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Catchment-Scale Land Use and Land Cover Change Analysis in Two Coastal Ramsar Sites in Ghana, Using Remote Sensing

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Abstract: Coastal wetlands are complex ecosystems that support biodiversity. They provide many benefits, including flood mitigation and sustenance for communities. The unique characteristics of wetlands make them vulnerable to natural and human-induced disturbances. Numerous factors, including industrialisation, urbanisation, and climate change, add to this phenomenon. The activities that threaten coastal wetlands in the world are relevant to coastal wetlands in Ghana. The Songor and Sakumo wetland catchments are international ecosystems endangered by land modifications and sea level rise. There are gaps in the body of knowledge that need investigation as regards underlying processes and transformation. This study assessed land use and land cover (LULC) changes between 1990 and 2020. The study used geospatial techniques and intensity analysis. LULC change results were from Landsat images (1990, 2000, 2011, and 2020). These changes were attributed to an increase in human activities. Changes in the Sakumo wetland catchment fell more into human-induced LULC categories, and vice versa for the Songor wetland catchment. The study recommends comprehensive methods of LULC change analysis. This would enhance biodiversity and allow the sustainable usage of wetland resources.

Keywords: land use; land cover; Ramsar site; remote sensing; geographic information systems; intensity analysis

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1. Introduction

Wetlands are unique ecosystems with diverse characteristics regarding hydrology, soils, altitude, and vegetation. The landscapes within which wetlands are formed are catchments [1]. Catchments embody the water resources and the surrounding environment from which the water drains. Interconnections between the water resources and the surrounding environment are key factors impacting the changes in catchments. A catchment-based approach to wetland conservation ensures that the whole catchment system, including land, air, and water resources, is safe [1]. Wetlands exist on a spectrum: natural artificial, and tidal or non-tidal [2]. They serve as interactive zones between nature and man. Wetlands in coastal-urban catchments provide useful services. These services include food provision, climate regulation, nutrient cycling, and biodiversity sustenance [3]. Irrespective of the stark contributions from coastal wetlands, human activities and natural processes impact coastal wetland sustainability. Some of these impacts are urbanisation, over-harvesting, sand mining and pollution from human activities. Natural processes include sea level rise and climate change [4]. Human interventions perform a dominant and persistent role, aside from the actions of natural agents. To buttress the aforementioned, Davidson and Finlayson [5] noted a 35% global loss of coastal wetlands to land transformations from 1970 to 2015. More coastal zones (wetlands) will be lost because of increasing human activities. These activities (including sand mining and mangrove over-harvesting) are dire and are worst in developing countries [6].

Ghana, situated in West Africa, has a 550 km coastline that accounts for 10% of the overall landmass. The coastal zone holds over 90 wetland landscapes, which help to maintain ecological processes. Five of these coastal wetlands have international recognition as Ramsar sites and cover 1761 km^2 [7,8]. Relevant to this paper are the Sakumo and Songor wetland catchments found within the central and eastern coastal zones. These areas of interest (AOIs) are prime ecosystems supporting migratory birds, sea turtles, and human livelihoods. However, the rates at which these wetlands are being lost are alarming, primarily due to population dynamics, climatic changes, and weak management and conservation efforts. These factors have led to declines in water and ecosystem qualities and quantities [9]. The 1964 construction of the Akosombo Dam has retained and reduced water and sediment flow from the Volta River into the eastern coastal zone of Ghana [10]. The eastern coast of Ghana experiences erosion rates of 2 metres/year. This is anticipated to cause increased coastal erosion, floods, and morphological change in the near future, as a response to global warming [9–11]. The relevance of ecosystem services is therefore imperative to the development of Ghana's coastal zones.

Parallel to the global ecology, the aforementioned face similar threats. Over the years, literature has abounded about this subject. Regarding the study area, Asomani-Boateng noted that 60% of the wetlands in the Greater Accra Region of Ghana have been lost to urbanisation [12]. Takyi et al. expanded on the management and challenges of coastal lagoons in Ghana. Yeboah et al. [13] noted that land use land cover (LULC) changes were due to urban growth in Accra. Ofori-Danson [14] and Ntiamoa-Baidu and Gordon [8] assessed coastal wetlands management. These literary works indicate various methods and techniques leading to the contamination of water bodies, increased land degradation, and reductions in natural resources.

Pertinent to this study is the LULC change. The assessment of coastal wetland catchments applies spatial and temporal dimensions. This relates to the direct comprehensive modification of the LULC. Geographic information systems (GIS), remote sensing (RS), and ground-truthing are viable methods for assessment. These methods allow for consistency and detailed multiple LULC. The LULC is a change or transitional matrix that allows for multiple assessments, regardless of time and/or spatial scales. By means of enhancing the negligible gross changes of LULC, an intensity analysis quantifies the underlying links to changes in land use. This provides a better understanding of a conventional analysis of the LULC matrices. Over the decade, the literature has supported this assertion on the clarity of the intensity analysis [15–18].

Based on the study area, the literature presents varied contexts of issues and methods, as well as variables. Adade et al. [17] assessed the changes in the Songor Ramsar Site over a 25-year period. Ekumah et al. [18] investigated the LULC change in the Densu Delta, Muni-Pomadze, and Sakumo Lagoon between 1985 and 2017. These studies were only focused in and around wetlands and thus neglected the impact of the surrounding catchment to the wetlands. Further, the changes in the Songor and the Sakumo wetland catchments have precursors, which indicate certain results based on different timeframes, spaces, and variables. However, these previous studies have only assessed LULC change statistics and have not quantitatively discussed the factors influencing the changes. This study employs a catchment-based LULC assessment of the Sakumo and Songor Ramsar sites. Population and water balance variables are evaluated quantitatively as key explanatory factors that manipulate these Ramsar sites.

The objective of this study is to evaluate the LULC changes in the Sakumo and Songor wetland catchments from 1990 to 2020. The evaluation uses intensity analysis to understand LULC class transitions and quantitatively explores the impact of population and water balance variability on the wetland catchment changes.

The results of this research would reveal the important role of catchment-based LULC changes to wetland protection, conservation and restoration in Ghana.

2. Materials and Methods

2.1. Study Area

The Sakumo and Songor wetland catchments are pertinent to the study area. They are located in Greater Accra, a coastal region of Ghana (Figure 1). The region is a hub of political, administrative, and social activities. This region has the highest population density, with 1681 individuals per km^2, and covers the smallest land area of 3245 km^2 [19]. Asomani-Boateng [12] highlights the threats posed by population density and rural–urban migration to wetlands and ecological zones in the region.

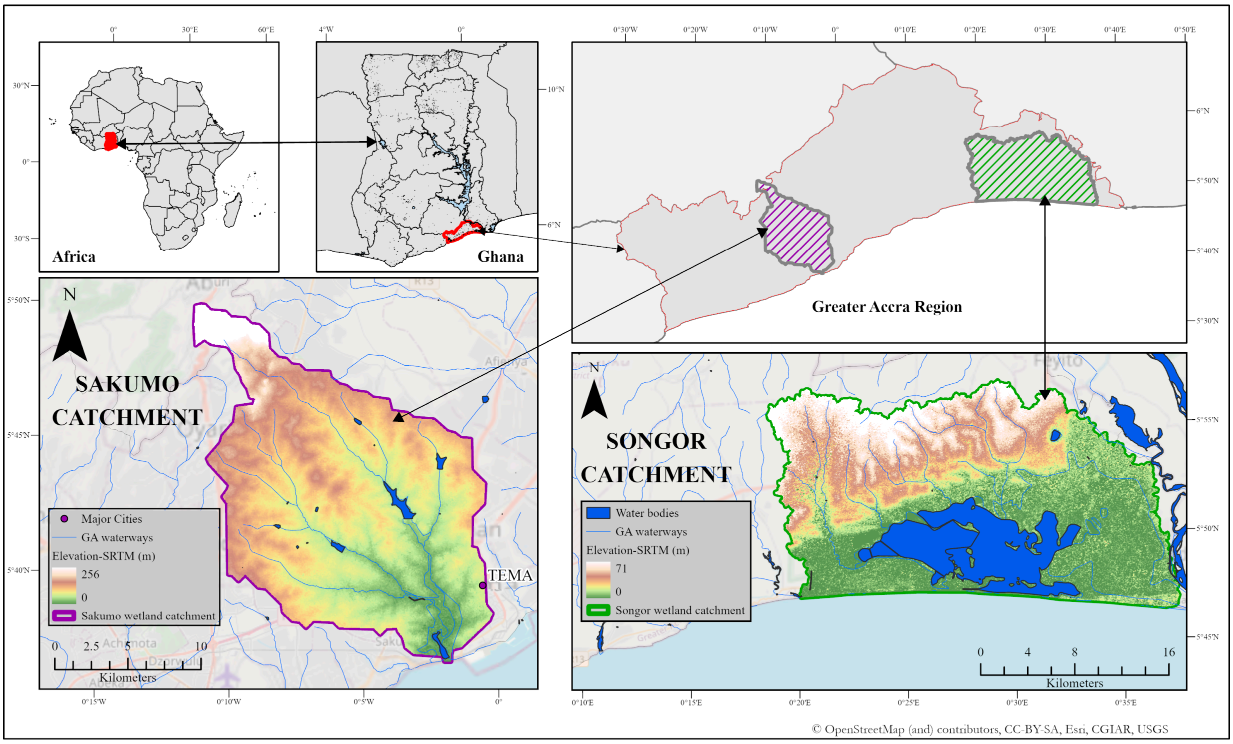


Figure 1. Map of Ghana's coastal region, showing the areas of interest (AOIs) (Sakumo and Songor catchments).

The Sakumo Ramsar Site (05°30′ N, 000° 08′ W) is 20 km east of Accra. The coverage area of the site catchment is 276.34 km^2. Four main streams (the Onukpawehe, Mamahuma, Dzorwulu, and Gbagbla-Ankonu) drain the catchment to the wetland and have active flow in the rainy season. The Mamahuma and Dzorwulu rivers are the main rivers feeding the Sakumo Ramsar Site [20]. Impacts of rapid urbanisation on the streams has led to these streams being used primarily for agricultural irrigation purposes, aside from feeding the wetland. The four habitat types in the area are an open lagoon, floodplains, freshwater marshes, and coastal savanna grasslands. The catchment records a mean rainfall of 800 mm/year and average atmospheric temperatures of 26.7 °C. The average elevation of the catchment is 46 m. Inhabitants of the area rely on fishing, farming, and petty trade as sources of livelihood. The area is predominantly urban and has industrial developments [17].

The Songor wetland (5°45′ N, 0°30′ E) is the second largest Ramsar Site along Ghana's coast. The area covers 511.33 km^2. It is located in the Dangme East District and 79 km from the capital, Accra. The habitats in the catchment are a closed brackish lagoon with mudflats, sandy beaches (southward), floodplains with mangroves, and coastal savanna vegetation in the east and north. Elevation ranges from 71 m in the north and 15 m in the south. The average rainfall is 750 mm/year and the average atmospheric temperature is between 23 °C and 33 °C. Multiple streams drain the Songor lagoon, and none of these streams are gauged.

Key among them is the Sege River, which drains the north-western part of the Songor lagoon and another stream that flows from north to south and passes through Hwakpo. The wetland is connected to the Volta River at the east by two canals. These canals feed the southern plains of the wetland through smaller channel networks [21,22]. Inland waters feeding the catchment are mainly used to support livelihoods, primarily through irrigation for agriculture and salt mining activities. Farming, fishing, salt mining, and petty trade are important sources of livelihood in the area [19,23].

2.2. Data Sources

Imagery Data Sources

The remote sensing data used were satellite imagery from the Landsat Collection 2 Level 1 (Level 1 Precision Terrain—L1TP) (Landsat-4 Thematic Mapper (TM), Landsat-7 Enhanced Thematic Mapper (ETM), Landsat-8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)). Satellite images were selected due to the extended temporal availability of the satellite mission. The images for LULC analysis for the period 1990 to 2020 were downloaded from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/ (accessed on 19 December 2022)). Obtained images represented 1990 (Landsat-4 TM), 2000 (Landsat-7 ETM), 2011 (Landsat-7 ETM), and 2020 (Landsat-8 OLI/TIRS) (Table 1).

Table 1. Landsat satellite images used.

Satellite (Sensor)	Acquisition Dates (dd-mm-yyyy)	Path, Row
Landsat 8 (OLI/TIRS)	02-01-2020	193, 056
Landsat 7 (ETM)	17-02-2011	
	04-02-2000	
Landsat 4 (TM)	25-12-1990	

Image selection criteria considered low cloud and scene cover over the AOIs. The images correspond to the major dry season (between December and February) in Ghana. The selected periods facilitated the assessment of the AOIs before the 1991 Ghana Coastal Wetlands Management Plans [8], the 1992 Ramsar Site designation, and the 1999 Coastal Wetlands Management Project Management Plans [7]. Long time intervals were selected to capture more dynamic changes in the LULC over space and time. This aided in the identification of trends and the impacts of influencing factors to the LULC. Additionally, population statistics, gridded meteorological variables, and water balance data for the AOIs were assessed.

2.3. LULC Classification and Validation

For the LULC classification preprocessing, scan line errors in the 2011 Landsat-7 ETM images were filled by interpolating using inverse distance weighting and smoothing algorithms. The Quantum GIS (QGIS) version 3.22 software was used for this [24]. All images were radiometrically and atmospherically corrected. The assessment of images from different sources requires consistency and comparability. The corrections ensured all images were alike, based on their quantitative measures, accuracy, and interpretation [25]. Corrections were performed using equations from the USGS (https://www.usgs.gov/landsat-missions/using-usgs-landsat-level-1-data-product (accessed on 19 December 2022)). The equations focused on the conversion of digital numbers (DNs) to top-of-atmosphere (TOA) reflectance values (Equation (1)) and the correction of TOA reflectance for the sun angle (Equation (2)).

$$\rho_{\lambda}{}' = M_{\rho} Q_{cal} + A_{\rho} \tag{1}$$

where $\rho_{\lambda}{}'$ is the TOA planetary reflectance without correction for solar angle, M_{ρ} is the band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number), A_ρ is the band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number), and Q_{cal} is the quantised and calibrated standard product pixel values (DN).

$$\rho_\lambda = \frac{\rho_\lambda{}'}{cos(\theta_{SZ})} = \frac{\rho_\lambda{}'}{sin(\theta_{SE})} \tag{2}$$

where ρ_λ is the TOA planetary reflectance and θ_{SE} is the local sun elevation angle (the scene centre sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION)), and θ_{SZ} is the local solar zenith angle (θ_{SZ} = 90° − θ_{SE}).

Corrected images were projected into the Universal Transverse Mercator (UTM) projection system (Zone: 30 N, Datum: WGS84).

Pixel-based supervised image classification was undertaken using the Maximum Likelihood Classifier. Spectral indices for vegetation (Normalised Difference Vegetation Index (NDVI)), water (Modified Normalised Difference Water Index (MNDWI)), and build-up (Normalised Difference Built-up Index (NDBI)) were derived to aid in the classification. Additionally, band combinations of Red, Green, Near-infrared, and Short-wave infrared 2/Mid-infrared were employed to highlight the identification of the LULC categories. Unsupervised image classification was performed for the Songor AOI, using the Iso-cluster classifier to ensure relative ease in the LULC selections. The combination of these techniques and ground-truth data from the field, as well as fine-resolution images from the Google Earth platform, helped in obtaining the thematic maps.

The LULC classes, including names and definitions were assigned after assessing multiple relevant works in the literature [8,26,27]. The Sakumo catchment was classified into seven categories: water, dense vegetation, sparse vegetation, wetland, development, agriculture, and barren land. The Songor catchment was classified into four categories: urban (developed and barren land), vegetation (including mangroves, dense and sparse vegetation, and agriculture (cultivated and fallow lands)), Wet1 (water, lagoons, and intertidal forested wetland), and Wet2 (marshes and mudflats). Similar to [26], LULC categories that were alike in the Songor catchment were merged during classification to reduce classification errors. This was because of the relatively low spatial resolution of Landsat imagery (30 m). The spatial resolution made it difficult to separate similar LULC categories in the Songor catchment due to the close spectral signature.

A comparison of four classifiers was undertaken to determine which classifier algorithm produced fairly accurate maps. The assessed classifiers were Random Trees (RT), K-nearest neighbour (KNN), Support Vector Machine (SVM), and Maximum Likelihood (ML). Accuracies of the classified maps were validated, prior to extracting statistics for the LULC categories. The classified maps for 2020 were validated using Google Earth Imagery. Classification results were evaluated with error matrices. Error matrices assess the conformity between the classified map and actual field conditions. Error metrics used to evaluate the classified maps were overall accuracy and kappa coefficient. The overall accuracy is a percentage-based metric that shows which classes have been correctly mapped. The kappa coefficient assesses the conformity between interpretation and actual field conditions. The rating criteria for the kappa coefficient ranges from 0 (poor) through 0.5 (moderate) to 1 (perfect) [28].

2.4. LULC Change Analysis

2.4.1. LULC Change

In the post-classification assessment, cross-tabulation matrices were evaluated for the three time intervals (1990–2000, 2000–2011, and 2011–2020) to characterise size variations in the LULC classes. The cross-tabulation matrices captured a pixel-by-pixel assessment of the classified maps and identified pixel changes from one class to another.

2.4.2. Intensity Analysis

Intensity analysis is a mathematical tool that measures and compares differences between categories over time. With this tool, the identification of changes in LULC quantities and intensities across various temporal periods and categorical scales was performed [29]. This analysis was performed at three levels (interval, category, and transition) to expose different types of information per level. The interval level examines LULC (size and speed) change variations across the time intervals. The category level analyses the size and intensity of gross losses and gross gains in each LULC category with respect to the other categories for each time interval. The transition level investigates how the size and intensity of an LULC category's transitions vary across the other categories that are available for that transition. At each level, the method checks for the stationarity of patterns across time intervals. A stationary result implies that the pattern of change in a time interval is the same as the pattern of change in a different time interval [29,30].

2.5. Analysis of Change Indicators

2.5.1. Trends in Population

Catchment-based population estimates were obtained from local census records taken by the Ghana Statistical Service (GSS). Available district-scale data used were from the 2010 and 2021 records. The population density of the AOIs is the ratio of the various district populations within the AOIs to the total coverage area of the AOIs.

The assessment of spatial population changes per catchment was undertaken with remote LandScan and WorldPop population data. These datasets had 30 arc-second spatial resolution. Data for 2000, 2011, and 2020 were downloaded from the Oak Ridge National Laboratory website (https://landscan.ornl.gov/ (accessed on 8 March 2023)) and the WorldPop Open Population Repository (https://wopr.worldpop.org/?GHA/Population/ (accessed on 10 March 2023)).

Population change rates per catchment were also assessed with the equation below.

$$Population\ change\ rate = \left(\frac{Population\ density\ difference}{Past\ population\ density} \times 100\right) / Year\ difference \quad (3)$$

2.5.2. Trend of Meteorological Variables and Water Balance

The characterisation of water availability per catchment from 1990 to 2020 was assessed annually, using certain parameters. The parameters assessed were total precipitation (PRE), average temperature (TAVG), total actual evapotranspiration (AET), and water balance (WB). These parameters are considered to be components that have the most influence on water availability over land surfaces. The availability of field observation data is a major challenge in less developed countries, and this was also revealed in this research, as it has been by other authors [31–34]. Gridded climate data from TerraClimate was used to assess the trends of the parameters. TerraClimate data from 1990 to 2020 were obtained from https://climate.northwestknowledge.net/TERRACLIMATE/ (accessed on 19 March 2023). Before the analysis, TerraClimate data were validated using Global Historical Climatology Network (GHCN) data from ground stations nearest to the AOIs (Accra, Tema and Ada). The average temperature data of TerraClimate were 98.7% accurate compared with that of GHCN. Water availability influences wetland extents. Thus, wetland proliferation is directly linked to water availability. The net available water within the catchments was determined by subtracting the actual evapotranspiration from precipitation following methods used by Abatzoglou et al. [35].

Trend assessments of the climate variables per catchment were evaluated using the Mann–Kendall (MK) non-parametric trend test and Sen's slope estimator. These were performed to evaluate the existence of monotonic trends. The MK trend test assumes a null hypothesis that there is no trend, against the alternative hypothesis that a trend exists. This trend test compares the relative magnitudes of data rather than the data values themselves. It is extensively employed for trend detection in climatological and hydro-meteorological data time series [36,37]. The MK statistic (S) test was undertaken using equations shown in Abbam et al. [38]. Statistics derived from the equations include Tau, Z statistic, and Sen's slope. Tau (τ) ranges from -1 to 1 and characterises the strength of the trend. Values of -1 indicate strong negative trends, 0 for no trends, and 1 for strong positive trends. The Z statistic (Zs) measures the standard score of the MK trend test. The Sen's slope estimates the overall slope of the time series [36–38].

3. Results

3.1. Accuracy Assessment of Landcover Classification from Satellite Observations

Table 2 shows validation outcomes. The outcomes are for four classification methods. The 2020 classified maps per AOI were assessed for the overall accuracy and kappa coefficients. The ML classification registered the best outcomes. The overall accuracy was 72% for the Sakumo catchment and 77% for the Songor catchment. The kappa coefficient was 0.63 for the Sakumo catchment and 0.70 for the Songor catchment. The kappa coefficients fell within the high–moderate strength of agreement.

Table 2. Validation of classification methods (K-nearest neighbour (KNN), random trees (RT), maximum likelihood (ML), and support vector machine (SVM)). OA—overall accuracy, SK—Sakumo catchment, SG—Songor catchment.

	OA_SK	**kappa_SK**	**OA_SG**	**kappa_SG**
KNN	66%	0.55	65%	0.56
RT	60%	0.45	62%	0.52
ML	72%	0.63	77%	0.70
SVM	67%	0.55	59%	0.48

3.2. LULC Change Analysis

3.2.1. LULC Change

The LULC maps of the AOIs for the four time points are shown in Figure 2. The cross-tabulation matrices (Tables 3 and 4) show the LULC category changes for the AOIs. This covered the time intervals (first: 1990–2000, second: 2000–2011, and third: 2011–2020). Each matrix shows the comprehensive data. These include LULC category gross losses, gross gains, and net changes per time interval. The rows and columns display the categories of an initial time and a subsequent time, respectively, while boldened entries on the diagonal indicate persistence. The analyses included relative percent proportions of the LULC categories.

The LULC categories over the time intervals in Sakumo showed variations. These variations showed significance in percentages and coverage areas. The dominant LULC categories in the Sakumo catchment were agriculture (129.94 km^2; 45.67%) in 1990 and developed in 2000 (101.07 km^2; 35.52%), 2011 (99.19 km^2; 34.86%), and 2020 (179.95 km^2; 61.84%). In 1990–2000, agriculture converted to developed (53.24 km^2; 18.71%) and sparse vegetation (38.79 km^2; 13.63%). Within the second time interval (2000–2011), sparse vegetation (54.65 km^2; 19.21%) lost the most. Agriculture (20.01 km^2; 7.03%), barren (22.53 km^2; 7.92%), and developed (11.79 km^2; 4.14%) gained from the loss. For the third time interval (2011–2020), barren converted to agriculture (13.75 km^2; 4.83%), developed (39.08 km^2; 13.74%), and sparse vegetation (6.53 km^2; 2.29%).

In the Songor catchment, vegetation (186.83 km^2; 37.25%) dominated the LULC categories for 1990. Vegetation persisted in 2000 (240.91 km^2; 48.03%), 2011 (246.94 km^2; 49.23%), and 2020 (271.02 km^2; 54.03%). In 2000, urban was the second dominant LULC category (97.31 km^2; 19.40%). Wetland-related categories changed in order. In 2011, Wet1 registered 18.72% (93.90 km^2) and Wet2 18.58% (93.22 km^2). For 2020, Wet2 covered 103.94 km^2 (20.72%) and Wet1 had 92.20 km^2 (18.38%).

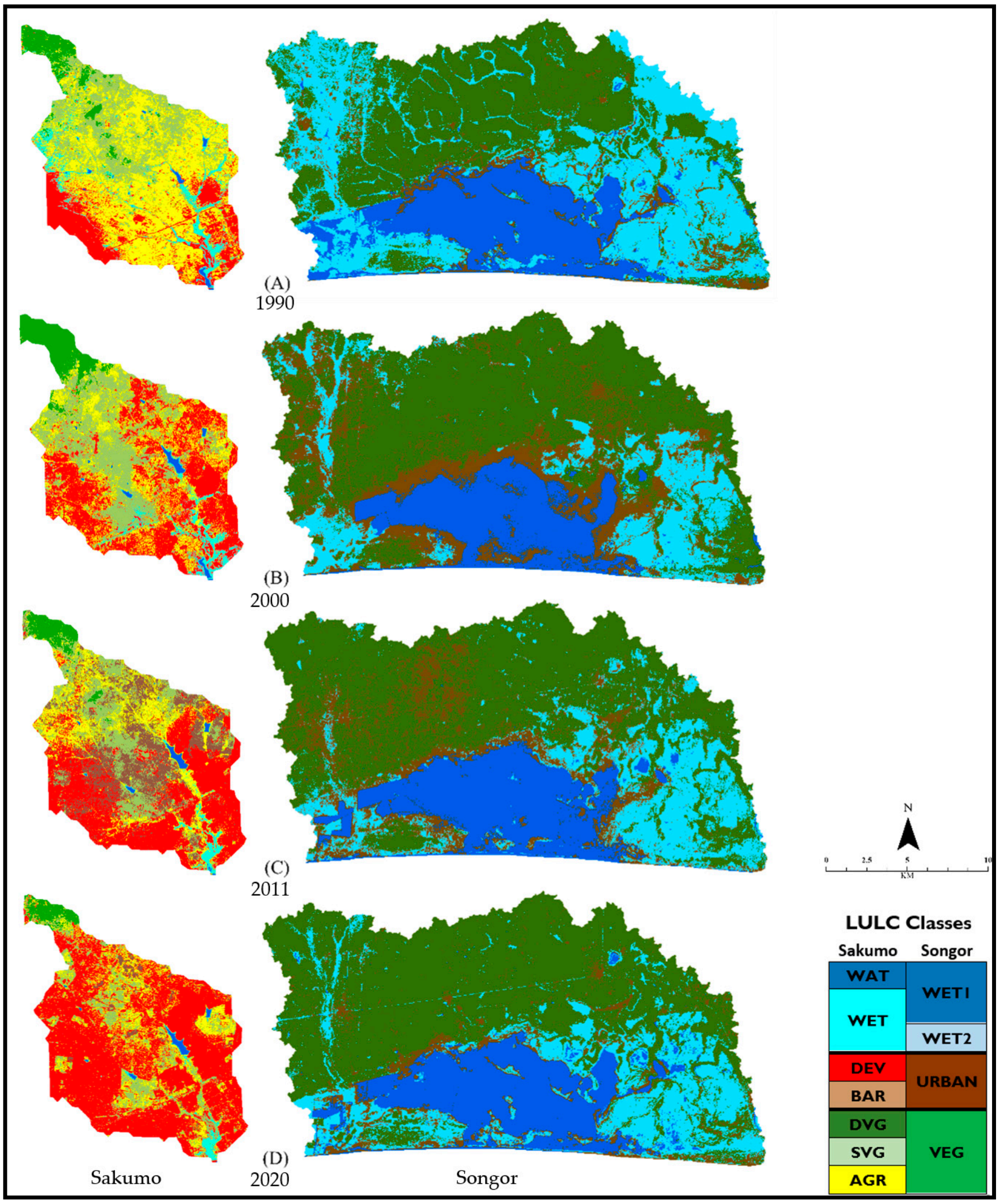


Figure 2. LULC maps of the Sakumo (left) and Songor (right) catchments for (**A**) 1990, (**B**) 2000, (**C**) 2011, and (**D**) 2020. NB: LULC classes: Sakumo (WAT—water, WET—wetlands, DEV—development, BAR—barren land, DVG—dense vegetation, SVG—sparse vegetation, AGR—agriculture); Songor (WET1—water, lagoon, open water and inter-tidal forested wetlands, WET2—marshes, URBAN—development and barren land, VEG—vegetation and agriculture).

Gross changes fluctuated between LULC categories in the Sakumo catchment over the time intervals. In the first time interval (1990–2000), agriculture (34.60%; 98.46 km^2) lost the most and developed (67.10 km^2; 23.58%) gained the most gains. Within the second time interval, sparse vegetation (54.65 km^2; 19.21%) lost most to barren (63.26 km^2; 22.23%). In the third time interval, barren (20.87%; 59.39 km^2) lost the most area to developed (87.40 km^2; 30.72%).

Table 3. LULC cross-tabulation matrices (km^2) for the Sakumo catchment (1990–2000, 2000–2011, and 2011–2020).

		LULC 2000								1990–2000
	Category	Agriculture	Barren	Dense Veg	Developed	Sparse Veg	Water	Wetlands	TOTAL	Gross Loss
LULC 1990	Agriculture	**31.478**	0.616	2.526	53.235	38.789	0.614	2.681	129.938	98.461
	Barren	0.269	**0.019**	0.016	0.768	0.148	0.007	0.018	1.245	1.226
	Dense Veg	1.934	0.000	**12.618**	0.018	1.301	0.000	0.006	15.878	3.260
	Developed	7.486	0.243	0.091	**33.962**	5.244	0.178	3.746	50.951	16.988
	Sparse Veg	15.177	0.022	4.877	7.911	**33.462**	0.191	1.436	63.075	29.613
	Water	0.040	0.000	0.000	0.016	0.040	**1.383**	0.129	1.607	0.224
	Wetlands	5.279	0.008	0.721	5.156	5.998	0.428	**4.258**	21.847	17.589
	TOTAL	61.662	0.907	20.849	101.066	84.982	2.801	12.273	284.540	
1990–2000	Gross Gain	30.184	0.888	8.231	67.104	51.520	1.418	8.015		167.360
		LULC 2011								2000–2011
	Category	Agriculture	Barren	Dense Veg	Developed	Sparse Veg	Water	Wetlands	TOTAL	Gross Loss
LULC 2000	Agriculture	**11.447**	16.254	0.691	19.241	13.393	0.026	0.609	61.662	50.215
	Barren	0.046	**0.320**	0.000	0.527	0.015	0.000	0.000	0.907	0.588
	Dense Veg	4.024	1.449	**8.911**	0.513	5.952	0.000	0.001	20.849	11.939
	Developed	9.232	22.635	0.001	**62.745**	5.757	0.005	0.690	101.066	38.321
	Sparse Veg	20.012	22.529	0.037	11.790	**30.334**	0.005	0.276	84.982	54.648
	Water	0.097	0.080	0.002	0.002	0.020	**2.012**	0.589	2.801	0.789
	Wetlands	3.188	0.311	0.000	4.375	1.555	0.143	**2.702**	12.273	9.572
	TOTAL	48.046	63.577	9.642	99.193	57.026	2.191	4.867	284.540	
2000–2011	Gross Gain	36.599	63.257	0.731	36.447	26.692	0.179	2.165		166.071
		LULC 2020								2011–2020
	Category	Agriculture	Barren	Dense Veg	Developed	Sparse Veg	Water	Wetlands	TOTAL	Gross Loss
LULC 2011	Agriculture	**9.149**	1.228	0.119	27.014	9.798	0.044	0.695	48.046	38.897
	Barren	13.751	**4.191**	0.016	39.083	6.526	0.000	0.009	63.577	59.386
	Dense Veg	1.075	0.124	**5.945**	0.589	1.887	0.000	0.022	9.642	3.696
	Developed	3.993	2.170	0.000	**88.547**	4.388	0.000	0.095	99.193	10.645
	Sparse Veg	14.564	3.219	0.581	20.304	**18.122**	0.000	0.236	57.026	38.903
	Water	0.004	0.004	0.000	0.057	0.059	**1.754**	0.313	2.191	0.437
	Wetlands	0.408	0.040	0.000	0.357	1.857	0.035	**2.171**	4.867	2.696
	TOTAL	42.943	10.976	6.661	175.951	42.638	1.833	3.540	284.540	
2011–2020	Gross Gain	33.794	6.784	0.716	87.404	24.515	0.079	1.369		154.661

Note(s): Boldened numbers on the diagonal indicate persistence. Off-diagonal entries are transitions from an LULC category to a different category. "TOTAL" shows the total area of cover for an LULC category at each time point. The analyses include relative percent proportions of the LULC categories.

In the Songor catchment, gross change statistics reported landscape change decreases over the time intervals. Wet2 (112.35 km^2; 22.40%) lost most in the first time interval. Urban lost most in the second (67.51 km^2; 13.46%) and third (53.74 km^2; 10.71%) time intervals. From 1990 to 2000, urban (80.10 km^2; 15.97%) gained the most. These gains were greater than the two highest gains in the subsequent intervals. Vegetation remained the largest gross gainer in the second (10.74%; 53.87 km^2) and third (9.72%; 48.78 km^2) time intervals.

The most persistent LULC categories per catchment increased consecutively. Developed persisted (first = 11.94%; second = 22.05%; third = 31.12%) in the Sakumo catchment, and vegetation (first = 32.41% (162.60 km^2); second = 38.49% (193.07 km^2); third = 44.31% (222.25 km^2)) in the Songor catchment. In both catchments, the total land changes decreased steadily over successive time intervals. For the Sakumo catchment, they declined from 58.82% (167.36 km^2) through 58.36% (166.07 km^2) to 54.35% (154.66 km^2). In the Songor catchment, they shrunk from 35.84% (179.79 km^2) through 30.40% (152.49 km^2) to 23.73% (119.04 km^2).

Table 4. LULC cross-tabulation matrices (km^2) for the Songor catchment (1990–2000, 2000–2011, and 2011–2020).

	Category	Urban	Veg	Wet1	Wet2	TOTAL	Gross Loss
			LULC 2000				1990–2000
LULC 1990	Urban	**17.22**	9.74	2.33	2.97	32.27	15.05
	Veg	18.49	**162.60**	0.24	5.50	186.83	24.23
	Wet1	19.28	1.92	**73.76**	6.97	101.93	28.16
	Wet2	42.33	66.65	3.37	**68.25**	180.59	112.35
	TOTAL	97.31	240.91	79.71	83.69	501.62	
1990–2000	Gross Gain	80.10	78.31	5.94	15.44		179.79
			LULC 2011				2000–2011
	Category	Urban	Veg	Wet1	Wet2	TOTAL	Gross Loss
LULC 2000	Urban	**29.80**	35.46	16.08	15.97	97.31	67.51
	Veg	24.23	**193.07**	0.86	22.74	240.91	47.84
	Wet1	4.09	0.04	**73.66**	1.92	79.71	6.05
	Wet2	9.43	18.37	3.30	**52.59**	83.69	31.10
	TOTAL	67.55	246.94	93.90	93.22	501.62	
2000–2011	Gross Gain	37.75	53.87	20.24	40.64		152.49
			LULC 2020				2011–2020
	Category	Urban	Veg	Wet1	Wet2	TOTAL	Gross Loss
LULC 2011	Urban	**13.81**	30.61	6.89	16.24	67.55	53.74
	Veg	7.84	**222.25**	0.53	16.33	246.94	24.70
	Wet1	8.39	0.21	**80.23**	5.08	93.90	13.68
	Wet2	4.41	17.96	4.56	**66.29**	93.22	26.93
	TOTAL	34.45	271.02	92.20	103.94	501.62	
2011–2020	Gross Gain	20.64	48.78	11.98	37.64		119.04

Note(s): Urban; development and barren land, Veg; sparse vegetation and agriculture, Wet1; lagoon, open water, and intertidal wetland (mangroves), Wet2; marshes. Boldened numbers on the diagonal indicate persistence. Off-diagonal entries are transitions from an LULC category to a different category. "TOTAL" shows the total area of cover for an LULC category at each time point.

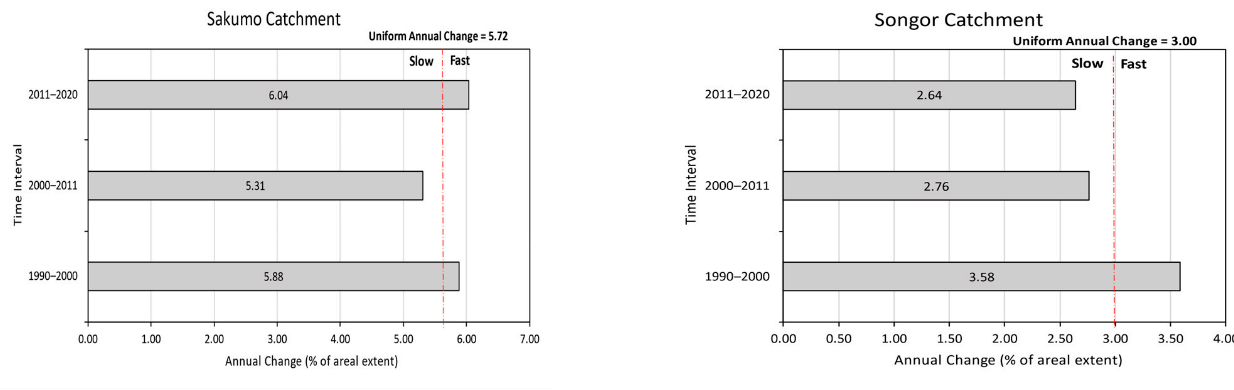
3.2.2. Intensity Analysis

Interval Level

The results of the interval level intensity analysis over the three time intervals are displayed in Figure 3. Figure 3 relates the overall annual changes to the uniform annual change for the Sakumo catchment (Figure 3A) and for the Songor catchment (Figure 3B). The uniform annual change describes the consistent rate of change that would occur if all changes were evenly distributed over the entire period of study. If the annual change of a time interval is greater than the uniform annual change, it is characterised as fast, and slow when an opposite trend is observed. The Sakumo catchment recorded a uniform annual change of 5.72%. The Sakumo catchment reported fast changes in the first (5.88%) and third (6.04%) time intervals and a slow change in the second time interval (5.31%). The Songor catchment had a uniform annual change of 3%. Fast changes occurred in the first time interval (3.58%), and slow changes in the second (2.76%) and third (2.64%) time intervals.

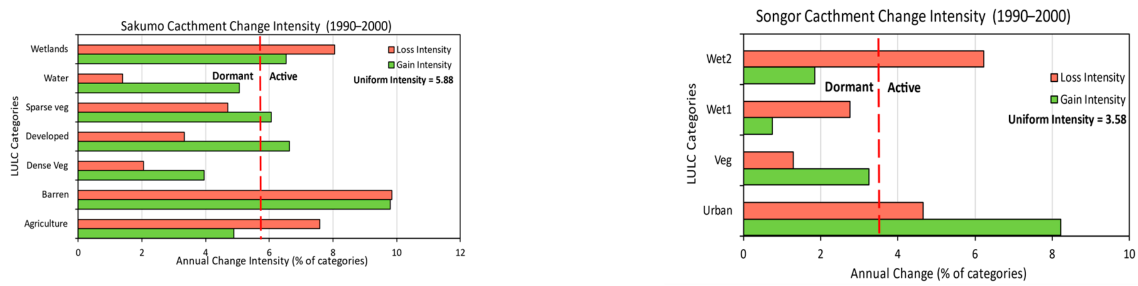
Category Level

The category level intensity results display the intensity for a category's annual change for both AOIs (Figure 4). The uniform intensity line links the interval and category level analyses. For each time interval in an AOI, LULC categories behind the uniform line were dormant and those ahead of it were active. Across all time intervals in the Sakumo catchment, LULCs of water and dense vegetation remained dormant gainers and losers. Barren actively gained and lost. Wetlands and development were only active during 1990–2000. Wetlands lost actively in all time intervals. Agriculture and wetland remained active losers over the three time intervals.

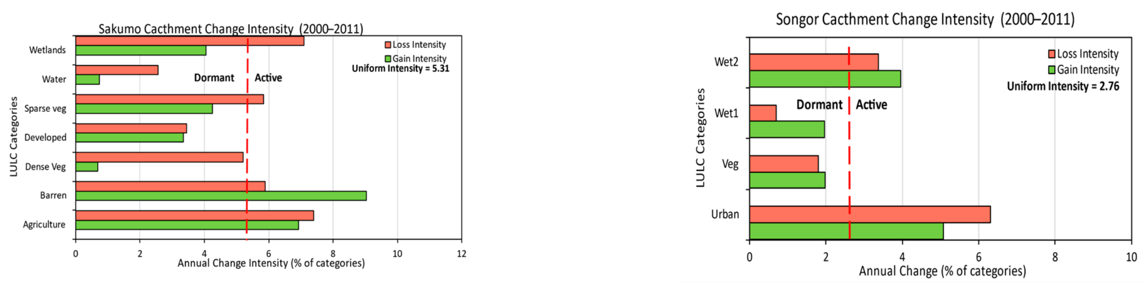


(**A**) (**B**)

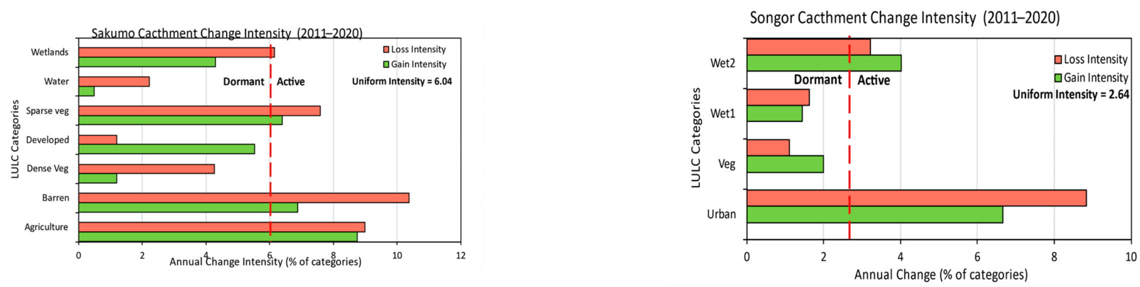
Figure 3. Interval level intensity analysis results at the AOIs (Sakumo (**A**) and Songor (**B**)). The bars represent the intensity of annual area of change within each time interval. The red line shows uniform annual change, if all changes were evenly distributed over all study periods.



(**A**)



(**B**)



(**C**)

Figure 4. Category level intensity analysis at the Sakumo and Songor catchment for 1990–2000 (**A**), 2000–2011 (**B**), and 2011–2020 (**C**). The bars show the intensity of annual gains and losses within each category. The red line represents uniform intensity change, if all changes were evenly distributed over all categories.

In the Songor catchment, urban had the highest gains and actively gained and lost over the three time intervals. Vegetation and Wet1 remained dormant over the time intervals. Wet2, on the other hand, actively lost in all time intervals and actively gained in the second and third intervals. The bars for each category ended at varied points from the uniform line. This means that across all categories, the intensity of change was not uniform.

Transition Level

The transition level focused on categories with the most significant gains. LULC categories that extended beyond the uniform intensity line showed categories targeted by the gaining category. Categories behind the uniform intensity line indicated categories avoided by the gaining category. Figures 5 and 6 show transition level changes to the highest gaining LULC category for the three time intervals.

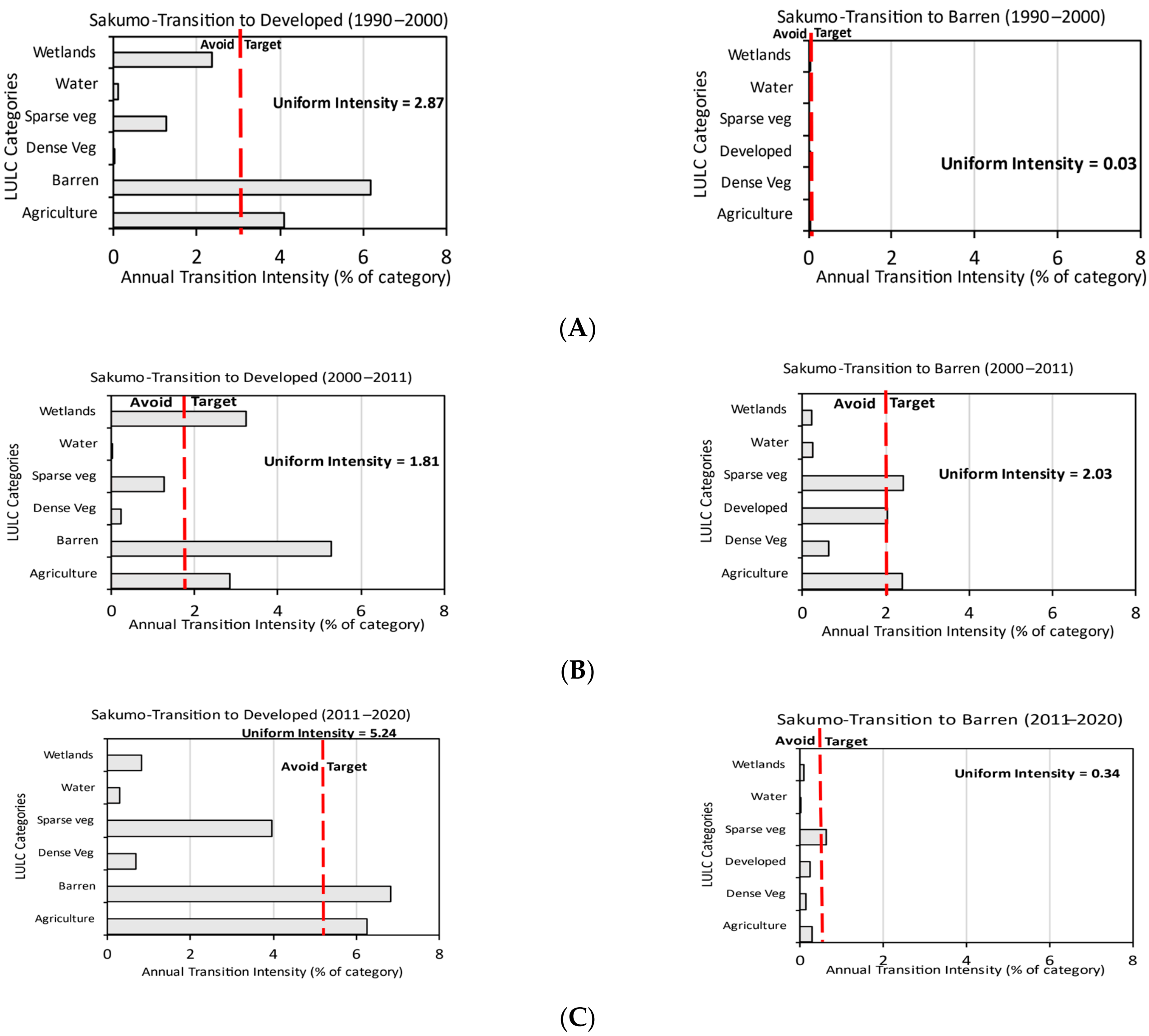


Figure 5. Transition to developed and barren at the Sakumo catchment for 1990–2000 (**A**), 2000–2011 (**B**), and 2011–2020 (**C**). The bars show the intensity of annual transitions to developed and barren from other categories. The red line represents the uniform intensity of change.

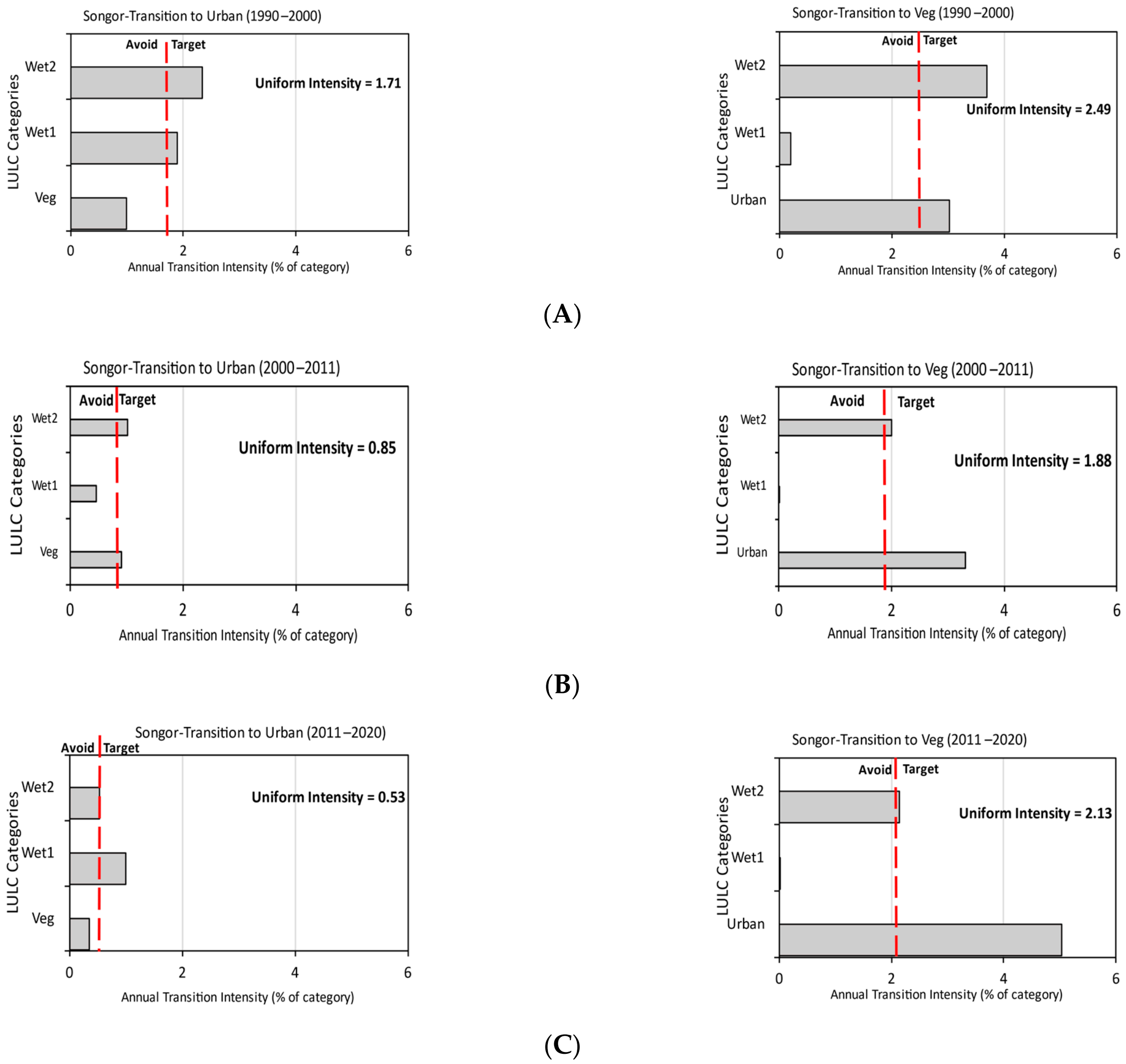


Figure 6. Transition to urban and vegetation at the Sakumo catchment for 1990–2000 (**A**), 2000–2011 (**B**), and 2011–2020 (**C**).

For the Sakumo catchment (Figure 5), in 1990–2000, barren targeted agriculture and developed at 0.05%. Subsequent intervals showed that barren intensively targeted agriculture (2.40%) and sparse vegetation (2.41%) in 2000–2011, and only sparse vegetation (0.63%) in 2011–2020. Developed targeted barren more intensively than agriculture over the three time intervals. In the second time interval, developed also targeted wetland.

For the Songor catchment (Figure 6), urban had the most significant gains in all the time intervals. During 1990–2000, urban targeted Wet1 (1.89%) and Wet2 (2.34%), while avoiding vegetation (Figure 6A). In 2000–2011 (Figure 6B), Wet2 (1.02%) and vegetation (0.91%) were targeted and Wet1 was avoided. However, in 2011–2020, urban targeted only Wet1 (0.99%).

3.3. Analysis of Change Indicators

3.3.1. Trends in Population

Figure 7 shows the population catchment estimates for the 2010 and 2021 local census. The Songor catchment grew at a rate of 9.51% and the Sakumo catchment at 5.21%. The population density rose faster in Sakumo than in Songor. The remote datasets showed a steeper incline of population densities in Sakumo (Figure 8). The spatial distribution of the populations within the AOIs showed a consistent surge over the years. This surge was relatively faster in the 2000–2011 interval than the 2011–2020 interval. Populations closest to the wetlands increased more than those further away. Overall (2000–2020), regions with higher populations more than doubled.

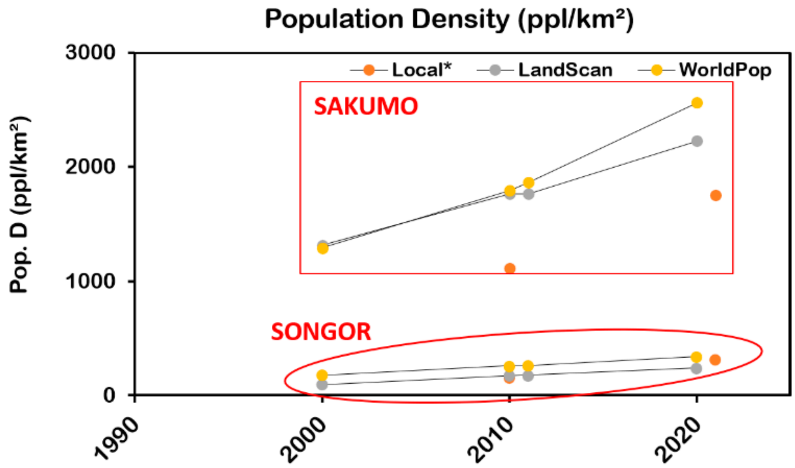


Figure 7. Population density of the AOIs (Sakumo and Songor wetland catchments) (* Data calculated from Local Census).

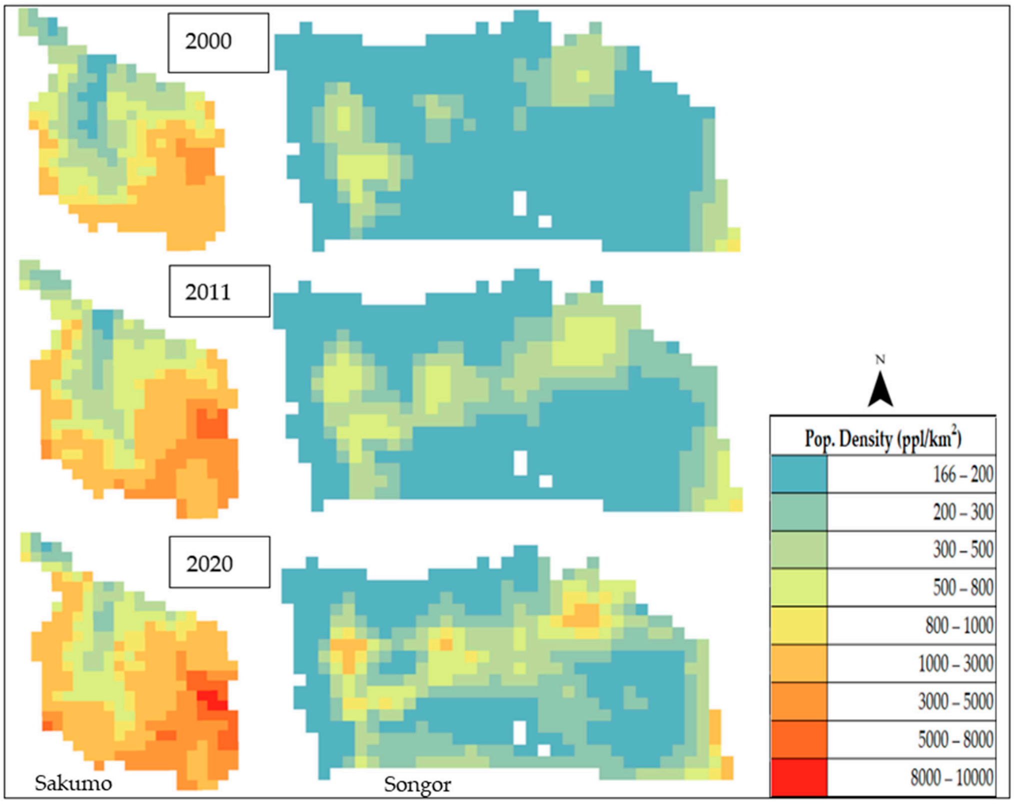
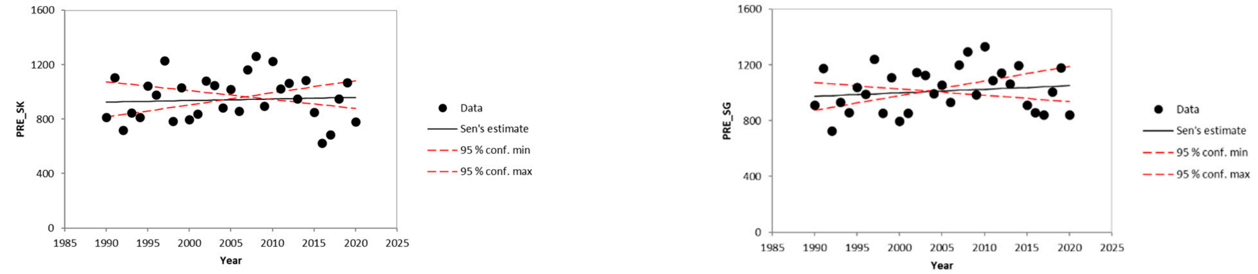


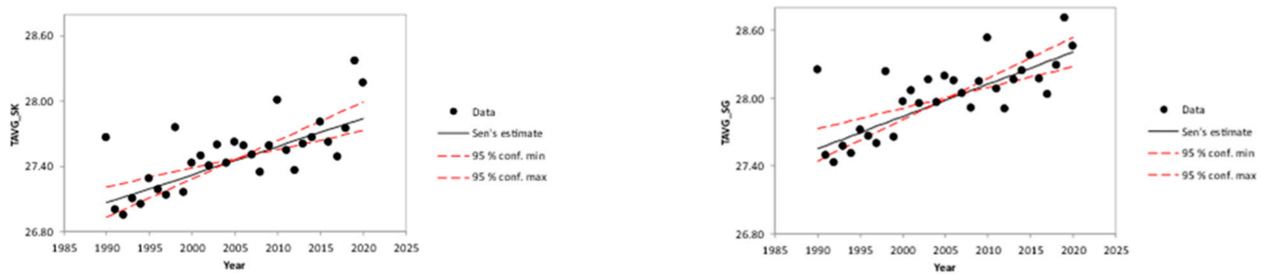
Figure 8. Spatial distribution (1 pixel = 1 km^2) of population within the catchments (Sakumo—left; Songor—right) in 2000, 2011, and 2020 (Source: WorldPop).

3.3.2. Trends in Meteorological Variables and Water Balance

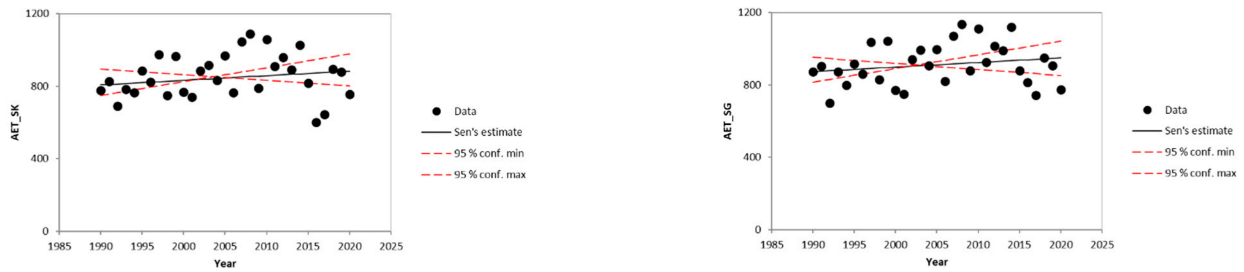
Figure 9 shows the 30-year (1990 to 2020) trends for the meteorological variables (annual total precipitation (A), annual average temperatures (B), annual total evapotranspiration (C), and annual water balance (D). Though the trend results (Table 5) showed positive increasing trends in both locations for most parameters, only temperature showed significance (p-value < 0.05).



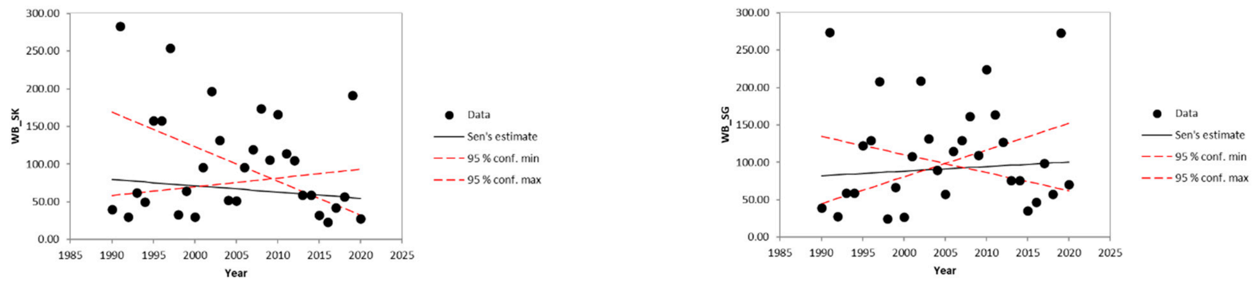
(**A**)



(**B**)



(**C**)



(**D**)

Figure 9. Trend plots of water balance components from 1990 to 2020 of the AOIs (Sakumo—left; Songor—right). (**A**) Annual total precipitation (mm/yr), (**B**) annual average temperature (°C), (**C**) annual total actual evapotranspiration (mm/yr), and (**D**) water balance (mm/yr).

Table 5. Mann–Kendall trend test results for the water balance components.

Catchment	Mann–Kendall Statistic (S)	Tau (τ)	Sen's Slope Estimator (Q)	Zs	p-value (Two-Tailed Test)
Annual Total Precipitation					
Catchment	**Mann–Kendall Statistic (S)**	**Tau (τ)**	**Sen's Slope Estimator (Q)**	**Zs**	**p-value (Two-Tailed Test)**
Sakumo	15	0.03	1.15	0.24	8.12×10^{-1}
Songor	43	0.09	2.53	0.71	4.75×10^{-1}
Annual Average Temperature					
Catchment	**Mann–Kendall Statistic (S)**	**Tau (τ)**	**Sen's slope Estimator (Q)**	**Zs**	**p-value (Two-tailed test)**
Sakumo	249	0.54	0.03	4.22	2.50×10^{-5} *
Songor	241	0.52	0.03	4.08	4.52×10^{-5} *
Annual Total Evapotranspiration					
Catchment	**Mann–Kendall Statistic (S)**	**Tau (τ)**	**Sen's slope Estimator (Q)**	**Zs**	**p-value (Two-tailed test)**
Sakumo	45	0.10	2.55	0.75	4.50×10^{-1}
Songor	55	0.12	2.53	0.92	3.60×10^{-1}
Annual Water Balance					
Catchment	**Mann–Kendall Statistic (S)**	**Tau (τ)**	**Sen's slope Estimator (Q)**	**Zs**	**p-value (Two-tailed test)**
Sakumo	−51	−0.11	−0.83	−0.85	4.00×10^{-1}
Songor	23	0.05	0.61	0.37	7.10×10^{-1}

Note(s): Values with * indicate significance (i.e. p-value < 0.05).

4. Discussions

4.1. Interpretation of Change Analysis

From the results, LULC change rates were inconsistent. This is in the purview of the three time intervals and catchments. These changes stemmed from multiple factors (natural and anthropogenic). As against natural factors, human-induced activities influenced most of the LULC changes in the catchments. Land changes in the Sakumo catchment were slow in the second time interval and relatively faster in the third time interval, compared to the first time interval. Throughout all four time periods, human activities significantly transformed the Sakumo catchment. The catchment is situated between the capital (Accra) and a major port city (Tema), thereby making it a prime urban hub for economic activities. Within the third time interval, encroachment stemming from rapid urbanisation led to the loss of 38% of the Sakumo Ramsar Site [39]. As presented in the LULC change analysis, the population explosion within the catchment has led to declines in vegetative cover and wetland areas, and a resulting rise in urban infrastructure, including roads and industries [40]. In this study, the Songor catchment area saw a rise in the coverage area of vegetation. In the north-eastern portion of the catchment, there was a conversion of Wet2 to vegetation. The intense transition of the land cover to agriculture–vegetation is driven by human behaviour in the catchment [23,26].

The outcome of the category and transition level intensity analysis showed changes in gains, losses, and significant transitions within different LULC categories. In the Sakumo catchment, the agricultural and barren land decreased at the expense of human developments. Also, in the second time interval, the wetlands were intensively targeted by developments. This can be credited to urbanisation. A high population growth is directly linked to an attendant surge in the demand for residential and commercial facilities [41,42]. The increase in the human-induced categories was alluded to by an earlier study in 2020 on three coastal Ramsar Sites in Ghana [43]. Additionally, it affirmed that urbanisation was the primary underlying process associated with the land transformations. Progressively, this will lead to the conversion of wetlands and vegetation to impervious surfaces, which has harmful effects on biodiversity.

The results show that Songor catchment LULC changes were unlike those of the Sakumo catchment, as changes were dominated by vegetation expansion. Vegetation is composed of mangroves, dense and sparse vegetation, and agricultural cover (fallow and cultivated lands). Expansions in vegetation were primarily derived from Wet2 (comprised of marshes and mudflats) and urban (consisting of development and barren land) categories. The main livelihood activities in the Songor catchment are farming, fishing, and salt mining [17]. This justifies the intense conversion of other LULC classes to agricultural lands–vegetation. Wet1 and Wet2 were unstable throughout the time intervals. This is predominately due to human reliance on the ecosystems in the catchment to meet their self-actualisation and survival needs [23]. Human overexploitation of the natural resources negatively impacts the Songor catchment. These exploitative acts have increased land fragmentation due to salt mining [44], intensified farming, and aquaculture activities in wetland areas [45], and the overharvesting of mangroves for many services (including fuelwood, fish net tanning, medication, weaving baskets, smoking fish, and drink distillation) [23,46], among others. Further to that, in a 2021 assessment of the nearby Keta Lagoon Complex Ramsar Site, which is less than 10 km east of the Songor catchment, all assessed time points recorded over 60% coverage area of naturally occurring LULC categories in 1991, 2007, and 2020 [26]. The decline in urban areas in the Songor catchment is due to rural–urban migration. This stems from regional economic disparities, environmental changes, and socio-cultural factors [46,47]. The persistence of these practices will lead to elevated levels of environmental degradation, caused by poor management strategies to protect wetlands.

4.2. Impact of Change Indicators

The Sakumo and Songor catchments registered a greater population density in the third time interval (2011–2020) than in the second time interval (2000–2011). This had a positive impact on economic growth. However, it contributed negatively to the environment, as natural land covers were substituted for urban and industrial developments [48]. This effect was larger in the Sakumo catchment because it is more urban than the Songor catchment. Predictions suggest that between 2019 and 2050, the sub-Saharan Africa will account for more than half of the growth of the world's population, and it is the only region projected to sustain a rapid population growth until the end of the current century [49]. Furthermore, urban areas are anticipated to absorb the bulk of the Earth's population [50]. The consequence is that natural environments will be converted to human-induced environments (urban). This robs communities of associated wetland values and services. Based on the literature, flow patterns, and studies, potential areas of high risk in the catchments are considered. In the Songor catchment, the direct coastal dwellers would be most affected. These dwellers combat threats from sea level rise, coastal erosion and changing wetland hydrological regimes. For the Sakumo catchment, likely areas of greater risk are regions within the lagoon buffer zone. These areas directly impinge on the drainage regimes of the wetland, thus making them vulnerable to subsidence and inundation.

The land transformations noted in this study are also consistent with Ghana's economic and population growth rate. The growth rate has been documented to be quicker than sub-Saharan Africa's average since 2007. Expansions of this nature result in accelerated and significant changes to LULCs [26]. This requires proper management to conserve the available natural resources.

Rainfall variability in both the Sakumo and Songor catchments showed a weak and unsteady pattern. This is typical with current global climate trends of increasing temperatures and varied rainfall magnitude [51]. The IPCC reported a low average increase in rainfall of 0.25% in tropical regions during the twentieth century [52]. Wetland ecosystems thrive on the availability of water. Hence, continued declines in water availability will lead to biodiversity losses, especially dwindling migratory waterbird populations in the Sakumo and Songor Ramsar Sites [17,41,53].

In this study, from 1990 to 2020, annual temperature increased significantly. An extended temperature rise will negatively affect society, the economy, and the environment [12,14]. With reduced rainfall, elevated temperatures result in higher evapotranspiration rates, cumulative drops in water balance, and higher hazard vulnerability (including sea level rise and extreme weather patterns). This research registered the Sakumo catchment with a decline in water balance, as the Songor catchment was fairly stable. This implies that the Sakumo catchment is losing more water than it gains. This is primarily credited to the high population density, which results in increased impervious surfaces and deforestation [54,55]. This indicates that with continued conditions, water resources in the Sakumo catchment will be lost, along with accompanying ecosystem services.

4.3. Implications on Water Resource Management

The surface waters draining into the catchment lagoons are primarily used for agriculture irrigation. These surface waters are threatened by untreated surface runoffs. These untreated surface runoffs come from varied sources, including residential, industrial, and agricultural sources. The primary constituents of these runoffs are waste materials. Population density increases proportionally with waste generation. Untreated wastes typically find their way into surface waters via stormwater drains and degrade the water quality.

The Songor Lagoon's water quality is influenced by natural and anthropogenic activities. The natural processes of tidal flushing and evaporation are heavily complimented by human pollution. The waters register high levels of nitrates, phosphates, sulphates, and total dissolved solids (TDS) [21,22]. This is indicative of toxicity from human sources, including agricultural runoff and untreated urban wastewater. With the continuation of these conditions, the waters will be eutrophic and unable to support aquatic organisms and associated vegetation. In the Sakumo Ramsar Site, from 1991 to 2018, significant elevated concentrations of Nitrate nitrogen (NO_3–N), Ammoniacal nitrogen (NH_3–N), and Phosphate compounds (PO_4–P) were recorded [20,56–58]. These levels were predominantly credited to anthropogenic pressures such as urbanisation, industrialisation, agriculture, and the overexploitation of wetland resources [12,59]. Aside from measures to treat and mitigate the pollution of these water resources, consistent monitoring and public education will support the protection of associated wetlands. Regular awareness on the wise use of wetland resources is imperative to guide conservation efforts in communities.

4.4. Limitations

Satellite images from the Landsat collection, though longstanding, have a medium spatial resolution of 30 metres, thereby increasing the complexity in distinguishing particular LULC categories within the AOIs. Higher resolution satellite imagery, dating back to the assessed periods, would have improved the accuracy of the land cover classification This challenge was marginally resolved by merging related categories, as undertaken by previous researchers [26,60]. Furthermore, time intervals of the assessment were not consistent, owing primarily to the presence of clouds in the AOIs. In resolving this challenge, reduced cloud or noise coverage over the AOIs and seasonal clear images were key considerations in the image selection criteria.

5. Conclusions

This study assessed the LULC changes for the Sakumo and Songor coastal wetland catchments using intensity analysis. The analysis covered three time intervals (1990–2000, 2000–2011, and 2011–2020). This approach facilitated a comprehensive understanding of LULC changes by examining the size and intensity of land transformations and testing for stability at three detailed levels. The findings revealed that various processes significantly influenced land transformations in both catchments, with human activities being the primary driving force. Interestingly, while human-led activities played a substantial role in these modifications, the resulting LULC categories differed between the two catchments.

In the Sakumo catchment, noticeable changes were predominantly directed towards development, reflective of urbanisation and industrialisation. Conversely, the Songor catchment witnessed transitions mainly towards vegetation–agricultural expansion. Urbanisation, industrialisation, and agriculture were found to be pertinent to LULC changes within the AOIs. The assessment of population and water balance variables as change factors showed an increasing potential influence of anthropogenic pressures against natural processes. These findings hold crucial implications for ecosystem management, especially in mitigating the ongoing decline of the wetland ecosystems in these catchments.

This research underscores the importance of proactive conservation measures and sustainable resource utilisation by relevant stakeholders. Ecosystem managers could use the research outcomes to determine the driving forces for monitoring in AOI conservation. Policy makers could use them to guide their decisions regarding anthropogenic impact on environmental resources. Environmentalists and researchers could improve on the methods used to enhance LULC and catchment evaluation.

The failure to prioritise the conservation of coastal wetland catchments and the sustainable use of their natural resources by relevant stakeholders could result in accelerated degradation and the eventual loss of associated ecosystem services. Within coastal wetland catchments, thorough analysis and the regular monitoring of the observed trends and drivers of catchment changes is necessary. This allows for sufficient understanding of the interactions between human-induced and naturally existing LULC categories. Additionally, comprehensive assessments relating to LULC changes and natural and anthropogenic change indicators are required. Future assessments will evaluate the impact of the landform morphometries on the catchment LULC.

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