The Peri-Urban Sprawl: Characterization and Analysis of Rice Cropland Conversion Using Remote Sensing and GIS Techniques in Butuan City

Charlene A. Bentozal
Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University

Glorie Joy C. Malaluan
Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University

Jun Love E. Gesta
Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University

Lorie Cris S. Asube
Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University

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The Peri-Urban Sprawl: Characterization and Analysis of Rice Cropland Conversion Using Remote Sensing and GIS Techniques in Butuan City

Charlene A. Bentozal[1], Glorie Joy C. Malaluan[1], Jun Love E. Gesta[1,2], Lorie Cris S. Asube[1,2]
[1]Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University, Ampayon, Butuan City,
[2]Caraga Center for Geo-Informatics, Caraga State University, Ampayon, Butuan City
Corresponding author email: lsasube@carsu.edu.ph

Abstract: *Some major cities in the Philippines have been experiencing an apparent conversion of rice cropland into non-agricultural use. Understanding the dynamics of rice cropland conversion in peri-urban areas is essential for minimizing excessive conversion. This study examines the conversion of rice cropland in Butuan City to non-agricultural uses over a 2-year decade from 2003 to 2023. Multispectral imagery and GIS techniques, biophysical and socioeconomic characteristics of areas undergoing conversion were analyzed. A total of 784 hectares were from 2003 to 2013 and 117 from 2013 to 2023. The results indicate significant patterns, with areas mostly less than 1000 square meters located at elevations around 12.49 meters and gentle slopes of 1.1° to 3° consisting of loam soil. Socio-economically, conversions were proximate to infrastructure, less than 230 meters from rivers and 85 meters from roads. These findings underscore patterns in managing land use effectively and preserving agricultural lands, particularly rice croplands.*

Keywords: Peri-Urban Sprawl, conversion, rice cropland, high-risk area, spatial analysis

1. INTRODUCTION

Peri-urban areas represent the transitional zones between rural and urban areas, experiencing significant and rapid transformations in their physical infrastructure, demographic composition, and socioeconomic activities. The issue of peri-urban development can only be adequately examined by considering the need for balanced development in both rural and urban regions [1]. Peri-urban areas are characterized by significant urban expansion processes that tend to encroach upon marginal agricultural activities. These areas often accommodate land uses that may not be desirable to the surrounding communities, such as large-scale commercial developments, entertainment facilities, and retail centers [2]. The rapid expansion of urban areas into peri-urban regions has resulted in the unintended conversion of rice cropland into non-agricultural uses, directly impacting farmers' livelihoods. Rice farming is best suited to loamy and clayey soils, which can hold water necessary for rice development. On the other hand, the chances of rice land conversion were significantly impacted by biophysical and socioeconomic factors, the elevation, slope, proximity to the road, the river, and the soil type of where the rice cropland is planted [3].

Rice fields are identified as the agricultural area most susceptible to conversion [4]. They are often close to urban areas and have better-developed infrastructure than dryland areas, as well as flat topography that facilitates rapid infrastructure development, residential facilities, and industrial estates. These elements contribute to higher population densities in rural areas with rice field agroecosystems. In the Philippines, agricultural land eligible for non-agricultural conversion, such as commercial, industrial, and residential uses, should be carried out through the local government unit or using a Presidential Proclamation, as stipulated by RA No. 6657, which came into effect on June 15, 1988. In the case of agricultural lands that were reclassified before June 15, 1988, the guidelines set forth by the Department of Agrarian Reform (DAR) regarding acquiring an exemption clearance should be followed [5]. In Butuan City, Philippines, the total land area is 81,728 hectares. Between 2014 and 2016, rice croplands covered 8,141.44 hectares, representing 10.038 percent of the total land area [4]. During this period, rice croplands were permanently converted to non-agricultural use. With this, the city's sustainable urban development challenge has arisen due to accelerated urban growth. This results in a significant loss of rice cropland, which can be attributed to inadequate planning and ineffective management.

Timely and accurate information on land cover changes is essential for policy decisions, natural resource planning and management, environmental modeling, understanding habitat distribution, and linking land use activities [6]. Remote sensing has significantly enhanced our ability to analyze and monitor urban dynamics, especially concerning urban expansion and land use changes [7]. Out of the remote sensing datasets, Landsat data is widely used in many urban land cover and land use change studies because it is the only long-standing digital archive offering moderate spatial resolution and consistent spectral and radiometric resolution.

The absence of current characterization information presents difficulty in evaluating the appropriateness of rice cropland for transformation into non-agricultural or in determining the parameters that may impact such conversions. Since there is an apparent conversion of rice cropland to non-agricultural uses, understanding the dynamics of rice cropland conversion in peri-urban areas is thus essential for minimizing excessive conversion to alternative land uses. This lack of information poses significant challenges for urban planners, policymakers, and agricultural stakeholders who need accurate and reliable data to make informed decisions about land-use planning and sustainable development practices. Thus, the study aims to identify the characteristic parameters of rice croplands converted into non-agricultural uses using

Remote Sensing and GIS. Specifically, it seeks to achieve the following objectives: to map the rice croplands in Butuan City for the years 2003, 2013, and 2023; to identify the characteristics of rice croplands that have been converted into non-agricultural uses; and to generate a map of high-risk rice cropland areas for future conversion.

2. METHODOLOGY

2.1 Study Area

Butuan City is located in the province of Agusan Del Norte, in the Caraga region of the Philippines, situated at approximately 8°57' North, 125°32' East (see Fig. 1). The total land area of Butuan City is 81728 hectares km^2, comprising 86 barangays. According to the Philippine Statistics Authority, Butuan City has a total population of 372,910 as of 2020 [8]. Butuan City presents a unique area for analyzing soil characteristics and agricultural practices. The city's landscape combines urban areas, agricultural lands, and natural ecosystems. The agricultural sector is a significant part of the city's economy, with a large portion of the land used for farming and now converted to non-agricultural uses.

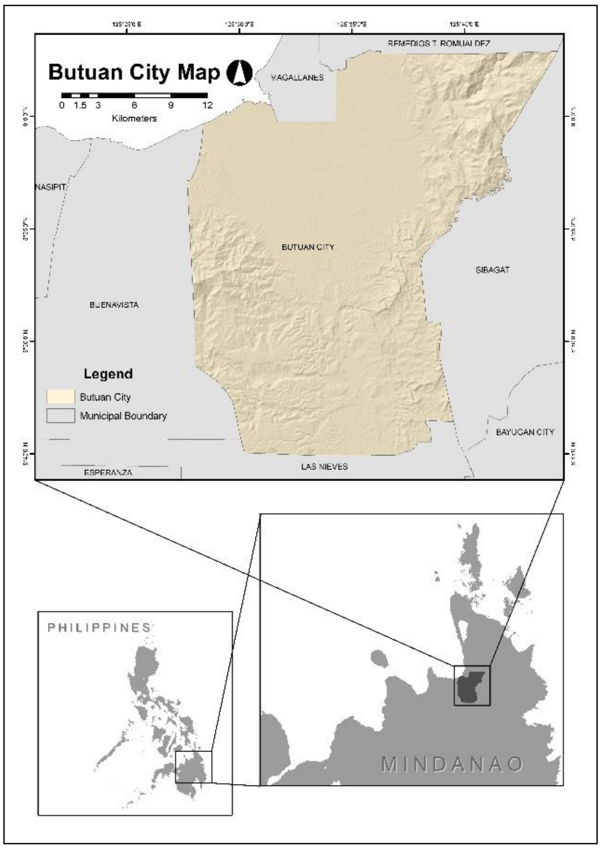


Fig. 1. Map of Butuan City.

2.2 Mapping Rice Croplands in Butuan City for 2003, 2013, and 2023

Cloud-free Landsat images from satellites 4 and 8, taken between 2003, 2013, and 2023, were utilized in this study. These images underwent systematic preprocessing, beginning with loading the raw satellite images into ENVI software to ensure proper alignment and readiness for further processing. The preprocessing started with radiometric calibration, which adjusts the images to normalize the effects of different solar radiation wavelengths, aiming to replicate ground reflectance in each spectral band closely.

Nine distinct LULC (Land Use/Land Cover) classes are predominant in the area. These classes are bareland, built-ups, fishponds, forest, grassland, palms, rice cropland (bare), rice cropland (planted), and waterbody. Training and validation samples of these classes were collected through visual interpretation of high-resolution Google Earth images. The classifier is trained with predefined training data, which includes representative pixel values for various land cover classes. The satellite images were then processed for image classification using a Maximum Likelihood Classification (MLC) classifier, and the resulting classified image was subjected to an accuracy assessment. The final classified images were refined using Google Earth to correct most of the misclassified pixels of rice cropland. The refined classified image was then used to extract the rice cropland boundaries in Butuan City.

2.3 Biophysical and Socioeconomic Characterization of Converted Rice Croplands

Change detection analysis was employed on the 2003, 2013, and 2023 classified images. Biophysical and socioeconomic characterizations were then conducted through spatial analysis using these converted rice croplands. For biophysical analysis, the variables examined included slope, elevation, soil type, and river proximity. Elevation data was obtained from the Digital Elevation Model (DEM) of the Shuttle Radar Topography Mission (SRTM) with a resolution of 1 arc-second (30 meters), sourced from the United States Geological Survey (USGS). The slopes of the converted areas were calculated by generating a slope raster from the DEM. For slope characterization, the classification of slopes according to the Barcelona Field Studies Centre [9] was followed. The standard slope descriptors are the following: flat/Level is 0° - 0.3°; Nearly Level is 0.03° - 1.1°; Very gentle slope is 1.1° - 3°; Gentle slope is 3° - 5°; Moderate Slope is 5° - 8.5°; Strong slope is 8.5° - 16.5°; Very strong slope is 16.5° - 24° and Extreme slope is 24° - 35°. Soil type data was overlaid on the converted areas to analyze the soil types within these regions. The Euclidean Distance tool was applied to river networks for proximity to rivers to determine the proximity of the converted areas to rivers.

Concerning socioeconomic characterization, proximity to roads was only considered. Since road networks vary due to socioeconomic activities in an area, the road networks for 2003 and 2013 were collected and edited. To determine how the converted croplands were affected by the road network in 2003, the 2003 road networks were used, and the same approach was applied for the year 2013. Soil type, road networks, and river systems within Butuan City were obtained from the Caraga Center for Geo-Informatics (CCGEO) of Caraga State University. All datasets were resampled to a 30-meter resolution to ensure the same spatial resolution and were co-registered with the change detection results.

2.4 Generation of a Map of High-risk Rice Cropland Areas for Future Conversion

To generate a map identifying high-risk areas of rice cropland likely to undergo conversion, the rice croplands from 2023 were characterized. Spatial analysis was conducted using zonal statistics to determine the elevations of rice cropland areas. Additionally, the slopes of these areas were calculated by generating a slope raster from the DEM using the same spatial analysis. Furthermore, the proximity to roads and rivers was preprocessed using the Euclidean Distance tool to generate a proximity raster. This raster was then applied with zonal statistics to measure the distance accurately. Data on different soil types was overlaid with the map of the 2023 rice croplands using an intersection overlay technique, allowing for quantifying the percentage of each soil type present in areas with the potential to transition from rice cropland to built-up land.

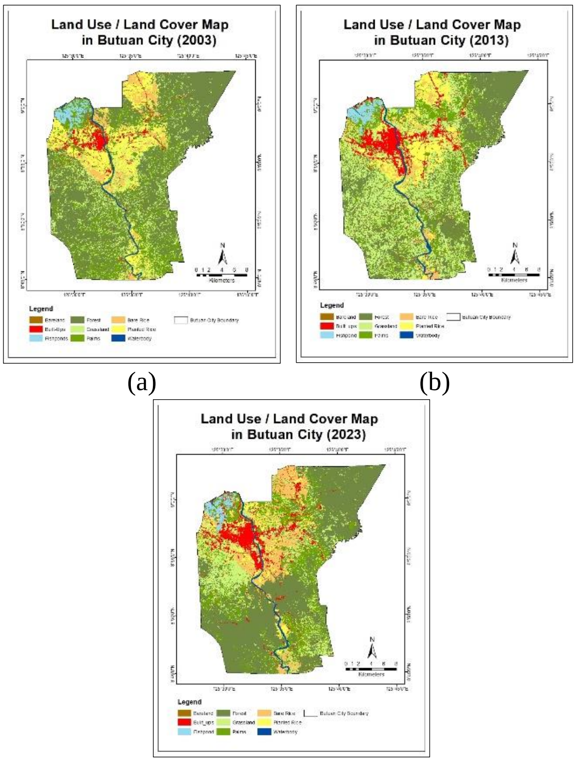
This study utilized Boolean logic to generate high-risk maps of rice croplands. Boolean logic uses the zero-one law [10], in which the map is divided into two classes: high-risk (value=1) and non-high risk (value=0). After completing the rice cropland characterization, the outputs were reclassified, with 0 indicating non-high-risk areas and 1 indicating high-risk areas for conversion. The reclassification of 0 and 1 was based on the characterization of converted rice cropland from the years 2003 and 2013. The reclassified outputs of each parameter were then combined using the Times Spatial Analyst tool, which multiplies the values of each cell in the input rasters to produce a new raster output, highlighting the high-risk areas for future conversion.

3. RESULTS AND DISCUSSIONS

3.1 Maps of Rice Croplands in Butuan City for 2003, 2013, and 2023

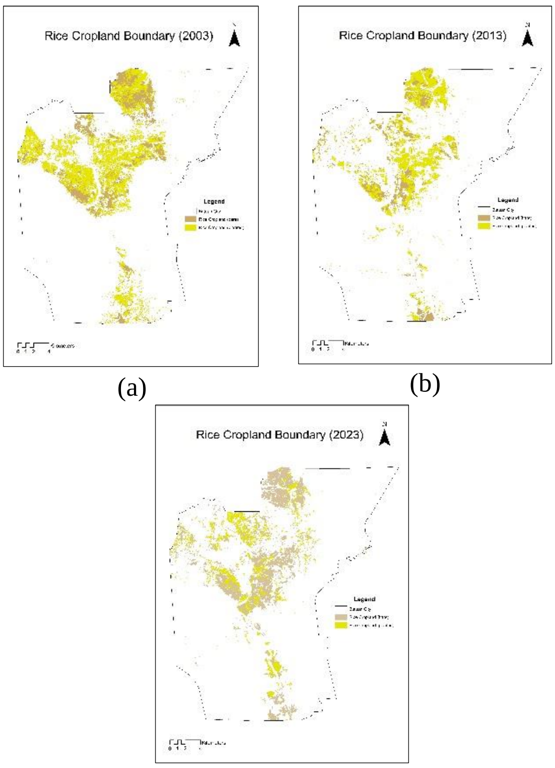
Multi-temporal Land Use/Land Cover (LULC) maps are a crucial output of the image processing and analysis conducted in this study, serving as critical tools for understanding the dynamics of the study area over time (see Fig. 2). The maps provide a detailed visual representation of the different land use types and land cover, showcasing the spatial distribution and changes across various categories. Specifically, Fig. 3 highlights the rice croplands in Butuan City for 2003, 2013, and 2023. Additionally, the LULC maps capture the distribution and expansion of built-up areas in Butuan City, revealing a progressive increase in urbanization from 2003 to 2023. This expansion underscores the growing urban footprint and the encroachment on previously undeveloped lands, emphasizing the importance of sustainable urban planning and management practices to accommodate this growth while preserving essential agricultural and natural landscapes.

For the accuracy assessment of these LULC maps, the ground truth points were systematically distributed across the study area for the 2003, 2013, and 2023 imagery, respectively. The classified images were accurately generated with overall accuracies of 94.25%, 93.44%, and 92.19% for 2003, 2013, and 2023, respectively. In addition, the kappa coefficient of the classification was 0.94 in 2003, 0.93 in 2013, and 0.91 in 2023.



(a) (b) (c)

Fig. 2. Land Use / Land Cover (LULC) maps of Butuan City for (a) 2003, (b) 2013, and (c) 2023.



(a) (b) (c)

Fig. 3. Rice croplands in Butuan City for (a) 2003, (b) 2013, and (c) 2023.

3.2 Biophysical and Socioeconomic Characteristics of Converted Rice Croplands

An analysis of land conversion data over a twenty-year period revealed that from 2003 to 2013, about 751.68 hectares of rice croplands were converted into built-up areas in Butuan City. The conversion continued from 2013 to 2023, with 115.29 hectares converted.

Fig. 4 shows the elevation of converted rice cropland in two different periods: 2003-2013 and 2013-2023. From 2003 to 2013, the elevations ranged from 483.21 hectares at 10 meters to 0.09 hectares at 60- and 70-meter elevations and decreased gradually. In contrast, from 2013-2023, the areas are generally lower across all elevation categories, with 89.73 hectares at 10 meters. This data suggests a potential trend of decreasing elevation of converted rice cropland over time, possibly indicating changes in land use, water management, or other environmental factors affecting the region.

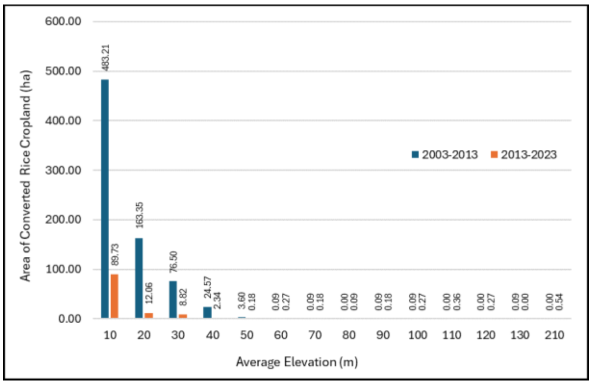


Fig. 4. Area of rice croplands converted relative to elevation.

Using the Barcelona Field Studies Centre [9] slope classification, Fig. 5 shows the distribution of converted rice cropland across different slope classes. Most of the converted rice croplands are on very gentle slopes, with an area of 538.29 hectares from 2003 to 2013 and 72.81 hectares from 2013 to 2023.

Additionally, small regions are located on very strong slopes, and no converted croplands are found on extreme slopes.

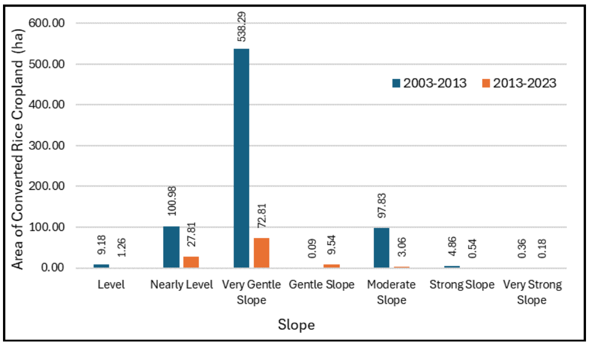


Fig. 5. Area of rice croplands converted based on slope.

In Butuan City, the soil types include clay, clay loam, hydrosol, loam, silt loam, and undifferentiated. Fig. 6 illustrates the area of rice cropland converted based on soil type. From 2003-2013, loam soil dominated the converted areas with 553.59 hectares, followed by clay loam with 129.51 hectares. Clay soil covered 68.31 hectares, while silt loam and undifferentiated soils accounted for smaller areas of converted cropland.

By 2013-2023, the highest conversion of rice cropland also occurred in loam, covering an area of 66.72 hectares. Notably, silt loam and undifferentiated soils increased in converted areas, suggesting changes in land use patterns or agricultural practices favoring these soil types.

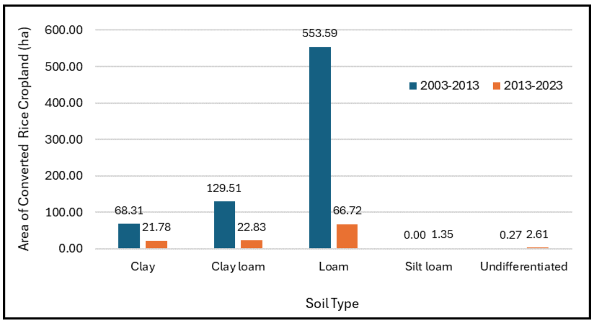


Fig. 6. Area of rice croplands converted based on soil type.

Fig. 7 illustrates that most areas converted between 2003 and 2013 and between 2013 and 2023 are within 100 to 200 meters of the river. In the earlier period (2003-2013), larger areas of croplands were located closer to rivers, with substantial areas of conversion observed at 100 meters (203.58 hectares) and 200 meters (178.74 hectares) from riverbanks.

As the distance from rivers increased, the converted areas gradually decreased. In contrast, by 2013-2023, there was a noticeable reduction in the overall area of converted croplands across all proximity categories. The largest areas of conversion were still observed closest to rivers (100 and 200 meters), albeit at lower levels than in the previous decade.

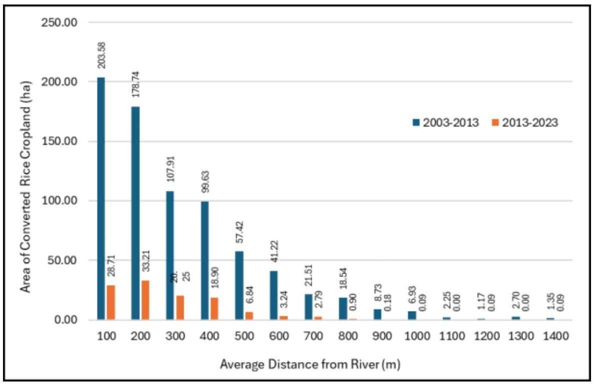


Fig. 7. Area of rice croplands converted based on proximity to a river.

With respect to the socioeconomic characteristics of the converted rice croplands, the proximity of converted rice croplands to roads was computed. Fig. 8 reveals that the largest conversion of rice cropland occurred within 100 meters of roads, with 527.31 hectares converted from 2003 to 2013 and a significant decrease to 69.21 hectares from 2013 to 2023.

Conversion rates generally decline as the distance from roads increases, with minimal changes observed beyond 300 meters. This trend indicates a higher development pressure closer to roads, notably decreasing over the past decade.

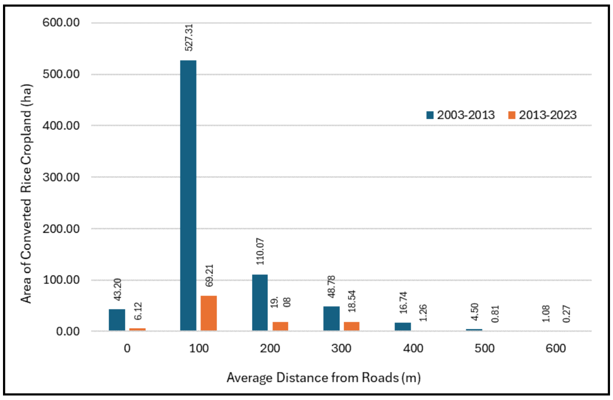


Fig. 8. Area of rice croplands converted based on proximity to roads.

3.3 Generated Map of High-risk Rice Cropland Areas for Future Conversion

In Boolean logic, the existing rice croplands in 2023 were characterized. Table 1 shows the characterized rasters were reclassified to 0, indicating non-high-risk areas, and 1, indicating high-risk areas for conversion. This is based on the result of biophysical and socioeconomic characterization. Based on these values, rice croplands with an elevation of 1-10 meters, 1.1° - 3° slopes, 0-300 meters proximity to rivers, soil type of loam, and less than 0-100 meters proximity to roads are areas in high risk of conversion.

Table 1. Criteria used as the basis for reclassification of 2023 rice cropland.

Factor	High-risk (value=1)	Non-High risk (value=1)
Elevation	0-10 meters	Other values
Slope	1.1° - 3°	Other classes
Proximity to rivers	0-300 meters	Other values
Soil type	loam	Other classes
Proximity to roads	Less than 0-100 meters	Other values

Fig 9 is the map for high-risk factors for rice cropland conversion in Butuan City, Philippines, regarding its elevation, slope, proximity to roads, proximity to rivers, and soil type. Each parameter was observed to impact rice cropland conversion on the map significantly. Hence, these parameters should be incorporated to generate the high-risk rice cropland areas for conversion.

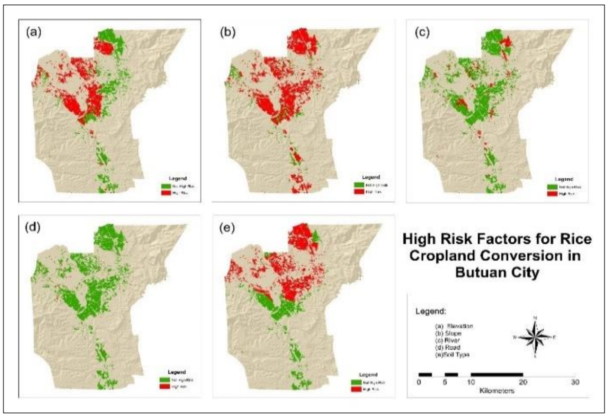


Fig. 9. High Risk Factors for Rice Cropland Conversion in Butuan City.

Fig. 9 depicts the high-risk areas for rice cropland conversion in Butuan City, Philippines. According to the legend, green areas are not at high risk, while red areas indicate high-risk zones, aligning with the city's Comprehensive Land Use Plan (CLUP). This information is crucial for policymakers to develop new strategies and enhance current policies to ensure sustainable land use management, particularly for rice cropland. The primary goal is to protect these lands from conversion, thereby maintaining rice production.

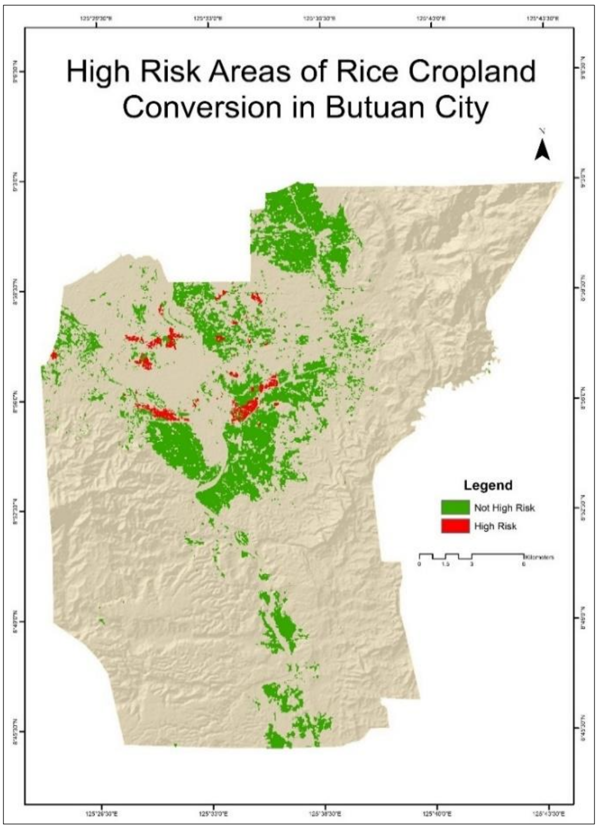


Fig. 9. High-Risk Areas of Rice Cropland Conversion in Butuan City.

4. CONCLUSIONS AND RECOMMENDATIONS

This study revealed rice croplands' biophysical and socioeconomic characteristics in non-agricultural uses. The trends in elevations showed that rice croplands at lower elevations are more frequently converted to non-agricultural uses. The slope parameter, divided into eight classifications, showed that the "very gentle slope" (slopes at 1.1° - 3°) class had the highest area of rice cropland conversion, indicating a preference for converting these areas. Regarding soil types, the loam classification had the most significant area of rice cropland conversion, suggesting a higher selection for conversion in these regions. From 2003 to 2023, cropland conversions were consistently concentrated within 100 to 200 meters of riverbanks, with significant areas of conversion observed. Although the total converted area decreased from the first decade to the second, the highest conversion rates remained close to rivers. This persistent trend highlights the critical impact of river proximity on land use changes and underscores the need for targeted conservation efforts in these vulnerable zones.

The analysis of road network proximity indicated that rice cropland areas with an average of 27.95 – 39.60 meters proximity to the nearest road had the highest conversion in 2003-2013, while in 2013-2023, 29.65-

52.94 meters proximity to the road had the highest area for conversion. This suggests that the mentioned average proximity to the road with the highest conversion area could be a standard distance or maximum distance for rice cropland to be converted into non-agricultural land use. The characteristics of rice cropland undergoing conversion must be considered for effective planning and mitigation strategies to address adverse effects. Since most converted rice cropland is near roads, has gentle slopes, and consists of loam soil, these parameters assist land use planners in assessing the potential for conversion.

There is a relationship between the biophysical and socioeconomic factors and conversion likelihood; specifically, the probability of rice cultivation conversion decreases with increasing elevation and slope. Urbanization tends to replace rice-growing areas in low-lying or level terrain. Additionally, the likelihood of rice cropland conversion increases with proximity to roads. Moreover, this study underscores the importance of assessing various parameters, including elevation, slope, proximity to roads and rivers, and soil type, to determine high-risk areas for rice cropland conversion in Butuan City, Philippines. By understanding these risk factors, policymakers can develop and refine strategies to protect rice cropland from conversion, ensuring sustainable land use management and maintaining rice production in the region. The study's practical implications highlight its value in understanding rice cropland conversion in Butuan City. The researcher recommends adding other parameters, such as population, that influence rice cropland conversion.

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