguindanao del Sur	0.453	0.425	0.122
	Special Geographic Area	0.267	0.277	0.455

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