Journal of Geomatics Vol. 18, No. 1, April 2024

Land use/land cover change along the coastline of La Union, Philippines

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(Received on 27 December 2023; in final form 29 March 2024)

***DOI**: https://doi.org/10.58825/jog.2024.18.1.129*

Abstract: With the hazards piling up on a global level, especially in the coastal areas, this study aims to employ remote sensing and Geographic Information System (GIS) in assessing the Land Use/ Land Cover Change (LULCC) data of the coastal municipalities of La Union, Philippines. Through spatiotemporal maps along with computer-generated results, landscape changes were observed and assessed qualitatively (LULC) and quantitatively (accuracy assessments and change detection analysis) for analyzing LULCC. The occurrence of landscape fragmentation was observed across the five classes (water, urban, barren, vegetation, and agricultural land), particularly between urban, vegetation, and agricultural land, showing interrelationship with landscape stability and fluctuations across a three-decade period (1990-2021) with an accuracy assessment result of 60%- 94%. Significant changes across the three decades showed a decrease in vegetation, -15.32%, and an increase in the remaining four (water, urban, agricultural land, and barren) with +3.11%, +2.71%, +7.01%, and +2.48%, respectively. The result of the study highlighted the need for developing conservation measures crafted on sustainable land use policies and interventions for coastal resources management and shoreline protection.

Keywords: ArcGIS, Coastal Area, Coastal Erosion, Landsat, Land Use/ Land Cover, Remote Sensing, Urbanization

1. Introduction

La Union, Philippines, particularly in San Juan, is identified as the Surfing Capital of the Northern Philippines. Surfing has become the province's leading tourism attraction, contributing to a great portion of La Union's economy. In fact, the World Surf League (WSL) has reinforced La Union's status as one of Asia's top surfing places, with numerous surfing enthusiasts, especially during the surfing season (Gonzales, 2023). In the year 2018, La Union registered 472,891 tourist arrivals, which is a 54.25% growth from the previous year, with an estimated 200,000 tourist arrivals in surfing destinations. Apart from surfing, La Union’s agri-tourism has been a new economic game-changer in its development, with the municipality's vision of turning the province into the Heart of Agri-Tourism in Northern Luzon by 2025 because of its potential in the fields of agriculture and tourism (*Provincial Government of La Union*, 2020).

In fact, alterations in the coastal regions can be ascertained that changes in the coastal morphology are due to sea surges that contributed to the coastal hazards. An increase in population growth leads to crowding in areas that will lead to migration, mostly from the urban to rural setting, and the effects are expansion of settlements even in low-lying areas and coastal areas, most prevalent in developing countries of Asia and Africa. Yet, anthropogenic activities such as land use changes, coastal infrastructures, land claims, and extraction of groundwater are intensifying the current hazards, posing a threat to the dense human population in these areas that are now prone to inundation or flooding and coastal erosion (Grases et al., 2020). Philippines’ coastal zone covers an estimated area of 11,000 square kilometers, which comprises merely 4% of the nation’s entire land area, with an estimated population of 50 million; hence, coastal hazards are prevalent in the archipelago with coastal erosion being the most frequent (Berdin et al., 2004). Moreover, the major consequences of climate change, rising sea levels (Mimura, 2013), and hazards on the coast continue to pile up, both local and international. The global mean sea level (GMSL) could increase between 0.43 m to 0.84 m by the end of the twenty-first century, based on the Intergovernmental Panel on Climate Change (IPCC) as cited by Nazeer (2020) in his study.

Remote Sensing (RS) through Geographic Information Systems (GIS) has been a useful technique in the assessment and analysis of Land Use Land Cover (LULC) change detection. By comparison, land cover refers to the Earth’s land attributes or the physical characteristics or simply the land surface, while land use is the utilization of the land cover or the land surface for human-related purposes; therefore, LULCC or land use/ land cover change, is referring to the dynamics of the two distinct terms that reflects how human actions have molded the land (Lambin et al., 2000). Through satellite-based remote sensing, the geographical information and its temporal information have provided significant data, allowing the conduct of a LULC study (Attri et al., 2015). Moreover, land use and land cover changes include the assessment of their impacts, which may lead to numerous adverse consequences on the environment: biodiversity loss, climate change effects, the impact of pollution on ecosystem quality, and anthropogenic negligence brought by urbanization (Niyogi et al., 2009).

Multiple research studies have been conducted on using LULCC, mostly around terrestrial and aquatic bodies (land-water boundaries). A great example is the study of Misra and Balaji (2021), which aimed to produce LULC and shoreline change maps in the Gulf of Cambay. Their results were then used by environmental managers in devising an effective coastal zone management plan. From the acquisition of Landsat images to LULC analysis to accuracy assessment, their study shows similarities with most LULC research. Furthermore, LULC information, particularly satellite images, had been accessible due to the many new generation Earth observation satellites deployed in space (Sekertekin et al., 2017). Brought about by different calamities that have entered the Philippines, natural factors and anthropogenic factors greatly contribute to the increased risk of affecting coastal areas, specifically the occurrence of coastal erosion and sea-level rise (Arias et al., 2015).

Therefore, with increasing risk in coastal areas, the study aims *to detect land use/ land cover change of the coastline of La Union over the last 30 years (1990-2020)* through the following specific objectives: to create a map showcasing changes in La Union's coastal area over 30 years, to verify results using machine learning, (i.e. user and producer accuracy, overall accuracy and Kappa analysis), and to show the major quantifiable changes that happened in the coastal area from 1990 to 2020. The study will greatly help the residents of La Union, especially the local community since several are living along coastal areas in which a problem in the area will also be their problem. The results of the study will also benefit the local government units (LGUs) in addressing the growing problem of coastal erosion and possible flooding of some areas close to the coast. Likewise, creating a plan of action to counter the hazards is essential. Along with those plans, it will also include natural resources management and wildlife habitat protection. Successful mitigation plans will, in turn, be of great help to the localities and their businesses around the beach by preserving the area of their source of income, which, on a greater scale, is equal to preserving or possibly boosting the economy, specifically through the tourism sector of the province.

2. Study Area

Located on the northwestern part of the Philippine archipelago, La Union, belonging to the Ilocos Region in Luzon Island, is known to be one of the Philippines' major tourist hotspots because of its kilometer-wide sandy beaches and ideal surfing area (Estoque & Murayama, 2010). Situated on the latitudes 16°12’N and 16°55’N and longitudes 120°17’E and 120°35’E, it is bordered by Ilocos Sur to the north, Pangasinan to the south, Benguet to the east, and the West Philippine Sea to the west (Figure 1).

3. Data and Methods

The approach used in the study is shown in figure 2. And explained in subsequent section.

3.1 Land Use Land Cover Data

Landsat images were acquired to track changes along the coast of La Union, which are made available for access through the United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/). The study area (path 117, rows 48 and 49) consisted of three (3) images obtained with the Landsat 5 Thematic Mapper (TM) on 1990-01-11, 2001-01-25, and 2010-02-03, and one taken by the Landsat 8 Operational Land Manager (OLI) sensor, in 2021–03-02 (Table 1). For the range of 1990 to 2020, a viable month in a year per decade that passes the low cloud cover range (≤ 10%) was selected to represent the average of the LULCC for that year in a given decade. On the other hand, DIVA-GIS will be utilized as a source for downloading the vector data from their website (https://www.diva-gis.org/). The LULC data characteristics are summarized in Table 2.

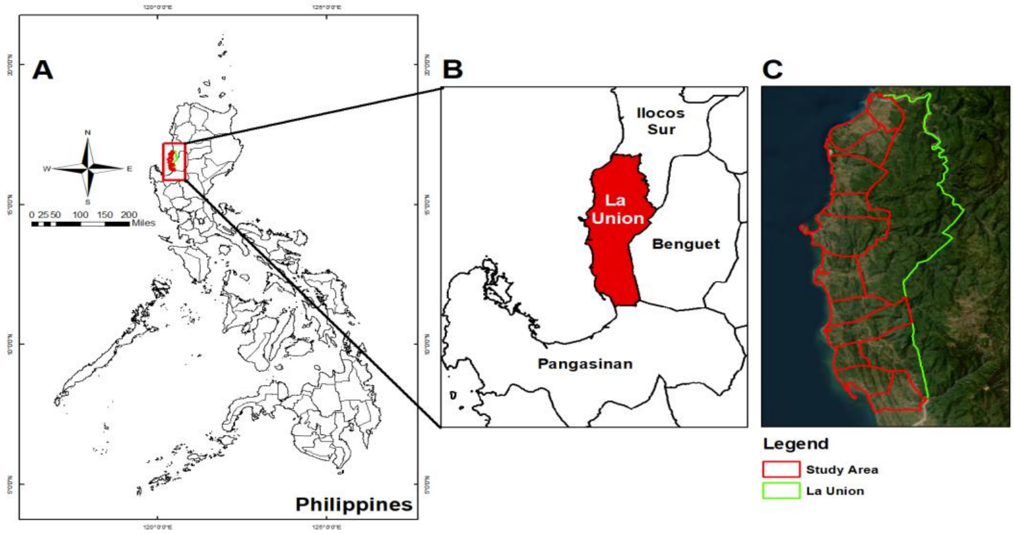

Figure 1. Map of La Union, Philippines, illustrating the research area's coverage.

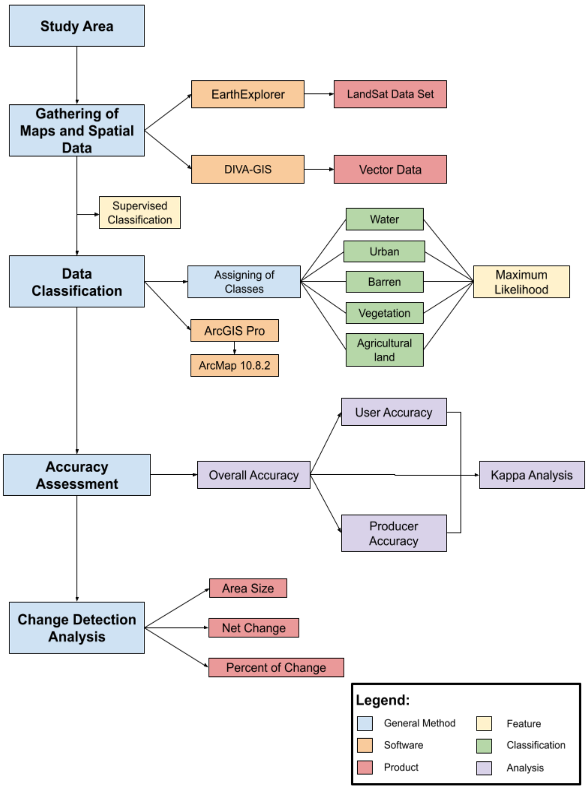

Figure 2. Schematic diagram of LULCC research.

3.2 Landscape Classification

Supervised classification was performed in selecting pixels from each obtained map image sample based on a specific class. The selected pixels (Training Samples) were categorized into five (5) classes: Water, Urban, Barren, Vegetation, and Agricultural land. Among the four (4) time stamps, 800-1000 training samples were collected for the landscape classification. The software utilized was ArcMap 10.8, a feature under the ArcGIS Pro that allows pixels to be automatically selected according to the assigned class properties. The approach in pixel selection was through the Maximum Likelihood classification feature (Figure 3), which classifies a pixel according to a specific class it has the highest likelihood to. However, it is important to take note of the user-specific biases that come along with supervised classification (mislabeled classes, unmarked classification, etc.) (Almadrones-Reyes & Dagamac, 2022).

3.3 Accuracy Assessment

The first model employs overall accuracy, which refers to the map's cumulative accuracy across all classes, particularly on the correctly classified pixels. Consequently, to showcase the error analysis (Table 3) among classes, producer accuracy, and user accuracy are obtained. The accuracy values (producer accuracy) refer to the probability of accurately classifying pixels into a category via the software. On the other hand, the Reliability values (user accuracy) refer to the probability that a classified image showcases the same pixel category on the ground by the user. Supervised classification enables the increased accuracy and lessened misclassification of Landsat images, allowing important judgment calls that assist the producer (computer) to correctly classify the pixels to their categorized class (Alshari & Gawali, 2021). User and Producer Accuracy was done through methods of cross-referencing. User accuracy was obtained by using the generated maximum likelihood map of each year on a class basis. On the other hand, producer accuracy was achieved by comparing the classified pixels (from maximum likelihood) to a higher quality base map (e.g., Google Earth Pro) as the reference among the timescales and using its actual classification. Among the three (3) error matrices (accuracy types), a 100% accuracy is the ideal result for the accuracy to be considered accurate, wherein all classifications were classified correctly. These accuracy measurements are insufficient to support the accuracy of the methods employed; hence, Kappa Analysis is considered. The Kappa analysis was done to assess classification accuracy and error matrix. The generated Kappa coefficient or ($\hat{k}$) ranges between 0 and 1, with values closer to one (1) showing a stronger agreement of the percent of the data that are reliable (Anand, 2017).

The maps were then subjected to the accuracy and reliability of the results. From this, higher overall accuracy rates (82.35% and 94.11%) with greater kappa coefficient values (0.77 and 0.93) were seen in the years 2010 and 2021, respectively. On the other hand, lower overall accuracy (60% and 62%) and lesser kappa coefficients (0.46 and 0.48) were seen for the years of 1990 and 2001, respectively. In this study, a total of 200 points (50 from each year, 1990, 2001, 2010, and 2021) were chosen at random within the focus area using the ArcMap software to confirm accuracy assessments

Table 1. Summary of the Landsat images acquired across three time periods with specifications.

Satellite	Sensor	Path, Row	No. of Bands	Acquisition Date	Spatial Resolution	Cloud Cover
Landsat 5	TM	117, 48 & 49	7	1990/01/11	30	0
Landsat 5	TM	117, 48 & 49	7	2001/01/25	30	0
Landsat 5	TM	117, 48 & 49	7	2010/02/03	30	3
Landsat 8	OLI_TIRS	117, 48 & 49	7	2021/03/02	30	3.78

Table 2. The study's land cover classes and their definition (Anderson et al., 1976).

Class	Definition/ Example
Water	Areas where water was primarily present during the year; may not cover areas with occasional or ephemeral water; contain little to no vegetation, no rock formations, or built-up elements like docks.
Urban	Human-constructed elements; major road and rail networks; huge undifferentiated impermeable surfaces, such as parking structures, workplaces, and residential homes; examples include housing, congested villages/towns/cities, road surfaces, and asphalt.
Barren	Dry salt flats, beaches, sandy places other than beaches, bare visible rock, strip mines, quarries, and gravel pits, transitional areas, combined vacant land, and bare cropland.
Vegetation	Any substantial grouping of tall (~15 m or higher) dense vegetation, usually having a closed or dense canopy; examples include mangroves, plantations, woodland areas, and dense tall vegetation clusters inside savannas.
Agricultural Land	Cropland and grazing land, orchards, groves, vineyards, nurseries, and ornamental areas, as well as intensive animal farming and others.

Table 3. Formulae utilized for accuracy assessment of classified data.

Accuracy Assessment	Formula
User Accuracy	(Number of correctly classified pixel per class/ Total number of classified pixel per class) x 100
Producer Accuracy	(Number of correctly classified pixel per class/ Total number of classified pixel per class (Column total)) x 100
Overall Accuracy	(Number of correctly classified pixel per class (Diagonal)/ Total number of classified pixel per class) x 100
Kappa Coefficient	(TS x TCS) - Σ (Column total x Row total) (TS)2 - Σ (Column total x Row total) x 100

Higher values for both user and producer accuracy were more evident in the years 2010 and 2021, while values were lower for both 1990 and 2001. Recent years (2010 and 2021) show high accuracy (user) and reliability (producer) values greater than 60% (>60%) in comparison to latter years (1990 and 2001) with lesser accuracy and reliability values. The discrepancy in accuracy and reliability among time periods indicates the quality of computer datasets, showing more favorable (high percentage) results as years' advance (Table 4). In addition, water was the only classification to receive a full hundred marks for producer accuracy and a relatively high user accuracy value over the three decades. Consequently, barren and urban classifications had some of the lowest values of accuracy and reliability, garnering 36.36 % and 25%, respectively, in later years (Table 5). Furthermore, producer accuracy shows a striking percentage for reliability; however, it is not totally immune to low reliability as well, as shown in later years of Urban (33.33% and 50%) and Barren (36.36% and 40.91%). Lastly, a major highlight shows the direct relationship between user and producer accuracies with low accuracy values influencing lower reliability, therefore, its overall accuracy as well, and vice versa. Even so, it is important to note that it may not apply to all error analyses.

Table 4. Overall accuracy and Kappa coefficient of 1990- 2021 maps.

Year	Overall Accuracy (%)	Kappa Coefficient
1990	60	0.46
2001	62	0.48
2010	82.35	0.77
2021	94.11	0.93

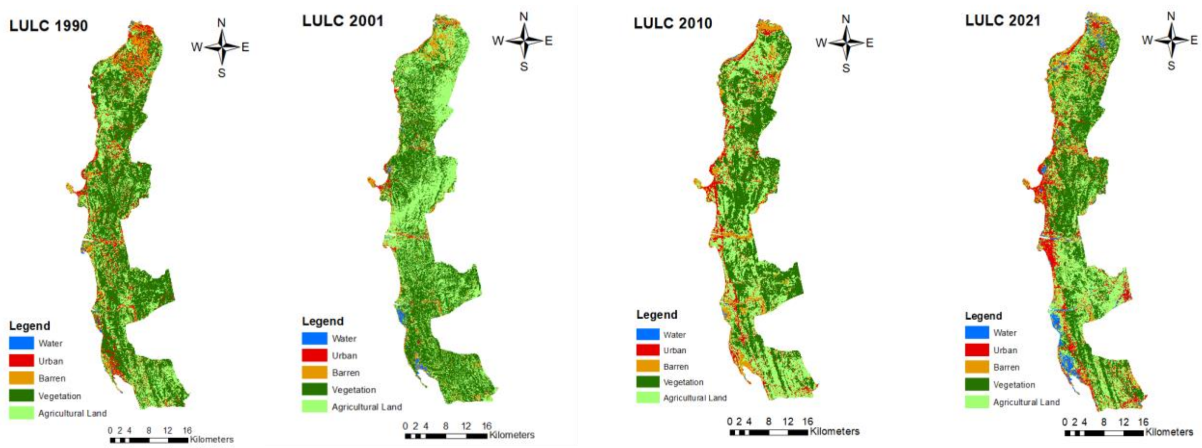

Figure 3. Generated LULC maps from the maximum likelihood classification of La Union in 1990, 2001, 2010, and 2021.

Table 5. User and Producer Accuracy of 1990, 2001, 2010, and 2021 maps.

Classes	User Accuracy (%)				Producer Accuracy (%)			
	1990	2001	2010	2021	1990	2001	2010	2021
Water	50	50	66.67	87.5	100	100	100	100
Urban	25	25	62.5	100	33.33	50	100	100
Agricultural Land	45	50	91.67	84.62	81.82	69.23	84.61	100
Vegetation	78.57	73.33	88.24	100	84.62	91.67	88.24	83.33
Barren	80	81.82	81.82	100	36.36	40.91	64.29	92.31

3.4 Land Use Land Cover Change Analysis

Associating changes through quantifiable data on change detection is deemed significant in addressing the dynamic relationship of identified classes. From the software-generated analysis, Table 6 mirrors Figure 4 through a graphical representation wherein the following observations can be deducted: (i) urban across the three decades has increased, with the 1990 year having the lowest value of percentage cover, (ii) barren land across the three decades remain constant but conversion from water to barren was observed as high as 75.10 on 2001 - 2010, (iii) the decade 2001- 2010 has the least percentage cover of vegetation at 46.92 as compared with the two other decades, and (iv) agricultural land increased across the timeline with a slight decrease only on the year 2001 - 2010 but multiple high conversions to other land cover classifications were observed.

Across the three (3) decades (1990- 2020), vegetation shows a decrease (-15.32%), which is supported by a decrease in each year. Alternately, a significant increase was observed in agricultural land (+7.01%), followed by water (+3.11%), then urban (+2.71%), and barren (+2.48%) (Table 7). Further in-depth, the trend of LULC changes was taken note of, hence the following observations can be made: (i) agricultural land areas in the year 1990-2001 greatly increased by 100.8 km^2, while urban and vegetation greatly decreased in area with 69.29 km^2 and 33.33 km^2, respectively. (ii) The following decade (2001-2010), urban significantly increased by 72.54 km^2, while vegetation significantly decreased by 56.88 km^2. (iii) During the last decade (2010-2020), urban continuously, along with barren and water, increased by 18.76 km^{2,} 23.17 km^{2,} and 26.91 km^2, respectively, while vegetation and agricultural land decreased immoderately by 32.68 km^2 and 36.19 km^2. Notably, there is a downward trend in vegetation across the years with a more apparent drastic change in the increase in agricultural land and decrease in urban areas during the years 1990 to 2001. Consequently, after the extensive increase or decrease in area, the following two decades show a downward trend in agricultural land and an upward trend in urban areas. This relationship highlights how urbanization and anthropogenic activities have utilized (land use) the natural topography (land cover), specifically affecting agricultural lands and vegetation of the area. Although interestingly, as urbanization flourishes, barren and water have increased as well.

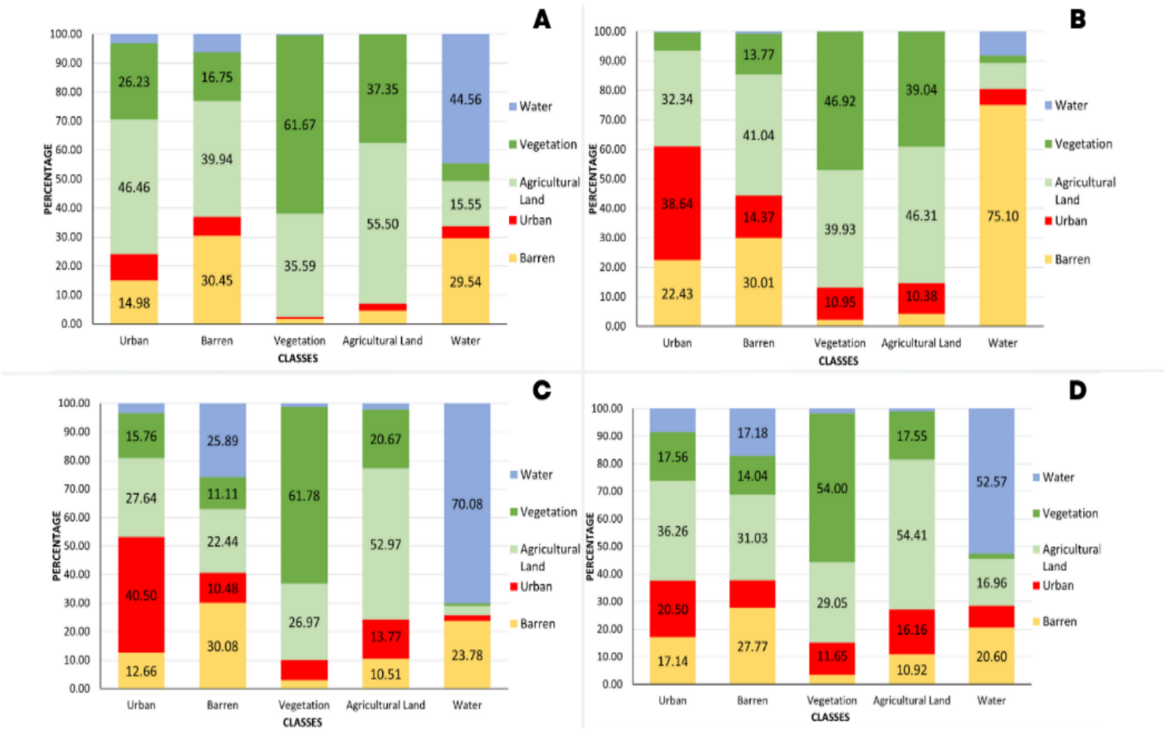

Figure 4. Land Use Land Cover Change of La Union in (A) 1990-2001, (B) 2001-2010, (C) 2010-2021 and D) 1990-2021.

Table 6. LULCC along the 12 coastal municipalities of La Union from 1990 to 2021.

From/ To	Water	Urban	Agricultural Land	Vegetation	Barren
Water	52.57	8.55	0.97	1.78	17.18
Urban	7.93	20.50	16.16	11.65	9.99
Agricultural Land	16.96	36.26	54.41	29.05	31.03
Vegetation	1.94	17.56	17.55	54.00	14.04
Barren	20.60	17.14	10.92	3.53	27.77

Table 7. Percentage and area size of each class in the categorized image of the study location.

Classes	Area (%)				Size of the Area (sq. km)				Changes in the Area (%)
	1990	**2001**	**2010**	**2021**	**1990**	**2001**	**2010**	**2021**	**1990-2021**
Water	0.41	1.14	0.18	3.52	3.30	9.22	1.48	28.39	+3.11
Urban	11.17	2.57	11.56	13.88	89.95	20.66	93.20	111.96	+2.71
Vegetation	51.21	47.06	39.94	35.89	412.31	378.98	322.10	289.42	-15.32
Agricultural Land	30.67	43.10	42.17	37.68	246.96	347.04	340.10	303.91	+7.01
Barren	6.54	6.13	6.15	9.02	52.65	49.39	49.61	72.78	+2.48

4. Discussion

Natural disasters affect landscape changes in an area economically and environmentally for the residents, including the vulnerability that natural resources are directly exposed to. Given that the Philippines is situated within what is known as the "Pacific Ring of Fire," susceptibility to coastal hazards is high, such as typhoons, earthquakes, flash floods, and rising sea levels (UNDRR, 2019). About three (3) deadly earthquakes hit the Ilocos Region provinces, including La Union. This seismic activity can induce landslides which may result to changes in the mountain vegetation given that La Union consists of an undulating topography brought by the Cordillera mountain ranges arranged linearly from north to south across San Fernando to Rosario (Silvestre, 1989), may also cause a blockage in the rivers that leads to changes in the water bodies and floods, and also lead to the deterioration of rock formations coupled with weathering from water through rain (Bian et al., 2022). Looking at the insights of Kargel et al. (2016), surface hydrology is altered during earthquakes, such as changes to the topography and blocking of water flows due to landslides or rockfalls (Touche, 2016). Additionally, the altered water flow could lead to huge surface discharges, as noted from the multiple findings of Touche (2016) among the earthquakes that affected different bodies of water across the globe. These could reflect the changes that happened during the 1990 – 2001 decade, wherein a decrease in the vegetation and urban cover is observed but a slight increase in water (Figure 4).

Looking at the changes in a decade (Figure 4), particularly the years 2010 to 2021, urban, barren, and water have increased in land cover; subsequently, agricultural land and vegetation decreased. These land cover changes are a result of typhoon aftermaths. Data obtained through the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) on Philippine Tropical Cyclones for the years 2017-2019 reports 64 typhoons (2017 with 22, 2018 with 21, and 2019 with 21) that have entered the Philippine Area of Responsibility (PAR), wherein five (5) of which affected the Ilocos Region, specifically, La Union. Typhoon aftermath greatly impacts agriculture, natural resources, and the environment directly and indirectly in positive and negative ways. Negative direct impacts on agriculture could be associated with reduced and damaged farm productions, inputs, and facilities; likewise, to natural resources and environment, the effect of soil erosion, siltation, and sedimentation, including a deformed land topography, may occur due to intense flooding. However, positive direct impacts also benefit agriculture by means of an increased water supply, which results in improved soil fertility and increased moisture rate in the environment (Israel & Briones, 2012). Vegetation dynamics post-disturbance does not necessarily instigate total loss; however, restoration and revitalization strategies have been in place influencing the rapid change of land composition, species diversity, and vegetation succession, particularly the occurrence of secondary succession and forest succession in areas affected by these natural calamity stressors (Tang et al., 2010).

Terracing is a farming technique useful in the landscape, specifically used for rice by which all twelve municipalities in the study contributed to 5,500 to more than 14,500 metric tons across all rice production in La Union, according to the Philippine Rice Research Institute (2021). Topography greatly affects impacts as the wind blows downhill, influencing the vulnerability of the slope stability of the sliding surface in the rock-soil interface and root-soil composite (Zhuang et al., 2022). The occurrence of typhoon-induced landslides supplements the decrease in vegetation and agriculture, particularly the vegetation present on mountainous slopes and the agricultural land found at the base of these mountains. Notably, external factors such as population increase, infrastructure, and agricultural and forestry activities may exacerbate landslides in the long term (Forbes et al., 2013). In the year 2001- 2021, the increase in conversion from water to barren is possibly due to sedimentation. Sedimentation built-up is natural in free-flowing waters. During heavy rainfalls, sediment transportation flows downstream to deltas as soils become oversaturated, thus running into rivers- carrying along sediments (Darby et al., 2016). In fact, land use is greatly impacted through means of agricultural run-offs, mining, urbanization, pipelines, and road construction, which increases sedimentation built-up (Hedrick et al., 2013). Land accretion and erosion have been observed in typhoon-affected areas like La Union. According to the locals, erosion has been prevalent in the area as a response to storms or typhoons; however, they are short-term as conditions normalize and the beach (shoreline/ coast) recovers. Likewise, sedimentation run-offs result in the land gain brought by the built-up along riverbanks and mouths. The constant flow of water and waves influences erosion by removing and wearing away hard materials (Berdin et al., 2004).

Furthermore, urbanization increases across the three decades (1990-2021) and is coupled with demographic changes and landscape transformation (land use conversions) to address the demands of a growing population (Patra et al., 2018). According to the Philippines Statistics Authority (PSA), La Union’s total population as of May 2020 is 822,352 thousand persons, which is 80.44 thousand higher than the population in 2010 (741.91) (Teñido, 2021; Teñido, 2022). The impacts of natural disasters have caused major changes in the land cover of the province, and human interventions were enacted to possibly counteract the effects. As a response to those, the local communities, along with government support through funding, have built (started around 1980) ripraps, sea walls, sea groins, bulkheads, and placed sandbags to protect the shores but ineffective in the long run because these are short-term solutions to long-term problems and very costly (Berdin et al., 2004). These engineered structures were thought to counter the erosion of the beaches by preventing the sediments from flowing offshore, but this natural process of erosion, once impeded, could lead to depletion elsewhere (Finkl & Makowski, 2020). Independent of the intensity of the waves crashing along the coasts, the carried substrates are being stockpiled on those structures that prevent littoral movement downdrift, which starves the supply of another area, leading to accretion and erosion on two different areas, disrupting the natural littoral movement (Finkl & Makowski, 2020), which is reflected as well in the findings of Berdin et al. (2004) including anecdotal reports.

Limited available sources and studies hinder the full-scale understanding of LULC and how it affects coastal areas. Hence, anecdotal reports and further research are recommended to address the learning gap present. The supplementation of ground truthing will further help identify, observe, and address real-time situations happening within the research site, particularly with the local narrative of the landscape changes over time, including factors promoting environmental, social, and cultural stressors in the area. The outcomes of the study show that the land conversion of the coastal municipalities and the ensuing problem that the recommendations suggested will be of use to the local government units (LGU) for enhanced land use management along with the conservation of the coastal resources. Proper and long-term mitigation efforts should be strengthened in handling the coastal areas. Through widespread information dissemination and awareness, concerned government offices are able to actively involve the locals in various initiatives that will pave the way for rehabilitation projects and an encompassing understanding of the risks should management efforts not be pursued. The take on the detrimental effects of the sea infrastructures will be given light, and efforts to counteract the presumed counteractive measures will be addressed.

Acknowledgement

NHAD and JEL-D acknowledge the funding for the research from the National Research Council of the Philippines (NRCP Proj.No. E-253) within the project MARVELS of the Program INFLORAS, partial financial support from UST-RCNAS as a small research grant, and research support from DOST Philippine Council for Agriculture, Aquatic, and Natural Resources and Development (DOST-PCAARRD) as NHAD's Balik Scientist grantee. AO-P and PAS-M are recipients of DOST ASTHRDP of DOST SEI.

References

Almadrones-Reyes K. J. and N. H. Dagamac (2022). Land-use/land cover change and land surface temperature in Metropolitan Manila, Philippines using Landsat imagery. *GeoJournal*. https://doi.org/10.1007/s10708-022-10701-9

Alshari E. M. and B. W. Gawali (2021). Development of classification system for LULC using remote sensing and GIS. *Global Transitions Proceedings*, *2*(1), 8–17. https://doi.org/10.1016/j.gltp.2021.01.002

Anand A. (2017). Unit 14. Accuracy assessment. Retrieved from https://www.researchgate.net/publication/324943246

Anderson J. R., E. E. Hardy, J. T. Roach and R. E. Witmer (1976). A land use and land cover classification system for use with Remote Sensor Data. *Professional Paper*. https://doi.org/10.3133/pp964

Arias J. K., M. A. Dorado and R. Dorado (2015). Economic vulnerability and possible adaptation to coastal erosion in San Fernando City, Philippines. *Cost-Benefit Studies of Natural Resource Management in Southeast Asia*, 325–343. https://doi.org/10.1007/978-981-287-393-4_15

Attri P., S. Chaudhry and S. Sharma (2015). Remote sensing & GIS based approaches for LULC change detection–a review. *International Journal of Current Engineering and Technology, 5*(5), 3126-3137.

Berdin R., C. T. Remotigue, P. Zamora and F. P. Siringan (2004). Coastal erosion vulnerability mapping along the southern coast of La Union, Philippines: Philippines. In Global symposium for hazard risk reduction: Lessons learned from the applied research grants for disaster risk reduction program 51-67.

Bian Z., D. Zhang, J. Xu, H. Tang, Z. Bai and Y. Li (2022). Study on the evolution law of surface landscape pattern in earthquake-stricken areas by remote sensing: A case study of jiuzhaigou county, Sichuan province. *Sustainability, 14*(20), 13032. https://doi.org/10.3390/su142013032

Darby S. E., C. Hackney, J. Leyland, M. Kummu, H. Lauri, D. R. Parsons, J. L. Best, A. Nicholas and R. Aalto (2016). Fluvial sediment supply to a mega-delta reduced by shifting tropical-cyclone activity. *Nature, 539*(7628), 276–279. https://doi.org/10.1038/nature19809

Estoque R. C. and Y. Murayama (2010). Suitability analysis for beekeeping sites in La Union, Philippines, using GIS and multi-criteria evaluation techniques. *Research Journal of Applied Sciences*, *5*(3), 242–253. https://doi.org/10.3923/rjasci.2010.242.253

Finkl C. W. and C. Makowski (2020). *Encyclopedia of coastal science* (2nd ed.). Springer International Publishing.

Forbes K., J. Broadhead, G. B. Bischetti, F. Brardinoni, A. Dykes, D. Gray, F. Imaizumi, S. L. Kuriakose, N. Osman, D. N. Petley, A. Stokes, B. Verbist and T. H. Wu (2013). Forests and Landslides: The Role of Trees and Forests in the Prevention of Landslides and Rehabilitation of Landslide-affected Areas in Asia

Gonzales E. J. (2023). La Union among Asia’s top surfing hubs. Malaya Business Insight the Online Version of Malaya Business Insight. Published at the Same Time with the Same Content for the Major Sections. https://malaya.com.ph/news_special_feature/la-union-among-asias-top-surfing-hubs/

Grases A., V. Gracia, M. García-León, J. Lin-Ye and J. P. Sierra (2020). Coastal flooding and erosion under a changing climate: Implications at a low-lying coast (Ebro Delta). *Water, 12*(2), 346. https://doi.org/10.3390/w12020346

Hedrick L. B., J. M. Anderson, S. A. Welsh and L. Lin (2013). Sedimentation in Mountain Streams: A Review of Methods of Measurement. *Natural Resources, 04*(01), 92–104.

Israel D. C. and R. M. Briones (2012). Impacts of Natural Disasters on Agriculture, Food Security, and Natural Resources and Environment in the Philippines. RePEc: Research Papers in Economics. https://www.econstor.eu/bitstream/10419/126912/1/pidsdps1236.pdf

Kargel J. S., G. J. Leonard, D. H. Shugar, U. K. Haritashya, A. Bevington, E. J. Fielding, K. Fujita, M. Geertsema, E. S. Miles, J. Steiner, E. Anderson, S. Bajracharya, G. W. Bawden, D. F. Breashears, A. Byers, B. Collins, M. R. Dhital, A. Donnellan, T. L. Evans, … and N. Young (2016). Geomorphic and geologic controls of geohazards induced by Nepal’s 2015 gorkha earthquake. *Science, 351*(6269). https://doi.org/10.1126/science.aac8353

Lambin E. F., M. D. Rounsevell and H. J. Geist (2000). Are agricultural land-use models able to predict changes in land-use intensity? *Agriculture, Ecosystems & Environment, 82*(1-3), 321–331. https://doi.org/10.1016/s0167-8809(00)00235-8

Mimura N. (2013). Sea-level rise caused by climate change and its implications for society. Proceedings of the Japan Academy. *Series B, Physical and biological sciences, 89*(7), 281–301. https://doi.org/10.2183/pjab.89.281

Misra A. and R. Balaji (2015). A Study on the Shoreline Changes and LAND-use/ Land-cover along the South Gujarat Coastline. *Procedia Engineering, 116*, 381–389. https://doi.org/10.1016/j.proeng.2015.08.311

Nazeer M., M. Waqas, M. I. Shahzad, I. Zia and W. Wu (2020). Coastline vulnerability assessment through Landsat and Cubesats in a coastal Mega City. *Remote Sensing, 12*(5), 749. https://doi.org/10.3390/rs12050749

Niyogi D., R. Mahmood and J. O. Adegoke (2009). Land-Use/Land-Cover Change and Its Impacts on Weather and Climate. *Boundary-Layer Meteorology, 133*(3), 297–298.

Patra S., S. Sahoo, P. Mishra and S. Mahapatra (2018). Impacts of urbanization on land use /cover changes and its probable implications on local climate and groundwater level. *Journal of Urban Management, 7*(2), 70–84. https://doi.org/10.1016/j.jum.2018.04.006

Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). (March 2019, June 2020, September 2021). 2017-2019 Annual Report on Philippine Tropical Cyclones. In GOV PH. Retrieved March 12, 2023, from https://bagong.pagasa.dost.gov.ph/tropical-cyclone/annual-report

Philippines– 2009– Typhoons Ondoy and Pepeng affected 9.3 million people | GFDRR. (n.d.). https://www.gfdrr.org/en/philippines-2009-typhoons-ondoy-and-pepeng-affected-93-million-people

Provincial Government of La Union. (2020, October 14). Retrieved May 5, 2022, from https://launion.gov.ph/quick-facts/

Sekertekin A., A. M. Marangoz and H. Akcin (2017). Pixel-based classification analysis of land use land cover using Sentinel-2 and Landsat-8 data. Int. Arch. Photogramm. *Remote Sens. Spat. Inf. Sci, 42*, 91-93.

Silvestre G. (1989). Towards Sustainable Development of the Coastal Resources of Lingayen Gulf, Philippines: Proceedings of an ASEAN/US Coastal Resources Management Project Workshop, Bauang, La Union, Philippines, 25-27 May 1988. WorldFish

Tang C. Q., M. Zhao, X. Li, M. Ohsawa and X. Ou (2010). Secondary succession of plant communities in a subtropical mountainous region of SW China. *Ecological Research, 25*(1), 149–161. https://doi.org/10.1007/s11284-009-0644-z

Teñido D. E. (2021). *Highlights of the Population of La Union 2020 Census of Population and Housing.* Philippine Statistics Authority Regional Statistical Services Office I. Retrieved May 5,2022, from http://rsso01.psa.gov.ph/content/highlights-population-la-union-2020-census-population-and-housing

Teñido D. E. (2022). *Urban Population of La Union (2020 Census of Population and Housing).* Philippine Statistics Authority Regional Statistical Services Office I. Retrieved February 28, 2023, from http://rsso01.psa.gov.ph/content/urban-population-la-union-2020-census-population-and-housing

Touche G. D. L. (2016). Earthquakes and Groundwater and Surface Water Management at Mine Sites. *IMWA 2016 – Mining Meets Water – Conflicts and Solutions*, 102 – 107.

UNDRR (2019). *Disaster Risk Reduction in the Philippines: Status Report 2019*.

USGS (n.d.). *Landsat known issues*. Landsat Known Issues | U.S. Geological Survey. Retrieved April 10, 2023, from https://www.usgs.gov/landsat-missions/landsat-known-issues

Zhuang Y., A. Xing, Y. Jiang, Q. Sun, J. Yan and Y. Zhang (2022). Typhoon, rainfall and trees jointly cause landslides in coastal regions. *Engineering Geology, 298*, 106561. https://doi.org/10.1016/j.enggeo.2022.106561