

Article

Assessment of Land Use/Land Cover Change and Morphometric Parameters in the Keta Lagoon Complex Ramsar Site, Ghana

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Abstract: The rapid urbanization, industrialization, agricultural activities, and increasing trend of some natural hazards, such as climate change, particularly in coastal areas, necessitate the continual assessment of critical but fragile ecosystems like that of the Keta Lagoon Complex Ramsar Site (KLCRS). This productive ecosystem in Ghana faces serious threats from intensive exploitation, physical modification, changes in water regime, and water pollution. The current study employed geospatial and intensity analysis to assess the pattern of land use/land cover (LULC) change for almost the past three decades and morphometric parameters of the KLCRS landscape. Landsat Satellite images for 1991, 2007, and 2020 were acquired to uncover the pattern of LULC change, while morphometric changes were assessed using global Advance Space Thermal Emission and Radiometer (ASTER) digital elevation model (DEM) data and the spatial analyst tools in GIS software. The result established that the acceleration of land transformation was intensive between 2007 and 2020, which could be linked to population growth and increased socio-economic activities. There was a net gross gain of built-up that originated largely from the conversion of marsh, dense vegetation, and cultivated land. Prior to this period, cultivated land recorded net gain (125.51 km²) between 1991 and 2007, whereas dense vegetation and marshland showed a net loss of 151.37 km² and 2.44 km², respectively. The gain of cultivated land largely targeted marshland in both time intervals. The construction of saltpans contributed largely to the small increase in water extent. The morphometric analysis revealed the groundwater potential of the KLCRS. The low-lying nature of the landscape makes the area susceptible to coastal flooding. The trend of the observed changes could invariably affect the ecological integrity of the landscape, hence suggesting the need for immediate preparation and implementation of marine and coastal spatial plans by relevant stakeholders.



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1. Introduction

Wetlands are permanent or temporary areas of swamps, marshes, peatland, and fens, including marine areas with a depth not exceeding six meters at low tide [1]. Globally, the extent of wetland ecosystem is estimated to be 12.1 million km² [2]. Coastal wetlands account for only 7.2% of the known wetlands worldwide. Even though wetlands occupy a small portion of the earth's landscape, they are one of the most valuable natural resources in the world. They provide numerous ecological and socioeconomic benefits that support human livelihoods and wellbeing [3]. In terms of ecological services, the wetland ecosystem is only comparable to rainforest and coral reef ecosystems [4]. These services, such as carbon sequestration, nutrients and pollution retention, protection of human settlements from flood, groundwater recharge, and provision of habitat for a rich variety of flora and fauna, are reported by several studies [1,5–11]. Wetlands also provide different recreational

opportunities (e.g., fishing, boating, swimming, hunting) and create an avenue for eco-tourism [1,5,8]. In economic terms, wetland ecosystem services across the globe are valued at 4.9 trillion U.S. dollars per annum [12].

Notwithstanding the ecological and socio-economic values of the limited wetland ecosystems worldwide, they are under intense pressure resulting in their fragmentation, loss of area, and degradation. At the global level, inland and coastal/marine wetlands together declined by 35% between 1970 and 2015 [13]. The threat to the sustainability of wetlands emanates from human activities (e.g., domestic and industrial waste discharge, land reclamation, and overexploitation) and natural hazards, like climate change [14]. Among the drivers of wetland extinction, human sources have become more pervasive. For instance, the alteration, degradation, and loss of more than half of the world's wetlands estimated over the last 150 years could be the result of a wide range of anthropogenic activities [12]. As a result of sea-level rise, coastal wetlands are expected to lose 5 to 20% of their area by the 2080s, which would be lower than that of human-induced destruction [15]. The situation is expected to be very critical in coastal areas of sub-Saharan Africa, especially the coastal countries of West and East Africa, which are experiencing rapid population growth and urbanization [16].

The increasing global warming, rapid populations growth, and degradation of coastal wetlands through pollution and overexploitation of wetland resources mean that the coastal zone and its resources are fast declining. This has far-reaching ecological and social problems [17], necessitating compelling concerns for the wise use and protection of wetlands [12]. To manage the use and conservation of wetlands, there is the need for knowledge on the status and health of the wetlands at any point in time through regular assessment and monitoring of the transformations of the natural landscape. Efforts at the assessment of change in wetland area in Africa, South America, and Oceania, however, are uneven and inconclusive [18]. Furthermore, it is uncommon to find a report that includes information on which habitat types or other land covers a wetland has converted to. This among other things point toward a great need for understanding the biophysical and morphometric parameters, like land use/land cover, elevation, land surface slope, aspect, flow direction, stream network, and stream density, associated with the flow and storage of water in a wetland environment. Geospatial technology offers the best solution to achieve this.

Geospatial technology as an integrated science technology uses remote sensing (RS), geographic information system (GIS), and ground-based approaches to observe the world's environment by collecting, storing, and analysing spatial data. This data can be manipulated and transformed into useful information using geoscientific, analytical, and visualization techniques to enable the making of effective decisions [19]. GIS and remote sensing are essential tools in ecosystem assessment and management, including the detection of changes occurring in the wetland environment and the evaluation of wildlife habitat quality [20]. Similarly, they are the most effective tools in land use/land cover (LULC) analysis that provide vital information for ecological management and planning [21,22]. The integration of geospatial and intensity analysis has been proven useful in the evaluation of LULC dynamics in different settings [17,23–25]. Furthermore, the generation of data on the spatial variances in morphometric characteristics of wetland landscapes has been achieved using satellite imagery and GIS data. Several of these morphometric characteristics identify the paths to surface water movement across a watershed and are therefore a major factor affecting the hydrological response to rainfall inputs in watersheds [26]. They also offer insights into the necessary hydrological conditions to develop watershed management strategies [27]. Additionally, biophysical factors, such as land use and land surface slope, considered in this study, are important determinants of irrigation suitability [28] and modulators of water erosion [29].

In Ghana, there are over 90 coastal wetland ecosystems that have been recognised for their critical roles in supporting biodiversity and supplying ecosystem services [29,30]. These coastal ecosystems occupy 10% of Ghana's land area [31]. The Keta Lagoon Complex

Ramsar Site (KLCRS) is the largest among all the coastal wetland ecosystems in Ghana. Aside from supporting the livelihoods of over 100,000 people distributed in six district assemblies [32], the Ramsar Site supports 72 species of migratory and resident birds [33] and provide habitat for Sitatunga (*Tragelaphus spekii gratus*), the only aquatic antelope in the world [34]. The sandy beaches of the Ramsar Site are also used as nest sites of various species of marine turtles [35]. The area is therefore one of the potential areas for ecotourism in Ghana [35]. The supply of these ecosystem services is critical to the long-term socio-economic development of the area as in the case of other coastal zones [36]. This wetland, however, faces serious threats from intensive exploitation, physical modification, changes in water regime, and water pollution [30]. Currently, there exists limited knowledge on the LULC, i.e., physical modification indicator and morphometric parameters, i.e., indicators of changes in water regimes of the wetland of KLCRS. Analysis of these landscape dynamics is relevant for policymakers and planners to make informed decisions towards achieving sustainable development. This study assessed the LULC change and morphometric parameters of the KLCRS landscape by utilizing geospatial technology and intensity analysis. We hypothesized the following: the natural LULC categories have substantially declined at the expense of the expansion of the human-induced LULC categories over the past 29 years, and the integration of geospatial techniques and intensity analysis provides insight into the biophysical and morphometric parameters of a wetland's landscape.

The study is relevant in improving the knowledge of a change in wetland areas, particularly for Africa, the Neotropics, and Oceania [18]. This study provides scientific evidence required by researchers, decision-makers, practitioners, as well as investors to support the planning and management of the Keta Lagoon Complex as a wetland of international importance. This could help improve and maintain the status of the KLCRS through ecological environment protection, wetland restoration, and rational utilisation of wetland resources and to develop appropriate management plans.

2. Materials and Methods

2.1. Study Area and Environmental Settings

The study focused on the Keta Lagoon Complex Ramsar Site (KLCRS), one of the six wetlands designated as Ramsar Sites in Ghana since 1992. The KLCRS is the largest among all the wetland ecosystems distributed along the coast of Ghana. The Ramsar site covers a surface area of approximately 2840 km² [37]. It is situated in the southern part of Volta Region between latitudes 5°45' N and 6°05' N and Longitudes 0°50' E and 1°08' E. It shares a border with Volta River to the west and the Gulf of Guinea to the south, and it covers all portions of the newly created Anloga district, Keta Municipality, South Tongu District, the southern portion of Akatsi district, Ketu North district, and Ketu South Municipality (see Figure 1). The KLCRS encompasses Keta Lagoon and the surrounding floodplains, consisting of extensive mangrove stands, scrub, marsh, fig-trees, and farmlands. The Keta Lagoon is an extensive and brackish waterbody situated to the east of the Volta River estuary and separated from the sea to the south by a narrow sandbar. The Avu Lagoon and a portion of the Volta estuary are also part of the Ramsar Site. As part of the south-eastern coastal belt of Ghana, the KLCRS falls within the Dry Tropical Equatorial climatic region [38]. Similar to the entire coastal zone of Ghana, the Keta Lagoon Complex area experiences two distinct seasons (wet and dry) annually, with an annual mean rainfall of 783 mm and evaporation of 1964 mm [39]. However, there is a major rainy season from May to July and a minor rainy season between September and November [40]. In January, the dry season starts, and it ends in March. The recorded average temperature of the area ranges between 24 °C and 31 °C [29], with a relative humidity varying around 95% at night and morning and 65% during the day [37]. Among several other important functions, the KLCRS acts as a habitat and breeding ground for several notable species of water birds, such as black-winged stilt. The dominant economic activities within the Ramsar Site are fishing, intensive vegetable farming, and salt extraction.

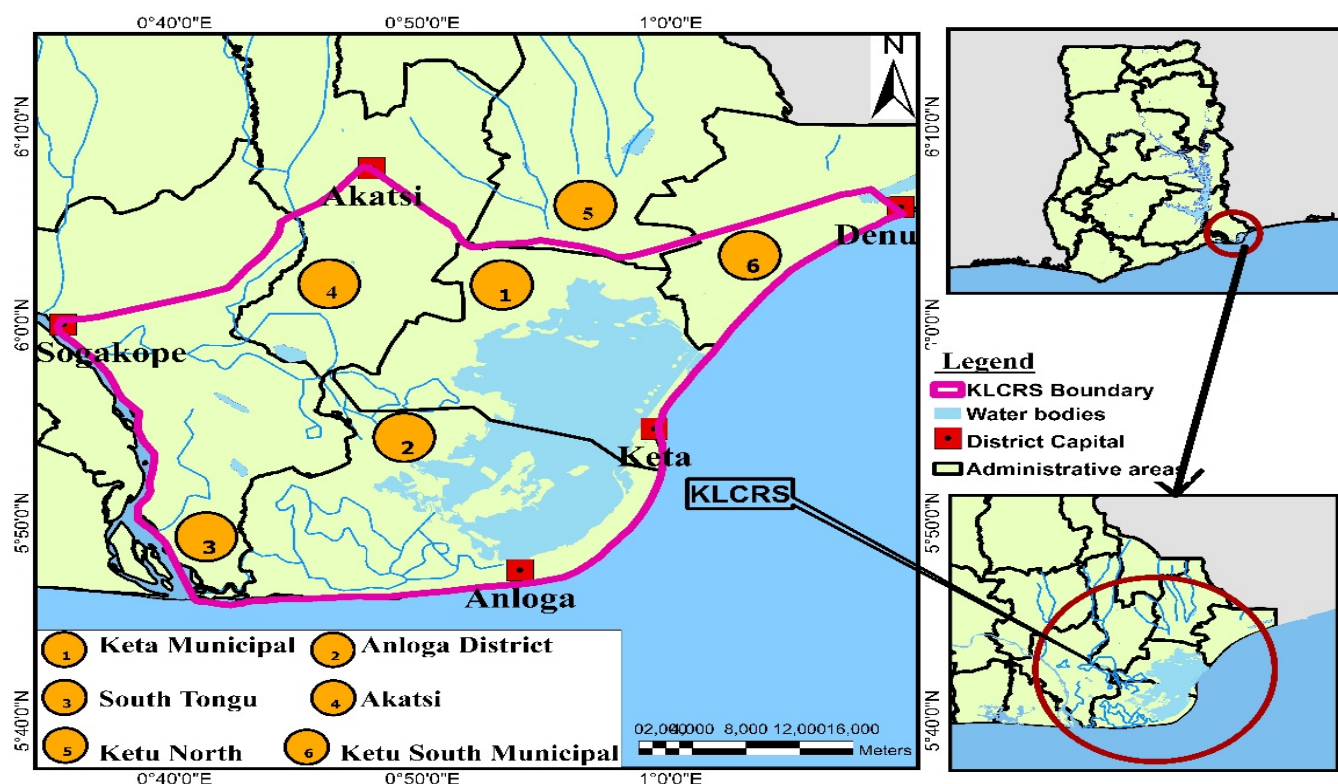


Figure 1. Map of the eastern coast of Ghana showing Keta Lagoon Complex and its surrounding floodplain, administrative areas, and district capitals.

2.2. Data and Sources

Landsat-4 Thematic Mapper (TM), Landsat-7 Enhanced Thematic Mapper (ETM), and Landsat-8 Operational Land Imager (OLI) and thermal infrared (TIR) images of two different scenes (192/056 and 193/056) covering the KLCRS were downloaded in GeoTIFF format from the United State Geological survey's website (<http://earthexplorer.usgs.gov/>) (accessed on 20 December 2020) for LULC analysis for the period 1991 to 2020. The images were in three segments years: 1991 (Landsat-4 TM), 2007 (Landsat-7 ETM), and 2020 (Landsat-8 OLI_TIRS) (Table 1). The selection of the satellite images was influenced by the availability of the images, the spatial resolution, and the overall quality of the images in terms of those with low cloud and scene cover. Out of all of this, these selected years helped assess KLCRS status before 1992, when it was designated a Ramsar Site, along with the 1991 management plan for Ghana's coastal wetlands [41], the 1993–1999 Ghana Coastal Wetlands Management Project (CWMP) [42], and the 1999 Keta Lagoon Complex Ramsar Site management plan [43].

Table 1. Satellite data for LULC change.

Spacecraft ID	Sensor ID	Path/Raw	Acquisition Date (Year/Month/Day)	Image Quality
Landsat-4	TM	192/056	1991/01/03	9
Landsat-4	TM	193/056	1991/01/10	7
Landsat-7	ETM	192/056	2007/01/15	9
Landsat-7	ETM	193/056	2007/01/22	9
Landsat-8	OLI_TIRS	192/056	2020/01/27	9
Landsat-8	OLI_TIRS	193/056	2020/01/02	9

Image quality varies from worst = 0, to excellent/best = 9 (see https://lta.cr.usgs.gov/DD/landsat_dictionary.html) (accessed on 20 December 2020)).

To perform morphometric analysis of KLCRS, Advance Space Thermal Emission and Radiometer (ASTER) global digital elevation model (GDEM) version 3 Worldwide Elevation Data with 30 m spatial resolution was used. The ASTER GDEM data made up of four different scenes covering the study area were download from the National Aeronautics and Space Administration (NASA) Earth data search (<https://search.earthdata.nasa.gov/> (accessed on 22 February 2021)) repository.

Eco sounder (Sonar Gun) was used to measure the depth of the lagoon at various locations for three different months (November 2020, January 2021, and March 2021) covering both wet and dry seasons of the study area. The sample locations were randomly selected with aid of the fishnet tool in ArcGIS 10.7 software (Figure S1). These were positioned with the help of the Garmin GPSMAP® 62 21E001502 (Model 01102381, Taiwan) and fibreglass boat. Using a participatory mapping approach, geographic coordinates of some physical features, including vegetated areas, open water, bare soils or beaches, salt pans, and buildings that were accessible, were taken as ground control points (GCPs). Additionally, we utilized the Google Earth Pro platform and available topographic map of the area [41] to record the geographic coordinates of the various landcover that were difficult to access directly from the field. These were used for classification and cross-validation.

2.3. Satellite Data Preprocessing

To ensure consistency between images of varying scenes and accurately retrieve wetland landscape data, the Landsat and DEM images were projected into the Ghana Metre Grid Coordinate System using ArcGIS software [44]. Before the projection of the Landsat satellite images, the Landsat-7 ETM, which had scan lines, was corrected using the Environment for Visualizing Images (ENVI) version 5.3 software (see <https://www.l3harrisgeospatial.com/Software-Technology/ENVI> (accessed on 18 December 2020)). This corrected image (Landsat-7 ETM) together with the Landsat-4 TM and Landsat-8 OLI_TIRS were subjected to atmospheric correction with the help of the Semi-Automatic Classification Plugin in QGIS version 3.16 (see <https://www.qgis.org/en/site/forusers/download.html> (accessed on 17 January 2021)). The individual bands for each Landsat scene were staked and projected to the Ghana Metre Grid. The projected Landsat scenes of each segment year were mosaic and subset to the KLCRS boundary. The boundary of KLCRS was obtained by georeferencing and digitizing the boundary of the Ramsar Site proposed by Ntiama-Baidu and Gordon [41] to the Ghana Metre Grid coordinate system.

2.4. Morphometric Analysis

In this study, morphometric characteristics of KLCRS landscape, like elevation, slope, aspect, flow direction, stream network and order, and stream density, were modelled with the help of the Spatial Analyst tools in ArcGIS [26,45,46]. The Fill tool in ArcGIS was used to create depressionless DEM to prevent any interruption of continuous flow paths [46]. Using the inbuilt D8 method in the Spatial Analyst tool, the flow direction of KLCRS was modelled out of the fill DEM. The flow direction was used as an input material to create a flow accumulation raster image. Following the procedures described in [46,47], the watershed was delineated, and stream network and stream density maps of KLCRS were produced. Based on Strahler's system of stream order [45,48] as a built-in tool in QGIS version 3.16, six stream orders of the study area were revealed. The percentage of landscape cover for the various classes of all the parameters except for stream density and total stream order length were calculated in ArcGIS. The total length of each stream order was calculated in kilometres (km) with the help of the field calculator in ArcMap 10.7. Following Singh, Gupta, and Singh [45], the land surface slope of KLCRS was classified into six classes in degrees: gentle slope ($<3^\circ$), moderate ($3\text{--}5^\circ$), steep slope ($5\text{--}10^\circ$), very steep ($10\text{--}35^\circ$), and extremely steep ($>35^\circ$). Maps showing the spatial and temporal variation of the depth of Keta Lagoon from November 2020 to March 2021 were generated using the Kriging spatial interpolation technique [49]. The Geostatistical Analyst extension in ArcGIS software was used for this spatial analysis [50,51].

2.5. Image Classification

Supervised classification with the maximum likelihood algorithm was applied to the Landsat satellite images. Before the supervised classification, spectral indices, specifically Normalized Difference Vegetation Index, Modified Normalized Difference Water Index, Normalized Built-up Index, and Normalized Difference Bareness Index, were calculated using the formulas provided in [52]. We also performed unsupervised image classification on the satellite images using the Iso Cluster algorithm with an initial classified raster of ten categories. Furthermore, various band combinations and visual interpretation were performed. These initial analyses were performed to help highlight and ensure efficient extraction of the LULC categories in KLCRS. These techniques together with the GCPs directly from the field, Google Earth platform, and other topographic maps helped to arrive at a final signature file and cross-validation points of six LULC categories: water-spread area (including lagoons, streams, ponds, and salt pans), mangrove/dense vegetation, marsh/grassland, cultivated land (made up of fallow and croplands), bareland (made up of bare soil, fine sand, and bare beaches), and built-up areas (mosaic of buildings and artificial surfaces). LULC maps were developed, and class statistics were generated for each LULC class for the three-segment years (1991, 2007, and 2020) in ArcGIS 10.7. The classification of some important land categories, like mangrove and dense vegetation (including fig trees, thicket), as one category is due to the relatively low (30 m) resolution of the satellite images that were classified. This makes it difficult to separate these two LULC categories because of their close spectral reflectance; hence, it was imperative to classify land categories with very close association to reduce the classification error.

2.6. Post-Classification

The post-classification covered accuracy assessment, change detection, and intensity analysis. Using a sample of 260 of the GCPs recorded during the field survey and from Google Earth imagery for each year, we validated the classified images. This was achieved by calculating and analysing the accuracy and Kappa statistic of each classified image using the formulas provided in the 2005 U.S. Geological Survey open-file report [53]. The accuracies of the classified images for 1991, 2007, and 2020 met the LULC categorization accuracy of 85% [54] with the Kappa statistic, also representing a substantial agreement [55].

The identification of the changes in LULC categories was first identified using the combine function in ArcGIS 10.7. We then converted the output raster showing the changes to polygon, which allows for the quantification of the changes and persistence of LULC categories in kilometres and construction of the transition matrix. These quantities served as input data for intensity analysis conducted at three levels as interval, category, and transition [17,23,25]. The intensity analysis is a mathematical framework that uncovers differences within a set of categories that exist across varying time intervals by comparing uniform intensity to observed intensities of temporal changes among categories [24]. This framework was developed as a Microsoft Excel programme by Safaa Zakaria Aldwaik and Robert Gilmore Pontius Jr. (<https://sites.google.com/site/intensityanalysis/free-computer-programs> (accessed on 22 February 2021)). An extensive description of intensity analysis and the equations on which the analysis is based have been pointed out in some studies [23–25,56,57].

3. Results

3.1. LULC Dynamics of Keta Lagoon Complex Ramsar from 1991 to 2020

The LULC map of KLCRS for the three segment-years designed from the supervised classification of Landsat satellite images is depicted in Figure 2. Table 2 also shows the LULC change matrices for 1991–2007 and 2007–2020. The LULC change matrices present the extent of area for each category of LULC in each segment year in kilometre square. These matrices further present the area of gross loss and gain of each LULC category for the two-time intervals (1991–2007 and 2007–2020) and the persistence indicated by the

boldface numbers on the diagonal of each LULC class. The net loss and gain are depicted in Table S1.

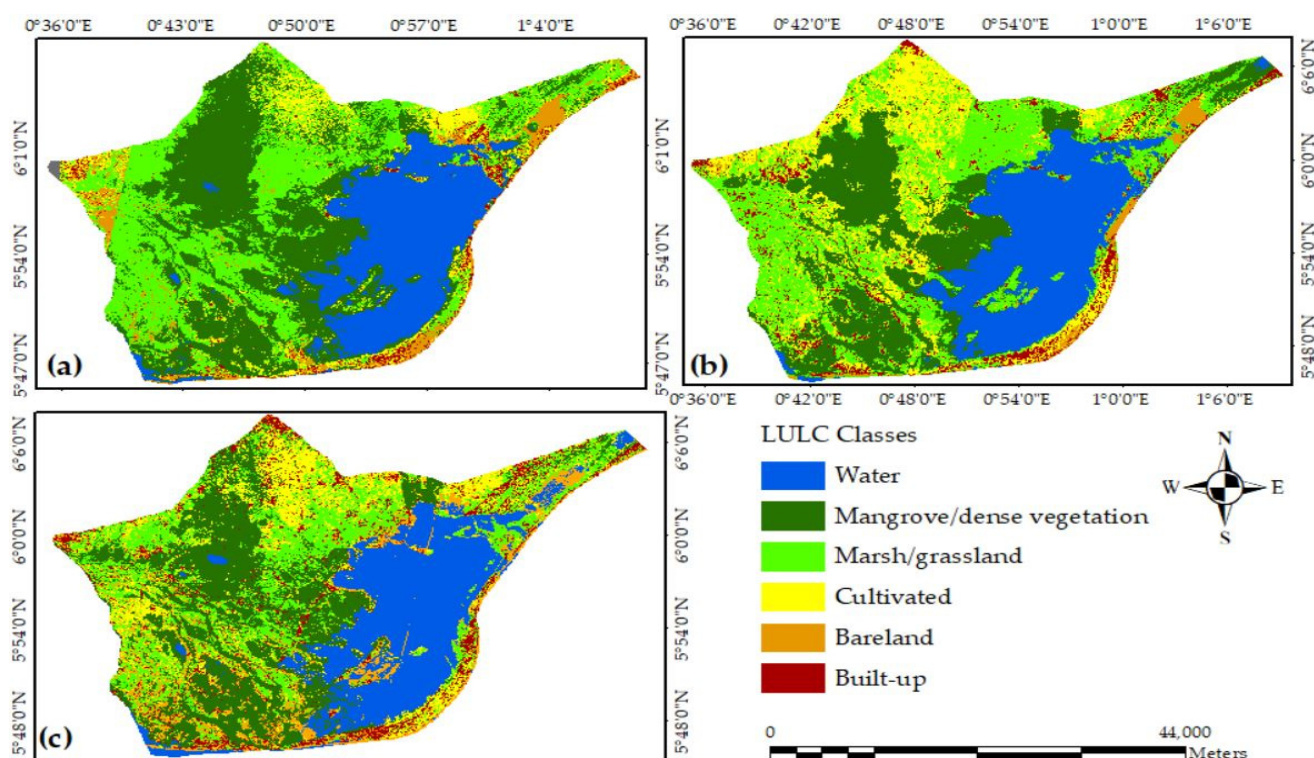


Figure 2. LULC maps of Keta Lagoon Complex Ramsar Site for (a) 1991, (b) 2007, and (c) 2020.

Table 2. LULC change matrix in km² of the KLCRS landscape for the two time intervals (1991–2007 and 2007–2020).

		2007						1991–2007	
	LULC Category	W	MDV	MGL	CT	BL	BU	1991 Total	GL
1991	W	277.57	5.18	3.94	0.26	3.24	0.88	291.07	13.5
	MDV	31.57	290.69	94.31	68.53	1.37	4.41	490.88	200.19
	MGL	2.43	29.78	211.18	105.85	2.46	35.66	387.36	176.18
	CT	1.17	10.9	43.93	36.85	1.57	10.19	104.61	67.76
	BL	1.74	1.84	21.88	10.67	16.69	15.71	68.53	51.84
	BU	0.79	1.12	9.68	7.96	2.62	13.89	36.06	22.17
2007	Total	315.27	339.51	384.92	230.12	27.95	80.74	1378.51	531.64
1991–2007	GG	37.7	48.82	173.74	193.27	11.26	66.85	531.64	
		2020						2007–2020	
	LULC Category	W	MDV	MGL	CT	BL	BU	2007 Total	GL
2007	W	291.15	13.91	0.25	3.43	6.28	0.25	315.27	24.12
	MDV	13.74	259.65	27.23	17.81	9.71	11.37	339.51	79.86
	MGL	11.04	53.23	160.35	79.12	45.48	35.7	384.92	224.57
	CT	0.78	45.1	71.8	64.82	18.16	29.46	230.12	165.3
	BL	4.1	0.18	6.06	3.53	10.51	3.57	27.95	17.44
	BU	0.73	1.85	18.35	11.23	20.76	27.82	80.74	52.92
2020	Total	321.54	373.92	284.04	179.94	110.9	108.17	1378.51	564.21
2007–2020	GG	30.39	114.27	123.69	115.12	100.39	80.35	564.21	

NB: W, water, MDV, mangrove/dense vegetation, MGL, marsh/grassland, CT, cultivated, BL, bareland, BU, built-up area, GL, gross loss, GG, gross gain. The “Total” represents the total area of cover for a LULC category in each time point. The boldface numbers on the diagonal indicate persistence and not change, while the thirty-six off-diagonal entries under the LULC categories indicate the change from one LULC category to a different category.

The statistics of the LULC maps show that mangrove/dense vegetation (490.88 km², 38.34%) was the dominant LULC category of KLCRS in 1991, followed by marsh/grassland (387.36 km², 28.10%) and water (291.07 km², 21.11%). The proportion of KLCRS land area covered by cultivated land, bareland, and the built-up area was 7.59%, 4.97%, and 2.62%, respectively. In 2020, mangrove/dense vegetation remained the dominant LULC category of KLCRS, with a proportion of 27.12%, still less than 1991. Marsh/grassland (27.92%), which was the dominant LULC category in 2007, decreased to 20.60% in 2020 as the third dominant LULC category. On the contrary, the area occupied by water (such as lagoon, streams, ponds, salt pans) increased from 315.27 km² (22.87%) in 2007 to 321.54 km² (23.33%) in 2020. Similarly, there was a sharp increase in built-up and bareland areas from 2007 to 2020 by 27.4354 km² and 82.95 km². However, the area of cultivated land decreased by 50.18 km² from 2007 to 2020.

The LULC analysis revealed some marked changes in the area for each LULC category over the 29 years (see Table 2). Between 1991 and 2007, the observed gross loss was higher than gross gains for all the LULC categories except for water, cultivated land, and built-up area. The gross gain for water (30.39 km², 5.39%), mangrove/dense vegetation (114.27 km², 20.25%), bareland (100.39 km², 17.79%), and built-up area (80.35 km², 14.24%) during 2007–2020 were higher than the gross loss. The gross loss (200.19 km², 37.66%) for mangrove/dense vegetation was the highest among the six LULC categories in the first time interval. Almost 47% and 32% of this gross loss for mangrove/dense vegetation LULC type were converted to marsh/grassland and cultivated land, respectively. Approximately 60% of the gross loss (176.18 km², 33.14%) for marsh/grassland was converted to cultivated land during 1991–2007. The gross loss of water increased from 13.5 km² (2.54%) in the first time interval to 24.12 km² (4.28%) in the second time interval, whereas the gross gain declined from 37.7 km² (7.09%) in the first time interval to 30.39 km² (5.39%) in the second time interval. Similarly, the gross loss of marsh/grassland increased from 176.18 km² (33.14%) in the first time interval to 224.57 km² (39.80%) in the second time interval, but the gross gain declined from 173.74 km² (32.68%) during 1991–2020 to 123.69 km² (21.92%) during 2007–2021. However, the gross gain of mangrove/dense vegetation was slightly above the gross loss during the second time interval. Bareland increased by 11.26 km² (2.12%) during 1991–2007 and 100.39 km² (17.79%) during 2007–2020. Similar, the gross gain of built-up area increased from 66.85 km² between 1991 and 2007 to 80.35 km² during 2007–2020. Approximately 60.1% of the net gain for the built-up area over the past 29 years (1991–2020) came from the conversion of marsh/grassland. During 2007–2020, 45.48 km² of marsh/grassland was cleared, resulting in bareland cover type. Persistence of water, cultivated land, and built-up area increased in the second time interval, whilst that of mangrove/dense vegetation, marsh/grassland, and bareland declined.

3.2. Interval Level Intensity Analysis

Figure 3 is the output of the interval level intensity analysis, which compared the overall change during 1991 and 2007 and the overall change during the 2007–2020 period. The interval level of intensity analysis quantifies the overall annual change within a specified time interval and compares it with the uniform annual change. Uniform annual change is the yearly change where all changes are uniformly distributed throughout the study period. The pace of annual change of a time interval is fast when it is higher than the uniform annual change, whereas annual change is considered slow when it is smaller than the uniform change. The uniform annual change that served as the benchmark was 2.74%. The overall annual change (2.41%) between 1991 and 2007 was relatively slower than the overall annual change (3.15%) in the second time interval. Additionally, the land area of KLCRS that experienced change (40.93%) during 2007–2020 was slightly higher than the total land change (38.57) recorded in the first time interval.

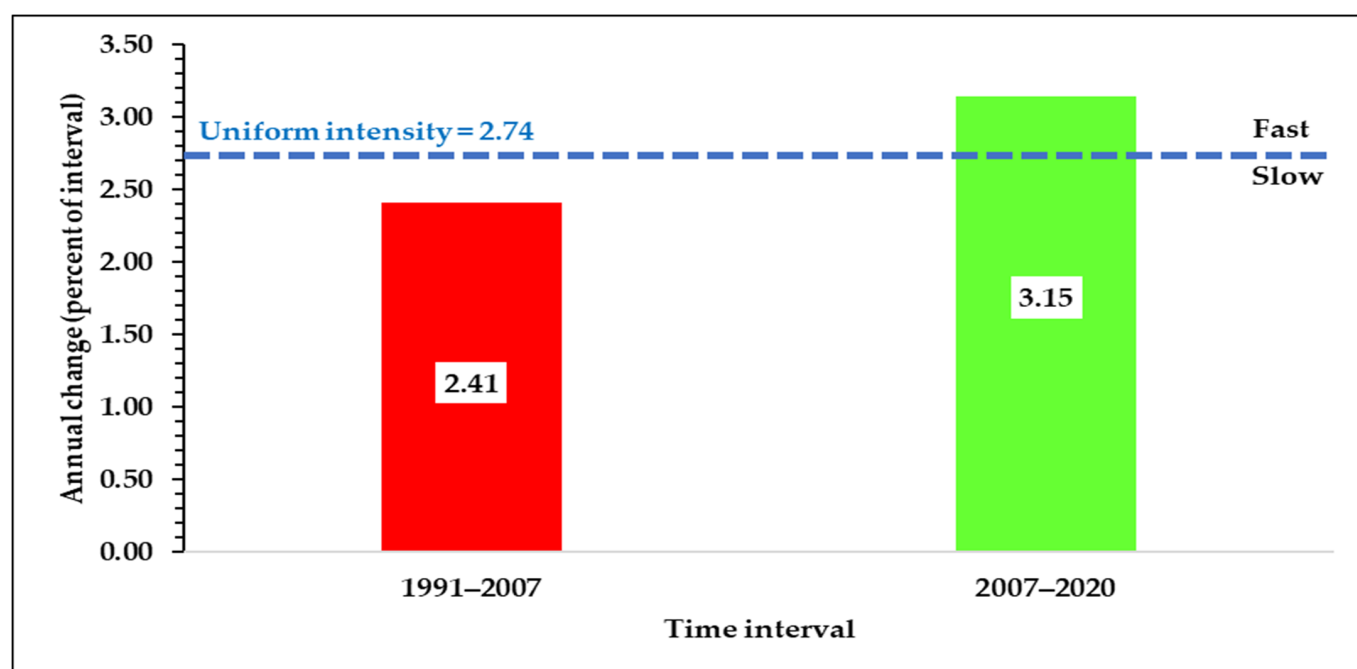


Figure 3. Interval level intensity during 1991–2007 and 2007–2020 for the KLCRS.

3.3. Category Level Intensity Analysis

Figure 4 shows the results for category level intensity analysis representing active or dormant losing and gaining LULC categories of KLCRS during 1991–2007 and 2007–2020. As indicated by the dashed uniform line in Figure 4, the intensity of each category's gain and loss is compared to the overall intensity of change in the entire study area. The bars below the uniform line depict the dormant gain or loss intensity of a LULC category, whereas the bars above the uniform line show that the category is an active gainer or loser [58].

Water is the only category that was a dormant loser and gainer in the first time interval (Figure 4a) and second time interval (Figure 4b). Mangrove/dense vegetation recorded active losses in the first time interval but dormant losses in the second time interval. The gains of mangrove/dense vegetation were dormant in both the first and second time intervals. Marsh/grassland, cultivated land, bareland, and built-up area were active in terms of losses and gains during both time intervals. However, the gain intensity of the built-up area was higher than the loss in both time intervals. Again, the gain of cultivated land was way higher than the loss during 1991–2007, but during 2007–2020, the loss intensity was slightly above the gain intensity. Additionally, the loss intensity of marsh/grassland was higher than the gain in both time intervals.

3.4. Transition Level Intensity Analysis

The transition level intensity focused on built-up and cultivated LULC categories, as they recorded significant active gains in either of the two time intervals or both. The bars of LULC categories that extend beyond the uniform intensity line imply that those categories were targeted by the gaining category. From Figure 5a,b, the gain of cultivated land targeted marsh/grassland, bare land, and built-up area LULC categories in both time intervals. The transition from marsh/grassland to cultivated land was more highly intensive than the other land categories, with a transition intensity value of 1.71% during 1991–2007 and 1.58% during 2007–2020.

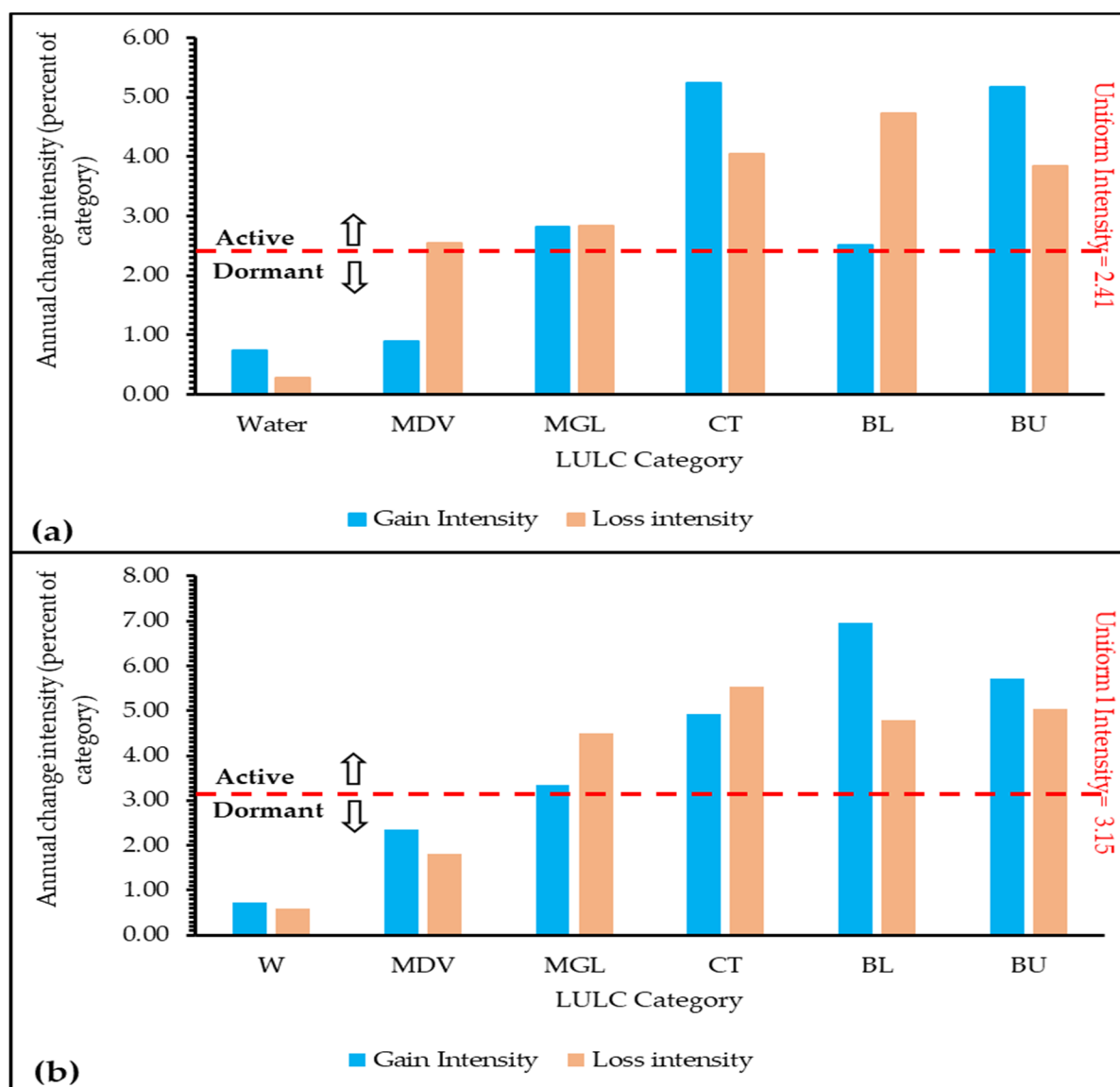


Figure 4. Intensity of gains and losses by category during (a) 1991–2007 and (b) 2007–2020 for the KLCRS.

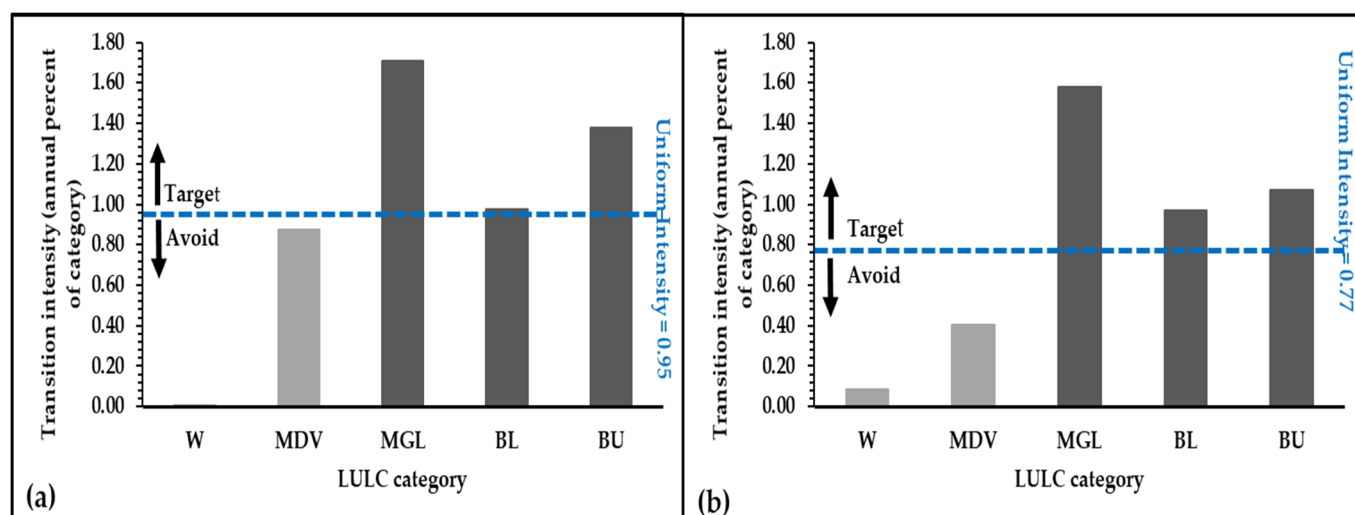


Figure 5. Transition to cultivated land for (a) 1991–2007 and (b) 2007–2020 for the KLCRS.

The gain of the built-up area targeted marsh/grassland, cultivated land, and bareland but avoided water-spread areas and mangrove/dense vegetation LULC category during both time intervals (Figure 6a,b). Among the land category targeted by the built-up gain in the first time interval, the transition intensity for bareland was the highest (Figure 6a). However, during 2007–2020, a both bareland and cultivated were intensively targeted by built-up area, followed by marsh/grassland (see Figure 6b).

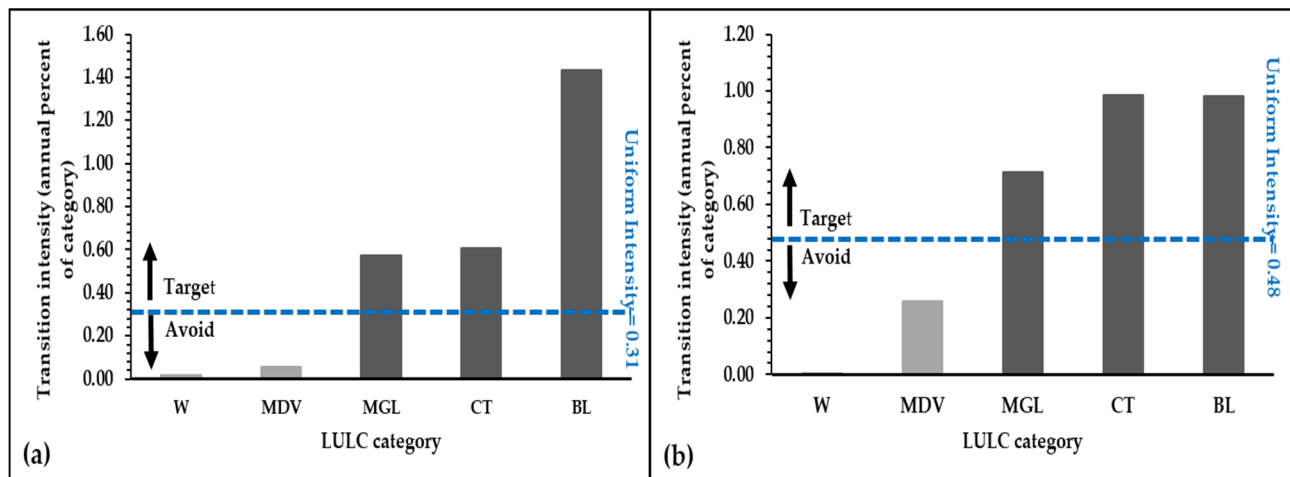


Figure 6. Transition to built-up for (a) 1991–2007 and (b) 2007–2020 for the KLCRS.

3.5. Digital Elevation Model and Morphometric Characteristics

Figure 7a–c are the maps of elevation, slope, and aspect, respectively. The distribution of class statistics for the surface topographic parameters (elevation, slope, and aspect) are presented in Table S2. Information in Figure 7a shows that the general elevation of the study area ranges from 0 to 108 m, with an average elevation of 12.39 m. From the class statistics, elevation values of the major (69.35%) part of the KLCRS landscape are not more than the average (see Table S2). The area of the lagoon and the narrow sand spit, areas close to the Volta River at Sogakope and Volta estuary towards the southwestern portion of the Ramsar Site and the northeastern section at Denu, fall within this category and are relatively low (≤ 12.39 m). Elevation was higher in most parts of the Akatsi South district at the northern section of the KLCRS. Five classes of the slope were detected from the surface analysis as shown by Figure 7b. The land surface slope of KLCRS is predominantly gentle ($0\text{--}3^\circ$), whilst few areas showed a slope of above 5° (Figure 7b; Table S2). In-depth visualization and overlay analysis showed that most of the northeastern and southwestern areas around the Volta estuary and southeastern portion, including Keta Lagoon, are of the lowest slope values (Figure 7b). The aspect map clearly shows the extent of the individual lagoons (Keta and Avu lagoon) within the KLCRS.

Flow direction, stream or drainage density, and stream network and watersheds of the study area are depicted in Figure 8a–c, respectively. The stream density is displayed in kilometre per square kilometre (km/km^2). The stream or drainage network also shows the ordering of streams. The pattern of the stream network observed in Figure 8c is of dendritic type. The watersheds found in KLCRS have been designated as W1 to W5. W5 watershed is the mosaic of smaller watersheds drained mainly by first- and second-order streams. The streams with the highest flow accumulation (sixth-order streams) were observed in the largest watershed (W1) within which the Keta Lagoon is positioned (see Figure 8c). Similarly, most of the areas with the highest stream density ($<4 \text{ km}/\text{km}^2$) were observed along the fifth- and sixth-order stream that flows into and through the Keta Lagoon. The first-order stream had the highest number of segments, whilst the sixth stream order had the least number of segments (Table S2). This watershed (W1) within which Keta and

Avu lagoon fall occupies the larger part of the KLCRS (Figure 8c). The flow-direction map shows that the Keta Lagoon flows toward the temporal outlet at Kedzi.

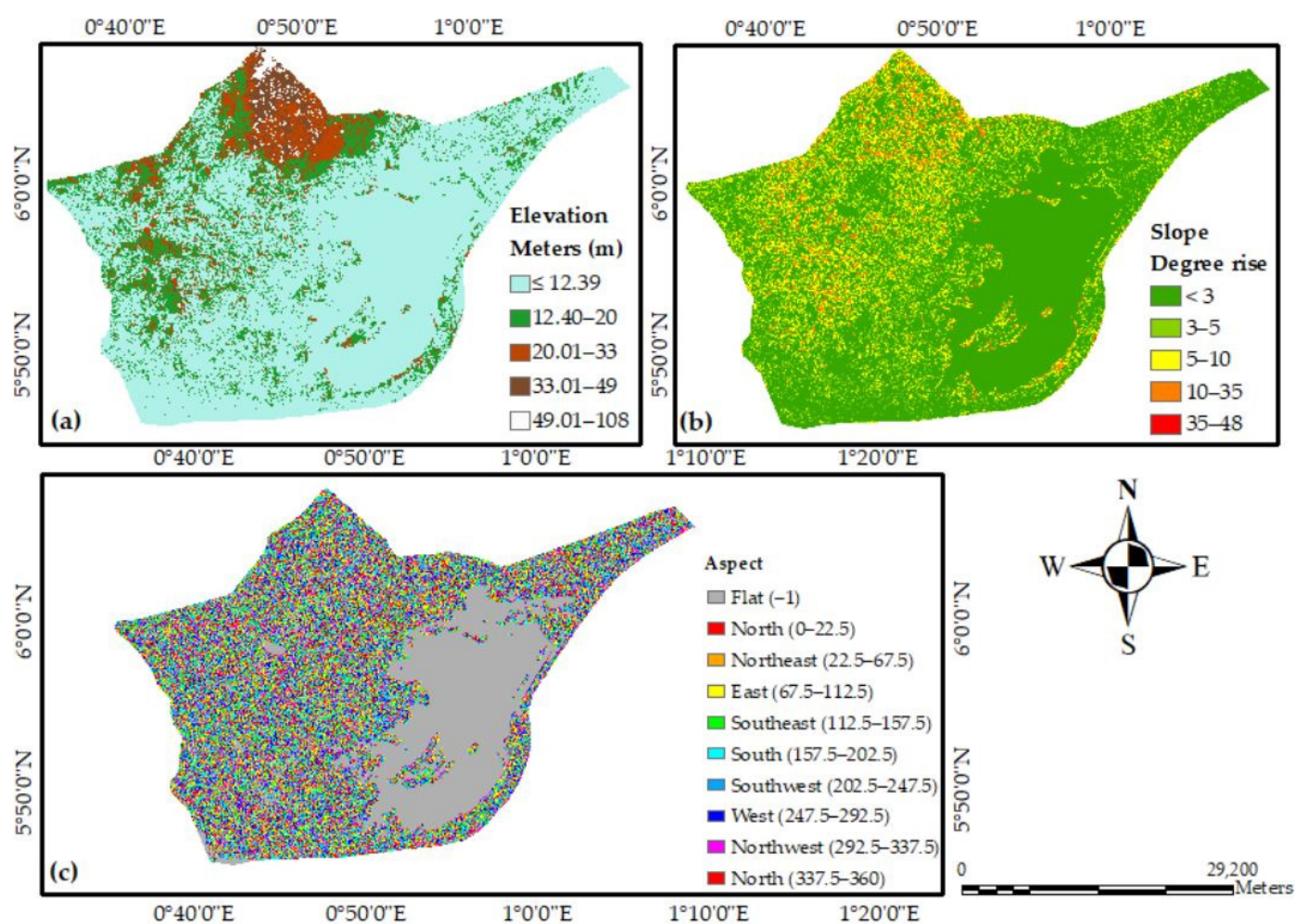


Figure 7. (a) Elevation, (b) slope, and (c) aspect map.

Figure 9 are maps from Kriging spatial interpolation showing the depth of the Keta Lagoon for three different months from November 2020 to March 2021. The depth of the lagoon varied across space and time, with the highest depth (1.46 m) recorded in November 2020 (see Figure 9a). A depth of 1.30–0.20 m was recorded in January 2021 but changed to 0.85–0.29 m in March 2021. The average depth of the lagoon decreased considerably from 0.73 m in November 2020 to 0.48 m in March 2021. This is largely due to the rainfall pattern of the study area.

In terms of spatial distribution, the lowest depth of the lagoon in the first month (November) covered small portions of the lagoon around Keta and Anloga. This was extended to include the northeastern side of the lagoon around Afiadenyigba, Kedzi, Vodza, and Keta (depicted by the deep blue colour) and a small part of the southwestern part close to Anloga, Atito, Adzato, and Salo communities in the final month. The highest depth for all the months extended from areas of the lagoon close to the Woe and Tegbi communities to the middle section.

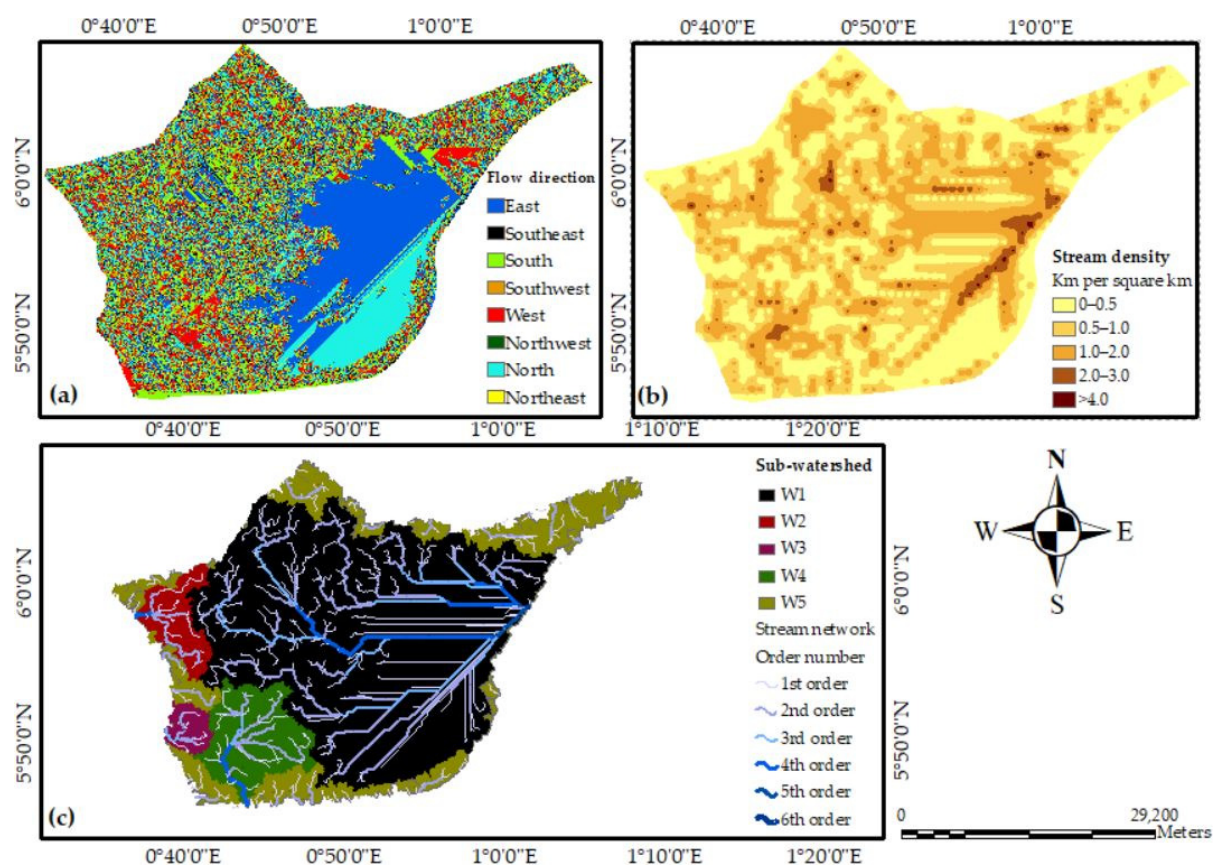


Figure 8. (a) Flow direction, (b) stream density map, and (c) stream network and sub-watershed.

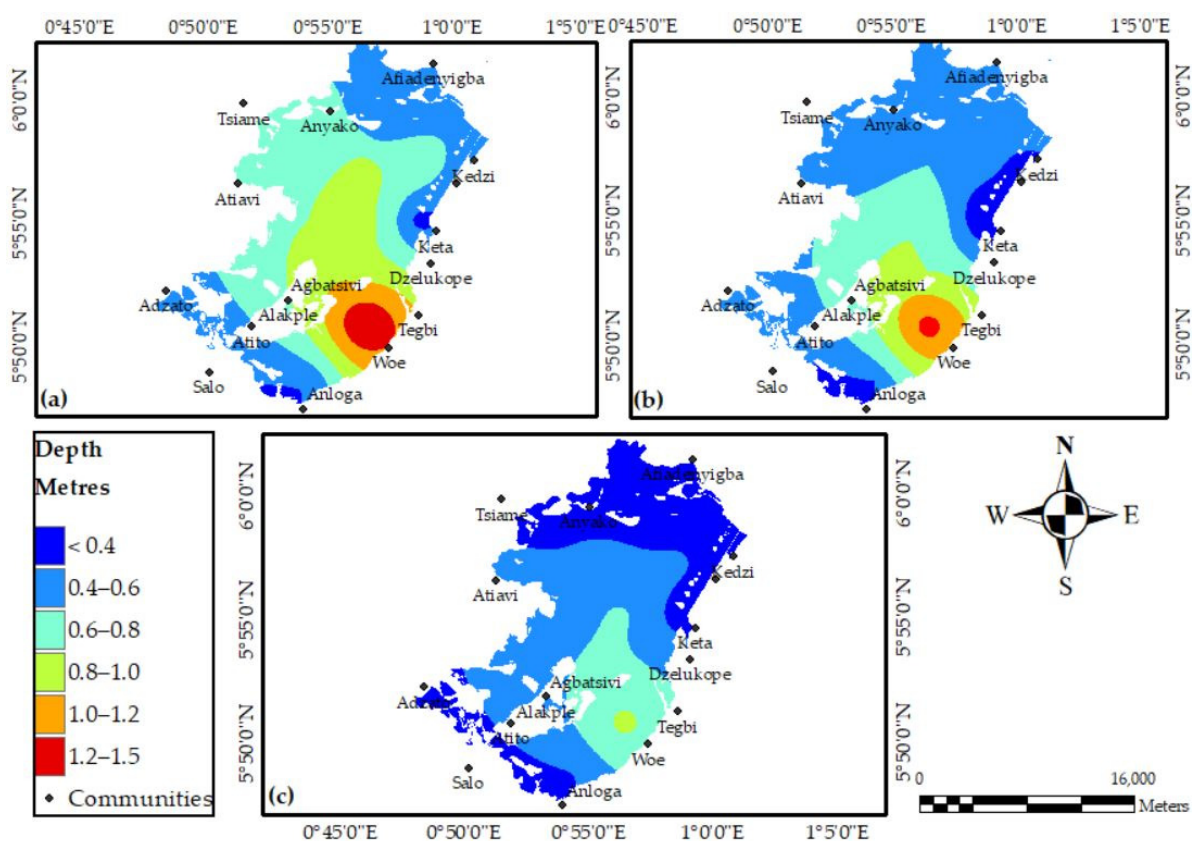


Figure 9. Maps showing the depth of Keta Lagoon in meters for (a) November 2020, (b) January 2021, and (c) March 2021.

4. Discussion

The study reveals dramatic changes in six major LULC categories of the KLCRS landscape during 1991–2007 and 2007–2020. However, the overall land change was slower in the first time interval than in the second time interval. The intensive land transformation of the KLCRS landscape in the second time interval (2007–2020) is consistent with Ghana's economic and population growth rate, which has been well documented to be faster than Sub-Saharan Africa's average since 2007 [59]. This is not surprising, as the fast-paced national development coupled with the expansion of human and economic activity leads to accelerated LULC change [23], hence the need to be properly managed and controlled. The observed intensity of land transformation over the 29 years also points to the fact that the underlying processes of changes have been progressive [17].

In terms of area extent, our study revealed that the naturally occurring LULC categories, including water, mangrove/dense vegetation, and marsh/grassland, were the major LULC types at KLCRS in all three time points. For instance, mangrove/dense vegetation, marsh/grassland, and water cover together accounted for more than 60% of the land area in all three time points. The result is not consistent with an earlier study by Ekumah et al. [17] on three of the five Ramsar Site distributed along Ghana's coast, which found that human induced LULC categories became the largest in 2017. Available evidence from elsewhere in Qeshm Island also found bareland and water occupying the largest portion of the land area in all the three time intervals of the study period (1996–2014) [25]. This shows that there are significant variations in the transition intensity of LULC categories across space and time, hence the need for site-specific assessment to uncover the pattern of change and the processes that drive the changes. Despite the natural LULC categories occupying a large portion of KLCRS land area, significant changes were observed in their area extent. The results from the change budget showed a net loss (151.37 km²) of mangrove/dense vegetation in the first time interval but a net gain (34.41 km²) in the second time interval. However, the net loss of mangrove/dense vegetation LULC type in the first time interval was about five times higher than the positive net gross gain recorded in the second time interval. Additionally, the persistence of mangrove/dense vegetation in the first time interval decreased in the second time interval. This among other things indicates that the KLCRS lost a substantial part of its mangrove/dense vegetation cover within the period under study (1991–2020). Plausibly, this significant loss may be linked partly to the increased harvesting of mangroves for fuelwood within the enclave of the Ramsar Site [34,39,60]. Similarly, Feka and Ajonina [61], in their review, observed wood harvesting together with conversion of mangroves for agriculture, bio-fuel plantations (like sugarcane, jatropha, and oil palm), and coastal development as important drivers of mangrove forest change in West Central Africa.

The positive net gain of mangrove/dense vegetation cover in the second time interval looks very promising considering the urbanized nature of Ghana's coastal zone coupled with increasing demand for wetland resources, such as wood for construction and fuelwood. This suggests that the various conservation initiatives implemented under management regimes as well as the conscious effort by various stakeholders towards reforestation, conservation, and provision of alternative energy sources for fish processors and households within KLCRS is yet to yield significant results. One such conservation initiative that was geared toward mangrove restoration and sustainable use as well as the creation of alternative activities to generate income for local communities in KLCRS is the "Regeneration, Sustainable Use, and Management of Mangrove in the Keta Lagoon Complex Ramsar Site Project" [62]. In addition, the catchment of Avu Lagoon as part of the KLCRS was created as a community protected area (CPA) in 2006 by the surrounding communities together with the Wildlife Division of Ghana's Forestry Commission and the Nature Conservation Research Centre (NCRC) [34]. The persistent nature of the vegetation around the Avu lagoon over the study period (see Figure 2) could be the result of this initiative. This calls for improvement in conservation initiatives, implementation of proper

management plans, and continual awareness creation on the wise use of wetland resources throughout KLCRS as envisioned by the Ramsar Convention [63].

Marsh/grassland also experienced net gross loss in both time intervals, which was largely due to the expansion of built-up areas and cultivated lands. It was evident from the transition level of the intensity analysis that the gain of cultivated land and built-up area intensively targeted marsh/grassland in both time intervals. This implies that marsh/grassland areas have been the hotspots for land reclamation, purposely for housing development and agriculture development. The continual encroachment of marsh/grassland, which is an important habitat for aquatic species, point to the fact that such lands are less valued in the physical landscape of the study area, of which relevant stakeholders need to pay much attention to enhance the environmental sustainability of the area.

With regards to the trend of human population in KLCRS, the expansion of built-up areas is likely to increase, resulting in increased demand for land for commercial, residential, and other infrastructure establishments and agriculture. For instance, the projected population of Keta Municipality was 171,178 in 2016, showing an increase of 14% from the 2010 figure (147,618) [64]. This among other factors discloses urbanization as a significant driver of the observed changes. Not only did the expansion of built-up areas significantly affect marsh/grassland but also cultivated and bareland. A net gross loss of cultivated land was observed during 2007 and 2020. Ampim et al. [65], in their study, also reported the loss of agricultural land in Ghana after 2015, whereas Ekumah et al. [17] observed otherwise in the Muni-Pomadze Ramsar Site during 2002–2017. It is worthy of note that differences in societal needs and management strategies at different times as well as other commitments towards the wise use of natural resources while improving human wellbeing could account for the site-specific variations in the trend of LULC changes.

Similar to the findings of a previous study [66], the small increase in water coverage in KLCRS during 1991–2020 was partly due to the increased construction of saltpans and ponds around the Keta Lagoon, particularly at the northeastern section of the Ramsar Site. This was directly observed from the field survey, as part of the lagoon, specifically at Kedzi, Afiadenyigba, and Adina, was used for salt production. Critical examination of the classified satellite images and Google Earth imagery further confirmed these changes (see Figure S2). These activities when not managed properly could pose a significant threat to mangrove forests and the water quality of the area. The construction of saltpans and ponds for aquaculture development together with urban expansion, which is likely to continue, emphasizes the need for better land use and management in and around large coastal wetlands like that of the study area.

With the LULC change analysis showing significant changes in the study area, a study by Orimoloye et al. [5] demonstrated the need to assess other features, like land surface slope, hill shade, flow direction, and aspect of wetland landscape, that are vulnerable to wetland extinction owing to the hydrologic and geomorphic processes occurring within the wetland environment. For instance, the land surface slope is among the most important indicators associated with land degradation as well as runoff and infiltration [45]. In this study, we analysed the surface topographic and hydrological attributes of KLCRS by developing an elevation map and generation of land surface slope map, aspect, flow direction, stream order, stream density, and delineated watershed map. More than half of the KLCRS land area has lower elevation values and comes under a gentle slope, confirming the flat topography of the area reported in some studies [37,43,67]. Therefore, the continual decline of mangrove/dense vegetation and marsh/grassland, which serve as a natural sea defence, could render the area and its ecosystems extremely vulnerable to accelerated sea-level rise and future storms. The vulnerability of the existing coastal habitat, biodiversity, and socio-economic activities of the inhabitants in the eastern coastal zone of Ghana to accelerated sea-level rise within KLCRS has been reported by Boateng [67]. Therefore, the current findings underscore the need for the Government of Ghana, international donors like the World Bank, and the United Nations as well as non-governmental organisations,

with the support of the local authorities and residents, to invest heavily in ecosystem restoration in KLCRS and beyond.

The quantification of the stream orders showed the presence of a high proportion of first-order streams, indicating structural weakness in the watershed, most notably in the form of fractures as pointed out by Fenta [68]. Similarly, the dendritic pattern of the stream network signifies homogeneity in soil texture [69]. The lower stream density in KLCRS generally also indicates a deep, well-developed permeable soil or geology under dense vegetation cover, which is more likely to increase the infiltration of water into the soil rather than become surface runoff [70]. The decrease of surface runoff in the basin could affect surface water availability but is likely to ensure maximum percolation, which is very good for groundwater management [45]. The gentle sloping nature of KLCRS will also intensify its groundwater potential but makes the area unlikely to experience water erosion. This is explained by the interrelationship that exists between slope steepness, the time available for the water to percolate into the soil, and runoff [19]. However, the susceptibility of the area to groundwater salinization [39] due to salt intrusion [38] could render the available groundwater less suitable for human usage. This calls for effective and efficient management strategies and regulations to deal with the menace. Even though the period is short, the variation of the Keta Lagoon's depth observed in this study is similar to the pattern observed during 1970–1980 and 1988/89–1991 [29]. Considering the limited flow of freshwater from upstream into the lagoon, a long period of drought together with increased usage of groundwater might result in depletion of the wetland, which may also negatively affect the biodiversity. The decline in the water level is likely to affect aquatic life, as both fish and invertebrates will be exposed to predation. Interactions with fishermen and other users of the Keta Lagoon also revealed that the decline in the lagoon's depth was significantly affecting fishing, tourism, and other uses of the lagoon due to the difficulty of navigation. This becomes more difficult when one does not have adequate knowledge of spatial and temporal variation of the lagoon's depth. Therefore, knowledge of the depth of Keta Lagoon, (i.e., the largest and the most dependent open water at KLCRS) could serve as a guide to fishermen, tourists, and researchers among other users at any point in time. It is imperative for the relevant stakeholders to devise a strategy that will help ensure the free flow of the limited streams into the wetlands.

Concerning the delineated watershed, more than ten different watersheds were observed in the Ramsar Site, with the largest watershed (W1) associated with Keta Lagoon. This watershed (W1) was the only watershed associated with the largest number of stream segments, specifically the fifth- and sixth-order streams. This shows that the Keta Lagoon was initially a large stream fed by multiple small streams and having a direct outlet connecting to the sea at the Kedzi community. This finding is substantiated by a past study [37] that cited Tamakloe (1966), reported that the outlet of the lagoon connecting the sea through the sandbar at Kedzi existed in the 1960s. Some of the residents who were part of the participatory mapping exercises bemoaning the blockage of the lagoon outlet attribute it to the construction of Keta-Aflao Road and other physical development around the area. Some studies have pointed to the fact that the construction of the Akosombo Dam in 1964 preserved large amounts of freshwater and sediment from the Volta River, which could flow into Keta Lagoon and other wetlands upstream [33,71,72]. This has far-reaching consequences not only on the aquatic life that inhabit the wetlands but also on downstream communities due to reduced freshwater availability. The lack of coastal sediments compounded coastal erosion and the risk of flooding in Keta [71].

5. Conclusions

Our findings reveal that the natural LULC categories dominated the landscape of KLCRS in all the three time points. However, there was a substantial reduction in their area extent largely due to the expansion of the human-induced LULC categories, like cultivated land and built-up area. This transformation of land change between 1991 and 2020 could be linked to increased anthropogenic activities mainly driven by population

growth and socio-economic development. The annual rate of land change was intensive in the second time interval, indicating progressively increased land transformation and associated underlying processes in KLCRS. The change in the physical structure of the Keta Lagoon is not only driven by anthropogenic activities, such as salt extraction, but also changes in rainfall patterns. Analysis of the morphometric parameters, like land surface slope, stream density, stream order, and flow direction, explain the changes in geological structure and subsurface soil characteristics of KLCRS. They also help in the identification of the paths to surface water movement and confirm the groundwater potential of wetland environments like that of KLCRS. The nature of the landscape changes and associated effects calls for immediate preparation and implementation of marine and coastal spatial plans in Ghana's coastal zone that would bring together the multiple users of the marine space to achieve the socio-economic objective while maintaining the ecological integrity of the area. In the present study, the integration of geospatial techniques and intensity analysis help in the understanding of biophysical and morphometric parameters of wetland landscapes for effective and efficient management.

With the current trend of changes in the wetland ecosystem of KLCRS, further study is required to understand the complex relationships between wetland ecosystem change and human wellbeing. Another study could focus on establishing the relationship between the geophysical and chemical characteristics of soil and groundwater quality.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/w13182537/s1>, Figure S1: Map of the eastern coast of Ghana showing Keta Lagoon Complex and its surrounding floodplain, and Keta Lagoon's depth sampling locations. Figure S2: (a) 1991 and (b) 2020 classified Landsat satellite images in comparison to Google Earth Images acquired in (c) 1991 and 2020 (d) showing changes on the ground for land reclaimed for salt pans (classified as part of "Water" LULC category). Table S1: Net gross gain and loss of LULC categories during 1991–2007, 2007–2020, and 1991–2020, Table S2: Distribution of morphometric characteristics of the KLCRS landscape.

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