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Assessing land use and land cover change in coastal urban wetlands of international importance in Ghana using Intensity Analysis

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Abstract In the era of global environmental change, land transformation is acknowledged as a critical subject that needs to be addressed. Even though some studies have been carried out in Ghana on land use and land cover (LULC) change of wetlands, the conventional methods used were unable to reveal the underlying processes associated with the land transformation. This study employed Intensity Analysis to assess LULC change pattern (1985–2017) in three coastal urban wetlands of international importance in Ghana in order to identify the fundamental processes driving the wetland landscape transformation. Wetlands considered for this study were the Densu Delta, Sakumo II and Muni-Pomadze Ramsar Sites. The observed overall annual change in the first time interval; 2.42% (Densu Delta), 1.47% (Sakumo II) and 2.65% (Muni-Pomadze) was smaller compared to that of the second time interval 2.60% (Densu Delta), 3.55% (Sakumo II) and 2.91% (Muni-Pomadze). The human-induced LULC categories continuously grew at the expense of natural LULC categories. Large transitions from natural LULC categories to built-up were observed in all the three wetlands and in addition, large transition of dense forest to cultivated land was recorded at the Muni-Pomadze Ramsar Site. The main underlying process associated with land transformation in the wetlands was urbanization. Besides, agricultural activities also contributed substantially to LULC changes at the Muni-Pomadze wetland.

Keywords Land transformation · Ramsar site · Wetland landscape · Urbanization

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Introduction

Wetlands are fragile ecosystems characterized by complexity, dynamism, and diversity (Keddy 2010). As interphase between aquatic and terrestrial ecosystems (Kadlec and Wallace 2009), wetlands provide important ecosystem services to humankind (Bacani

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et. al. 2016). Nonetheless, due to rapid urbanization, industrialization, agricultural activities (Zedler and Kercher 2005) and some natural processes such as climate change, these critical wetlands are continuously being degraded, generating several ecological and social problems (Bacani et. al. 2016).

Globally, more than 50% of wetlands have been lost (Davidson 2014; Li et al. 2018). Wetlands in urban landscapes in developing countries are most affected due to rapid urban growth (Kometa et al. 2017; Turner 1991). In the coastal cities, the pressure on wetlands is far worse because of the exponential growth in human population (Nicholls 2004). In developing countries, coastal urban areas are the hotspots for most of the economic activities and these increase rural urban migration (Hinrichsen 1999). Despite the fact that wetland ecosystems are subjected to unbridled destruction by anthropogenic activities, studies evaluating their state are patchy and limited, especially in Africa, South America and Oceania (Davidson 2014). Assessing and monitoring LULC change are necessary for evaluating impact of change on ecosystems at various spatial scales and time. LULC change has been identified as a primary cause of loss of ecosystem and fragmentation of wetland landscapes (Torbick et al. 2006). Remotely sensed data coupled with advancement in geospatial techniques have improved the assessment of wetland landscapes (Davidson et al. 2018).

Wetland ecosystems in Ghana constitute about 10% of the country's total land surface (Ministry of Lands and Forestry 1999). Studies have revealed that in Ghana, urbanization, high population growth, fuel wood gathering, salt production and sand winning are the main factors threatening wetland ecosystems along the coast (Attuquayefio and Wuver 2003; Gbogbo and Attuquayefio 2010; Nartey et al. 2011). In Ghana, several studies have been carried out to analyse the spatial and temporal patterns of LULC change (Abass et al. 2018; Ashiagbor et al. 2019; Basommi et al. 2015). However, the mere monitoring of LULC change does not reveal the underlying processes that drive the land transformation (Alo and Pontius Jr 2008). The conventional methods of analysing change matrix do not provide sufficient quantitative and intensive signals of LULC pattern (Huang et al. 2012). Researchers usually want to associate land change patterns with processes (De Alban et al. 2019). The fundamental understanding of patterns and processes that drive LULC changes in coastal urban wetlands in Ghana remain unclear. The understanding of patterns and processes associated with LULC change of wetlands will inform decision makers and researchers on appropriate wetland management strategies. Aldwaik and Pontius Jr (2012, 2013), developed a method known as Intensity Analysis that assesses the gains and losses of LULC categories and also reveals the patterns and underlying processes causing the transformations. The common application of Intensity Analysis is assessment of LULC change through time. It is useful in assessing the evidence of particular hypothesized process of change and can also be used to develop new hypotheses regarding processes of change (Pontius Jr et al. 2013). Braimoh (2006), employed Intensity Analysis to study random and systematic land cover transitions in northern Ghana and Alo and Pontius Jr (2008), also used it to identify systematic land-cover transitions of forests inside and outside protected areas in south western Ghana. Hitherto, no study has employed Intensity Analysis to analyse LULC change of wetlands in Ghana to reveal patterns and processes associated with wetland landscape transformation.

The study applies Intensity Analysis to assess LULC change of coastal urban wetlands in Ghana to quantify the patterns and to identify the underlying processes across two time intervals (1985–2002 and 2002–2017).

Materials and methods

Study area

Three coastal urban wetlands were selected for this study; Densu Delta, Sakumo II and Muni-Pomadze, Ramsar Sites. Among the six wetlands designated as wetlands of international importance in Ghana, the three wetlands considered in this study are the ones located in coastal urban areas. Based on the Ramsar Convention criteria, the three wetlands are classified under marine/coastal wetlands (Ministry of Lands and Forestry 1999).

The Densu Delta Ramsar Site is found in the south-western part of Accra, about 11 km from Ghana's capital city. The Ramsar Site constitutes the lower reaches of the Densu River water course and its confluence with the Atlantic Ocean and occupies an area of about 46.2 km^2 (Gbogbo and Attuquayefio 2010). It is located between latitude 5° 30′ 0″–5° 36′ 0″ N and longitude 0° 18′ 0″–0° 24′ 0″ W (Fig. 1). There are five major habitats found in the Ramsar Site; freshwater marsh, brackish lagoon, sand dunes, coastal savanna grassland and thicket (Ntiamoa-Baidu and Gordon 1991). The main livelihood activities of the people in the surrounding communities are fishing, large scale commercial salt extraction and peasant farming (Ntiamoa-Baidu and Gordon 1991).

Sakumo II Ramsar Site is located in the Tema Metropolitan Assembly, about 15 km East of Accra. It is situated between latitude 5° 36′ 0″–5° 42′ 0″ N and longitude 0° 0′ 0″–0° 6′ 0″ W (Fig. 1). The Ramsar Site covers a total area of 13.4 km^2 (Gbogbo et al. 2012). There are four main types of habitats in the Sakumo II Ramsar Site as identified by Ntiamoa-Baidu and Gordon (1991); the freshwater marsh, the open lagoon, the coastal savanna grassland and the surrounding floodplain. The main livelihoods of the surrounding communities are fishing, farming and industrial activities.

The Muni-Pomadze Ramsar Site is situated to the west of Winneba in the Central Region of Ghana, about 55 km from Accra and occupies an area of approximately 95 km^2 (Gordon et al. 2000). The Muni Lagoon covers an area of 3 km^2. It is located between latitude 5° 18′ 0″–5° 18′ 0″ N and longitude 0° 36′ 0″–0° 48′ 0″ W (Fig. 1). This Ramsar Site is bounded by the Atlantic Ocean at the south, to the west by the Yenku Forest Reserve and to the East by Winneba Township. It has four main habitat types; floodplain grassland, open water, forest and scrubland (Ntiamoa-Baidu and Gordon 1991). The primary livelihood

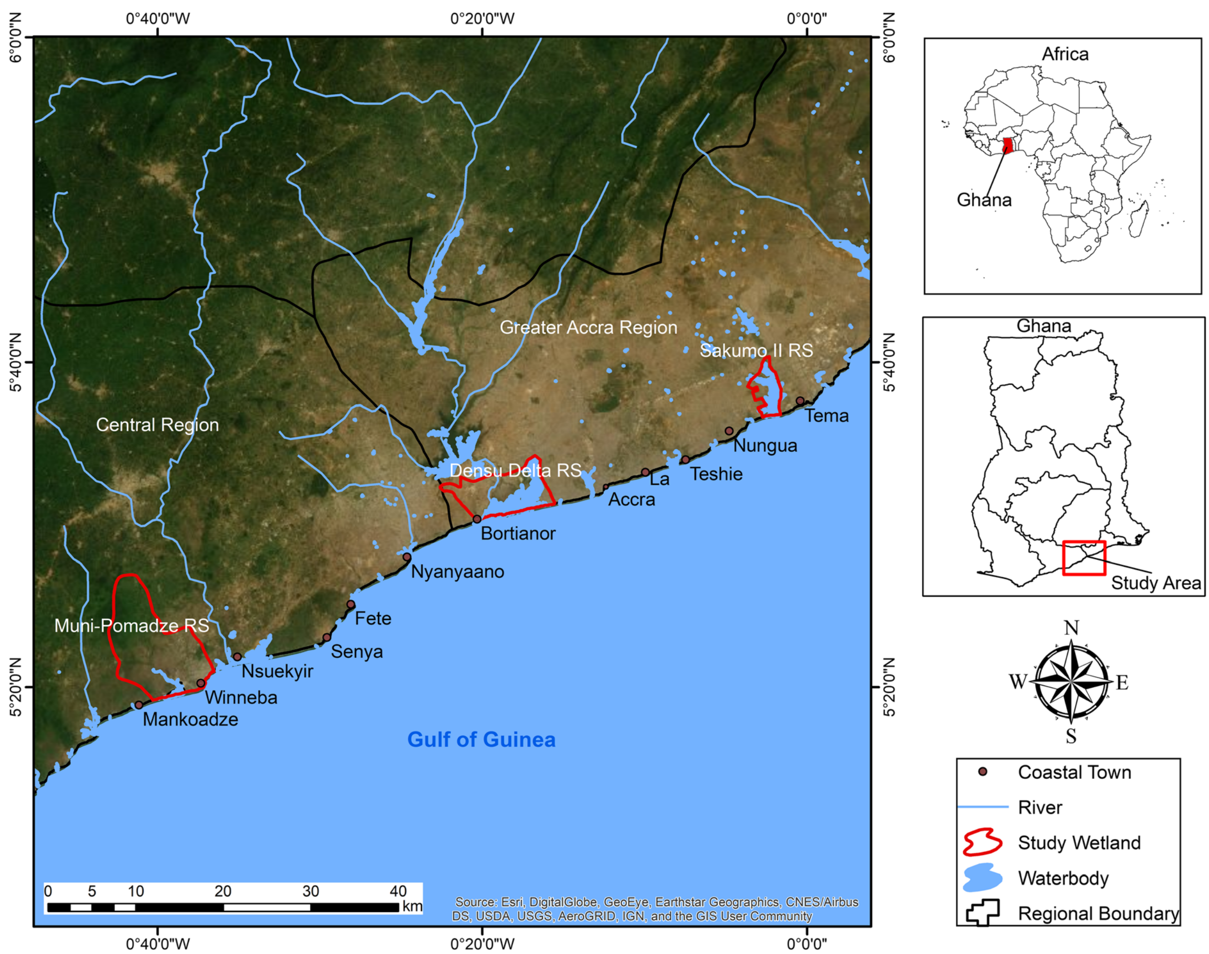

Fig. 1 A Map Showing the Locations of the Densu Delta, Sakumo II and Muni-Pomadze Ramsar Sites (**RS* Ramsar Site)

activities of the fringe communities are farming and fishing.

Landsat satellite image acquisition and classification

Landsat satellite images for the years 1985, 2002, and 2017 were downloaded from the United States Geological Survey website (USGS EarthExplorer 2019) for this study. The details of the Landsat satellite images are provided in Table 1.

The satellite images were classified using Supervised Classification with Maximum Likelihood Classifier in ENVI 5.3. Radiometric and atmospheric corrections were carried out at the preprocessing stage. The individual bands of the satellite images were stacked and projected into the Universal Transverse Mercator (UTM) projection system (Zone: 30 N, Datum: WGS84). The boundary of the wetlands were digitized from Ntiamoa-Baidu and Gordon (1991). Existing topographic maps, Google Earth images and GPS coordinates from ground information were used as reference data to classify the satellite images. Densu Delta and Sakumo II Ramsar Sites were classified into four LULC classes; marsh, thicket, water and built-up/bareland. The Muni-Pomadze Ramsar Site had a different classification scheme due to the prevailing conditions. It was classified into six categories; Dense forest, shrub/grassland, water, built/bareland, burnt land and cultivated land. Wildfires are common in the Muni-Pomadze Ramsar Site especially during the dry season (Attuquayefio and Wuver 2003). In essence, this study included burnt land as a LULC category in order to assess how it had changed over the time intervals. Cultivated land represents a mosaic of farm lands and fallow lands.

Land use and land cover (LULC) change

After the image classification, LULC maps of all the 3 years (1985, 2002 and 2017) of the study areas were developed. The accuracy assessment of the generated LULC maps was carried out using samples from UAV images, Google Earth and other available topographic maps. Post-classification comparison was carried out to estimate changes in the LULC categories. Change detection statistics tool in ENVI 5.3 was used to quantify changes that occurred during the two time intervals in the wetlands.

Intensity analysis

Intensity Analysis is a mathematical framework to express differences within a set of categories that exist at multiple time points (Quan et al. 2019). Intensity Analysis was carried out to assess the sizes and intensities of temporal changes among LULC categories. Intensity Analysis was conducted at three levels: interval, category, and transition. The interval level examines the overall change in each time interval. It determines how the size and rate of change varies across time intervals. The estimated annual area of overall change for each time interval is compared to the uniform intensity, which is the annual change if all the changes were distributed uniformly across the entire temporal extent. Interval Intensity Analysis determines the time interval in which the overall annual rate of change was relatively slow or fast. An annual change of a time interval is considered as fast when it is larger than the uniform change whereas a slow annual change occurs when the annual change is smaller than the uniform change.

The category Intensity Analysis examines the variations in terms of intensity of change among the categories of LULC. At this level, the intensity of annual gross gains and losses for each category are computed and compared to the uniform intensity that would have occurred if all categories gain or lose with the same intensity in each time interval. An annual change of a LULC category is said to be dormant when it is smaller than the uniform intensity of change in a time interval. An active change occurs when the annual change of a LULC category is larger than the uniform intensity of change in a time interval.

Table 1 Landsat satellite images used in the study

Satellite	Sensor	Path/row	Spatial resolution (m)	Acquisition date	Source
Landsat 5	TM	193/56	30	06/03/1985	USGS 2018
Landsat 7	ETM+	193/56	30	26/12/2002	USGS 2018
Landsat 8	OLI/TIRS	193/56	30	11/12/2017	USGS 2018

The transition level shows the variation in intensity with which the gain of a particular LULC category transitions from other LULC categories within each time interval (Aldwaik and Pontius Jr 2012). It compares how each category gains from other categories during each time interval (Quan et al. 2019). The transition level analyzes whether a category's gain intensively targets or avoids the other categories at the start of each time interval. The uniform transition intensity is compared to the observed intensities recorded in each time interval. If the observed transition intensity of a particular LULC category is greater than the uniform transition intensity, then it implies that the gain of that category targets the other category. Contrarily, if the observed transition intensity of a particular LULC category is less than the uniform transition intensity, then the gain of that category avoids the other category. In this study, transition analysis was done for the largest gaining categories for each time interval.

The Intensity Analysis was carried out using an open source Microsoft Excel programme from Intensity Analysis website (https://sites.google.com/site/intensityanalysis/). The programme was developed by Safaa Zakaria Aldwaik and Robert Gilmore Pontius Jr. The mathematical equations for the three levels of Intensity Analysis used in developing the Microsoft Excel programme and adopted in this study are found in Aldwaik and Pontius Jr (2012).

Results

Changes in LULC in the wetlands

The study revealed noticeable changes in LULC in the wetlands across the three time points. Figure 2 presents the LULC maps for the wetlands.

Table 2 shows the accuracy assessment report for the LULC maps generated. Both the overall and class accuracy were provided. The user's and producer's accuracy were reported for all the LULC classes. The accuracy of the maps for the three time points for all the wetlands was generally high.

The overall accuracy for the LULC maps were all above 80 percent with the exception of Sakumo II (2017) and Muni-Pomadze (2002) maps which were 79.0 and 77.5 percent repectively.

Tables 3 and 4 provide land transition matrices for the wetlands during two time intervals. Land transition matrix provides detailed information on the area of gross loss, gross gain and net change for each LULC category as well as the overall change for the wetlands in the two time intervals. The numbers on the diagonal (bold face) indicate persistence. The Densu Delta Ramsar Site had marsh as the largest LULC type in 1985 (17.5 km^2, 37.1%) and 2002 (17.2 km^2, 36.4%) but, built-up/bareland became the largest in 2017 (23.9 km^2, 50.6%). Marsh was the dominant LULC type for the Sakumo II Ramsar Site in 1985 (9.1 km^2, 63.6%) and 2002 (8.2 km^2, 56.9%). As observed in the Densu Delta, built-up/bareland became the dominant LULC type in 2017 (4.8 km^2, 33.8%). The Muni-Pomadze Ramsar Site had shrub/grassland as the largest LULC category in 1985 (41.3 km^2, 43.0%) and 2002 (30.1 km^2, 31.3%) however, cultivated land became the dominant LULC type in 2017 (30.8 km^2, 32.1%).

The gross gains for the first time interval for all categories with the exception of built-up/bareland were greater than the gross gains for the second time interval. Built-up/bareland decreased in gross loss in the second time interval at the Densu Delta Ramsar Site. Persistence of all the LULC categories decreased in the second time interval except built-up/bareland which increased. At the Sakumo II Ramsar Site, the gross gains in the second time interval for all categories with the exception of marsh were greater than the gross gains for the first time interval. Similar to the Densu Delta, persistence of all the LULC categories reduced in the second time interval except built-up/bareland which increased. At the Muni-Pomadze Ramsar Site, gross gain for the second time interval for cultivated land, built-up/bareland, shrub/grassland and water were greater than gross gain recorded in the first time interval. Dense forest and burnt land increased in gross loss in the second time interval. Persistence of shrub/grassland, dense forest and burnt land decreased in the second time interval while that of built-up/bareland, cultivated land and water increased.

Interval level Intensity Analysis

Figure 3 provides the interval level Intensity Analysis for the three wetlands for 1985–2002 and 2002–2017 time intervals. In all the wetlands, annual change in the second time interval was relatively fast compared to

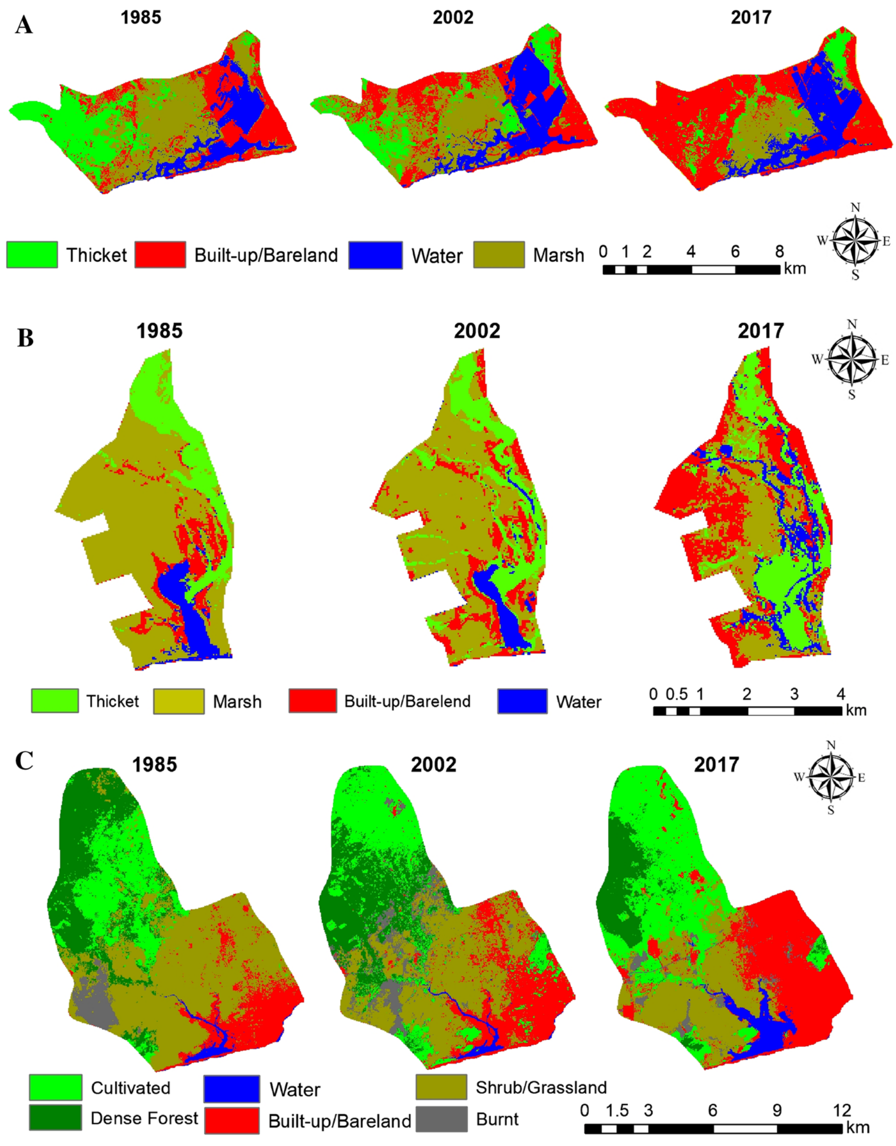

Fig. 2 LULC maps for 1985, 2002 and 2017. **A** Densu Delta Ramsar Site. **B** Sakumo II Ramsar Site. **C** Muni-Pomadze Ramsar Site

the first time interval. At the Densu Delta Ramsar Site, the annual change (2.42%) in the first time interval was slow compared to that of the second time interval (2.60%). Similar to the Densu Delta, at the Sakumo II Ramsar Site, the annual change in the first time interval (1.47%) was relatively slow compared to the annual change that was recorded in the second time interval (3.55%). The Muni-Pomadze Ramsar Site also experienced a slower annual change in first time interval (2.65%) compared with that of the second time interval (2.91%).

Category level Intensity Analysis

Figure 4 presents the results for category level Intensity Analysis for the three wetlands for 1985–2002 and 2002–2017. Thicket experienced active losses but dormant gains in the first time interval in the Densu Delta Ramsar Site. Marsh and water recorded dormant gains and losses. The gains and losses for built-up/bareland were active. In the second time interval, thicket recorded active gains and losses. Marsh was dormant in terms of gains but experienced active losses. Built-up/bareland recorded active gains and

Table 2 Accuracy assessment report for the LULC maps of the wetlands

	1985		2002		2017	
	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)
Densu Delta Ramsar Site						
Thicket	86.5	92.6	82.2	89.0	66.2	71.0
Marsh	88.1	70.8	88.2	72.0	86.1	84.8
Built	75.1	79.4	79.3	80.8	95.2	89.5
Water	68.4	94.3	77.1	97.7	87.3	97.4
Overall accuracy	81.5		82.3		88.4	
Sakumo II Ramsar Site						
Thicket	78.5	83.9	85.1	79.3	90.2	68.8
Marsh	90.7	84.8	92.1	89.5	81.6	92.1
Built	73.2	58.7	74.8	75.4	93.7	73.7
Water	63.3	89.6	72.3	90.2	45.7	81.9
Overall accuracy	82.2		85.5		79.0	
Muni-Pomadze Ramsar Site						
Degraded	75.6	86.4	74.8	81.3	93.3	83.7
Dense	84.2	72.6	80.2	72.4	84.7	92.2
Water	33.8	99.7	48.4	97.8	79.9	99.7
Built	84.7	84.8	83.0	79.5	86.2	94.0
Scrub	89.3	81.0	79.7	85.7	86.8	86.4
Burnt	88.9	99.7	73.2	47.7	64.7	50.4
Overall accuracy	81.4		77.5		87.0	

dormant losses. Water experienced dormant gains and losses in the second time interval.

At the Sakumo II Ramsar Site, in the first time interval, thicket and built-up/bareland recorded active gains and losses whereas marsh experienced dormant gains and losses. Water was dormant in terms of gains and active in losses. In the second time interval, thicket experienced dormant gains and losses. Marsh recorded dormant gains but experienced active losses. Built-up/bareland recorded active gains and dormant losses. Water experienced active gains and losses.

At the Muni-Pomadze Ramsar Site, cultivated land, dense forest and burnt land recorded active gains and losses in the first time interval. Built-up/Bareland, shrub/grassland and water experienced dormant gains and losses. In the second time interval, burnt land was the only category that experienced active gains and losses. Cultivated land, built-up/bareland and water recorded active gains and dormant losses. Dense forest and shrub/grassland recorded dormant gains and active losses. Contrary to the first time interval, water experienced active gains and losses in the second time interval.

Transition level Intensity Analysis

The study considered the large gross gains in each of the wetlands to quantify patterns of LULC change. Figure 5 shows results from Intensity Analysis' transition level for the Densu Delta and Sakumo II Ramsar Sites.

The two sites had large gains of built-up/bareland during both time intervals. The gain of built-up/bareland targeted marsh and thicket at the Densu Delta

Table 3 Land transition matrices (km^2) for the Densu Delta and Sakumo II Ramsar Sites for 1985–2002 and 2002–2017

		Thicket	Marsh	Built-up/Bareland	Water	Initial total	Gross loss
Densu Delta Ramsar Site							
2002							
1985	Thicket	**4.3**	4.3	2.3	0.0	10.9	6.6
	Marsh	2.2	**10.7**	3.9	0.7	17.5	6.8
	Built-up/Bareland	0.5	1.8	**6.7**	2.8	11.8	5.1
	Water	0.1	0.4	0.4	**6.1**	7.0	0.9
	Final Total	7.1	17.2	13.2	9.7	47.2	19.4
	Gross Gain	2.8	6.5	6.5	3.6	19.4	
2017							
2002	Thicket	**2.0**	1.4	3.7	0.0	7.1	5.1
	Marsh	1.2	**7.3**	8.0	0.8	17.2	9.9
	Built-up/Bareland	0.1	0.5	**11.5**	1.1	13.2	1.7
	Water	0.2	0.7	0.7	**8.0**	9.7	1.7
	Final Total	3.5	9.8	23.9	10.0	47.2	18.4
	Gross Gain	1.5	2.6	12.4	1.9	18.4	
Sakumo II Ramsar Site							
2002							
1985	Thicket	**1.8**	0.4	0.3	0.1	2.6	0.8
	Marsh	0.8	**7.4**	0.9	0.0	9.1	1.8
	Built-up/Bareland	0.2	0.3	**0.9**	0.0	1.4	0.5
	Water	0.3	0.1	0.2	**0.7**	1.2	0.5
	Final total	3.1	8.2	2.3	0.8	14.4	3.6
	Gross gain	1.2	0.8	1.4	0.2	3.7	
2017							
2002	Thicket	**1.7**	0.2	0.4	0.6	3.1	1.3
	Marsh	0.7	**3.7**	3.3	0.4	8.2	4.4
	Built-up/Bareland	0.4	0.4	**1.1**	0.5	2.3	1.2
	Water	0.7	0.0	0.0	**0.1**	0.8	0.7
	Final total	3.5	4.3	4.8	1.6	14.4	7.6
	Gross gain	1.8	0.6	3.7	1.5	7.6	

Ramsar Site. At the Sakumo II Ramsar Site, the gain of built-up/bareland targeted only water during the first time interval and targeted only thicket during the second time interval.

Figure 6 presents results from Intensity Analysis' transition level observed at the Muni-Pomadze Ramsar Site. The gain of cultivated land targeted dense forest most intensively during both time intervals. The gain of built-up/bareland targeted shrub/grassland during the second time interval.

Discussion

This study employed Intensity Analysis to assess LULC changes in three wetlands of international importance located within urban settlements in the coastal zone of Ghana. The study covers thirty-two (32) years, comprising two time intervals; 1985–2002 and 2002–2017. The interval level results show that LULC change in the wetlands was more intensive in the second time interval. This implies that the underlying processes that drive the changes progressively increased over the study years. These

Table 4 Land transition matrix (km^2) for the Muni-Pomadze Ramsar Site for 1985–2002 and 2002–2017

		Cultivated Land	Dense forest	Burnt Land	Built-up/ Bareland	Shrub/ Grassland	Water	Initial total	Gross loss
2002									
	Cultivated Land	**6.8**	8.7	1.1	0.1	0.4	0.0	17.1	10.3
	Dense forest	9.6	**9.1**	1.7	0.2	1.0	0.0	21.5	12.4
	Burnt Land	0.3	0.7	**0.6**	0.01	2.1	0.0	3.7	3.1
	Built-up/ Bareland	0.4	0.0	0.0	**9.6**	0.9	0.1	11.0	1.4
	Shrub/ Grassland	4.0	1.2	4.0	6.4	**25.6**	0.1	41.3	15.7
	Water	0.0	0.0	0.0	0.3	0.01	**1.0**	1.4	0.4
	Final total	21.1	19.6	7.4	16.6	30.1	1.2	96.0	43.3
	Gross gain	14.2	10.6	6.8	7.0	4.5	0.2	43.3	
2017									
2002	Cultivated	**15.6**	2.5	0.3	1.7	0.9	0.0	21.1	5.5
	Dense Forest	10.6	**7.6**	0.3	0.5	0.6	0.0	19.6	12.0
	Burnt	2.9	0.1	**0.4**	0.8	3.3	0.0	7.4	7.0
	Built-up/ Bareland	0.3	0.0	0.1	**12.5**	0.8	2.9	16.6	4.1
	Shrub/ Grassland	1.5	0.0	1.9	9.8	**17.0**	0.2	30.1	13.1
	Water	0.0	0.0	0.0	0.1	0.0	**1.1**	1.2	0.1
	Final Total	30.8	10.2	3.0	25.3	22.6	4.3	96.0	41.9
	Gross Gain	15.2	2.6	2.6	12.7	5.6	3.2	41.9	

underlying processes could be linked to anthropogenic activities because, in 1985 and 2002, the largest LULC categories for all the wetlands were natural LULC types but in 2017, human-induced LULC categories became the largest. Despite their ecological and social importance, these wetlands are rapidly being converted into built areas and this calls for the immediate attention of relevant stakeholders.

The increase in anthropogenic activities in the wetlands could be attributed to urbanization which is mainly as a result of increased human population. The human population of Accra and Winneba doubled between 1984 and 2010 according to the Ghana Statistical Service (2013). The population rise could drive the rapid land transformation observed in the second time interval. It is predicted that the shift from rural to a predominantly urban population will continue, with close to about 90% of this increase occurring in Africa and Asia (United Nations, Department of Economic and Social Affairs, Population Division 2019). The implication is that these urban wetlands will eventually become a built environment depriving urban dwellers of their important ecosystem services but supplying humans with housing.

The findings from the category and transition Intensity Analysis of the wetlands provide information on the gains, losses and the large transitions of the various LULC categories. At the Densu Delta Ramsar Site, built-up/bareland expanded in both time intervals while the natural LULC types decreased. Built-Up/ Bareland gains were intensively derived from thicket and marsh. It implies that marsh and thicket were cleared to give way for physical developments. Similar pattern was observed in the second time interval, built-up/bareland continued to expand at the expense of thicket and marsh. The land transformation pattern at the Densu Delta Ramsar Site clearly shows that urbanization is the main process driving the changes.

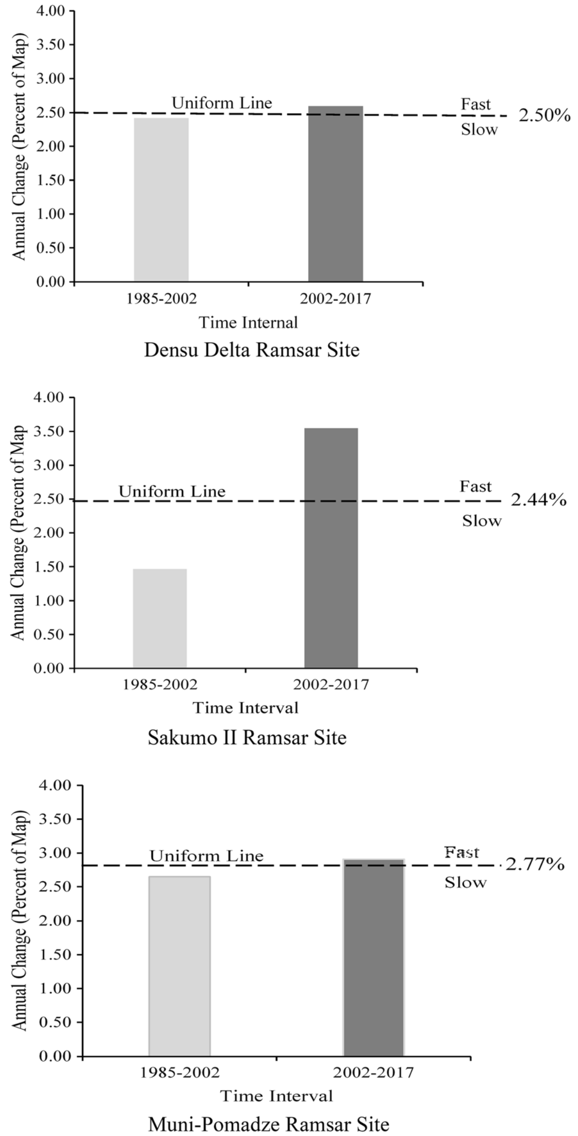

Fig. 3 Interval level Intensity Analysis results for 1985–2002 and 2002–2017 time intervals

The LULC changes at Sakumo II wetland had a similar trend like that of the Densu Delta wetland. Built-up/bareland gained substantially from the natural LULC types. The gains of built-up/bareland from water in the first time interval could largely be attributed to reclamation of wetlands for physical development such as residential facilities. However, data error from image classification might account for some of the apparent transition from water to built-up/bareland. In the second time interval, the land transformation pattern changed. Built-up/bareland expansion was derived from thicket. The wetland was dominated by human activities such as vegetable farming, livestock rearing, and industrial activities in the early 2000s (Nartey et al. 2011). In recent times the main threat to the wetland is built-up expansion. The results of the transition level Intensity Analysis show that LULC changes at the Sakumo II Ramsar Site in both time intervals were driven intensively by urbanization. The implication is that, progressively the wetland is being converted to impervious surfaces, which has multiple adverse effects on biodiversity.

LULC changes in the Muni-Poamdze Ramsar Site were unlike what was observed in the Densu Delta and Sakumo II Ramsar Sites which were largely driven by built-up expansion. In the first time interval, the active losing categories were cultivated land, dense forest and burnt land and they were the same categories that had large gains. These changes were primarily driven by agricultural activities. The only large transition observed was transition from dense forest to cultivated land. The Ramsar Site is surrounded by eleven communities whose main occupation is farming (Gordon et al. 2000). This explains why dense forest was intensely converted into cultivated lands. In the second time interval, two large transitions were observed; dense forest to cultivated land and shrub/grassland to built-up/bareland. The land transformation at the wetlands could be attributed to agriculture and urbanization. The massive reduction in dense forest and expansion of cultivated land was as a result of increased farming activities by the fringe communities. Built-up/bareland also grew substantially at the expense of shrub/grassland which implies that shrub/grassland areas of the wetland were the hotspots for development of residential infrastructure. Built-up expansion occurred more at the south eastern part of the wetland and close to the Winneba Township. This reveals that expansion of Winneba Town mainly occur at the shrub/grassland areas of the wetland.

Coastal urban wetlands in Ghana need urgent attention from the relevant stakeholders in order to protect them from rampant destruction as a result of increasing demand of coastal urban lands for physical infrastructural development for residential and commercial purposes. Interventions that seek to protect coastal urban wetlands should include innovative ways of maximising the use of limited urban space

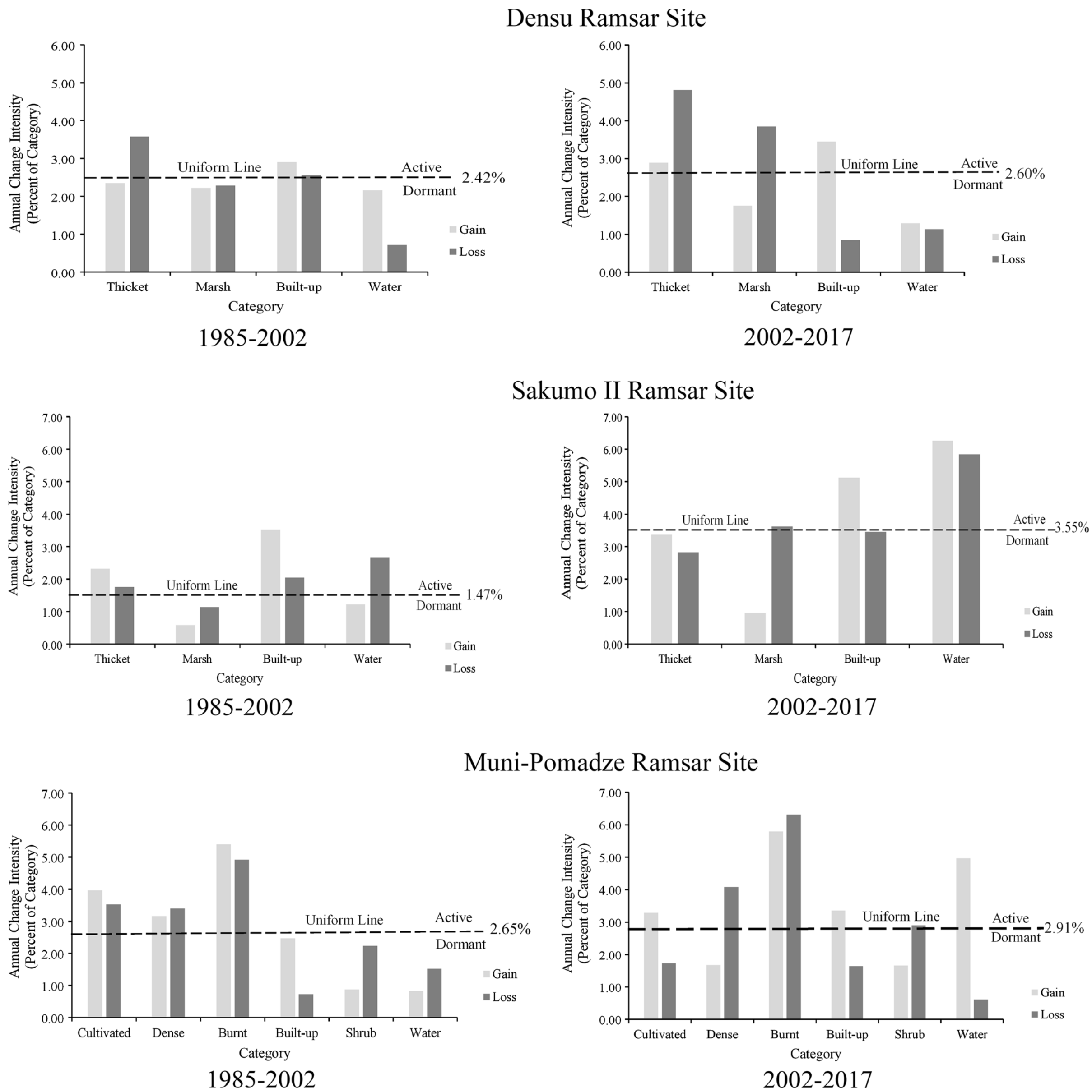

Fig. 4 Category level Intensity Analysis showing active losing and gaining categories in the wetlands for 1985–2002 and 2002–2017 time intervals

to accommodate the rising demand. There should be deliberate and concerted effort by the relevant agencies to coordinate for effective implementation and enforcement of laws and regulations that protect wetlands. Although massive efforts have been put in towards wetland conservation in recent years, Ghana must prevent more wetlands from being wiped out by urbanization in order to save the country from the associated ecological and social implications.

Study limitations

Some important LULC categories such as built-up and bareland were classified together as one because, the resolution of the satellites images (30 m) was not high enough to enable the separation of these two LULC categories. High resolution satellite images of the study areas were not available for all the 3 years considered in this study. The available high resolution

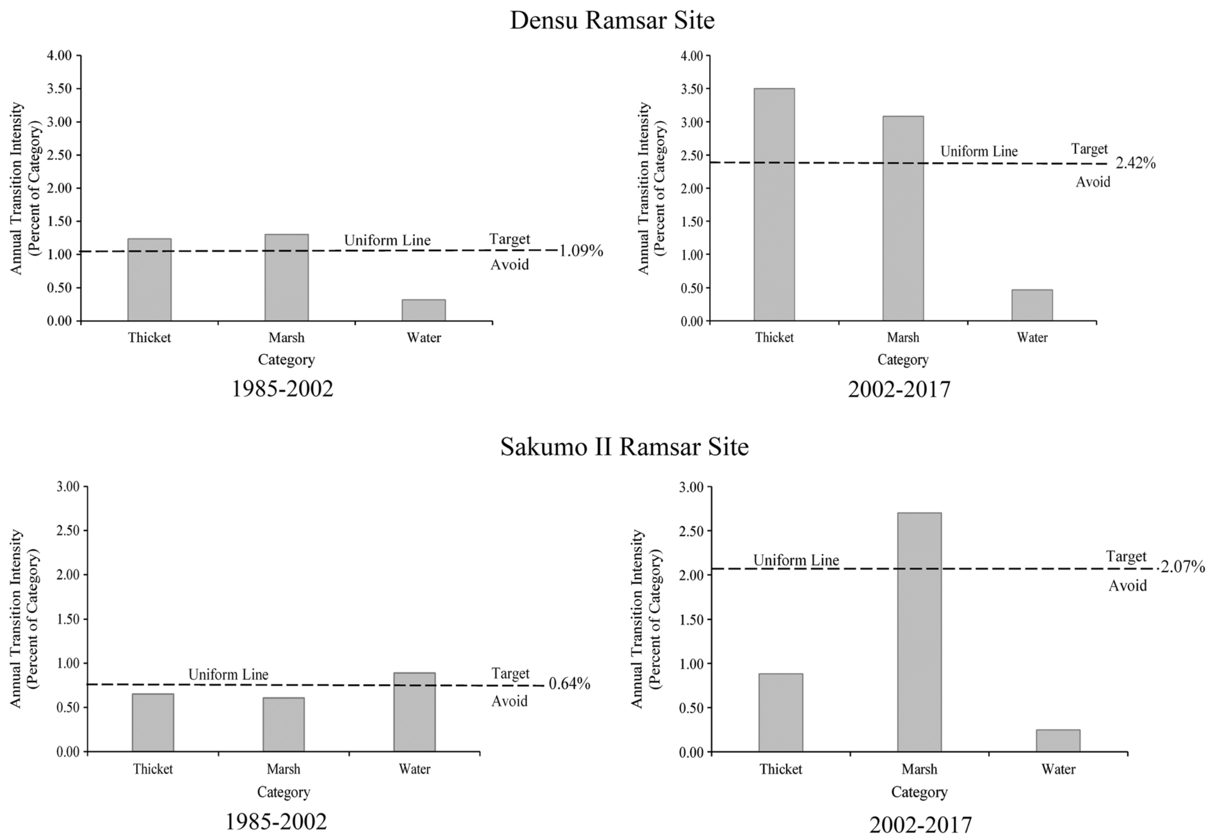

Fig. 5 Transition to built-up/bareland at the Densu Delta and Sakumo II Ramsar Sites for 1985–2002 and 2002–2017 time intervals

images were captured recently. A similar study also merged the two LULC categories into one (Ashiagbor et al. 2019). In addition, the two time intervals considered for this study were unequal. Even though Landsat satellite images have been available since 1972, most of the images did not meet the criteria set for this study. However, it is noteworthy that unequal time interval does not affect Intensity Analysis.

Conclusion

Intensity Analysis was used to assess LULC changes in three wetlands of international importance in coastal urban areas in Ghana. The findings of this study show that LULC changes in the wetlands progressively increased with time and this implies that the underlying processes that drive the changes became more intense with time. These underlying processes could be linked to anthropogenic activities because, in 1985 and 2002, the largest LULC category of the wetlands were natural categories but, human-induced LULC categories such as built-up (Densu Delta and Sakumo II) and cultivated land (Muni-Pomadze) became the largest in 2017. Vegetated surfaces were rapidly replaced by impervious surfaces, indicating the enormous influence of anthropogenic activities. This situation has potential implications on the frequency and magnitude of flooding in coastal urban areas, which in turn requires costly flood control infrastructure. The process that could be associated with the LULC change pattern observed in the Densu Delta and Sakumo II Ramsar Sites was urbanization whereas agriculture and urbanization were the main drivers of land transformation at the Muni-Pomadze Ramsar Site.

Given the many watershed services wetlands provide, wetland conservation and restoration should be an integral part of a comprehensive local watershed management strategy. Further research is required to comprehensively delineate the indirect impacts of LULC on urban wetlands, and several priority

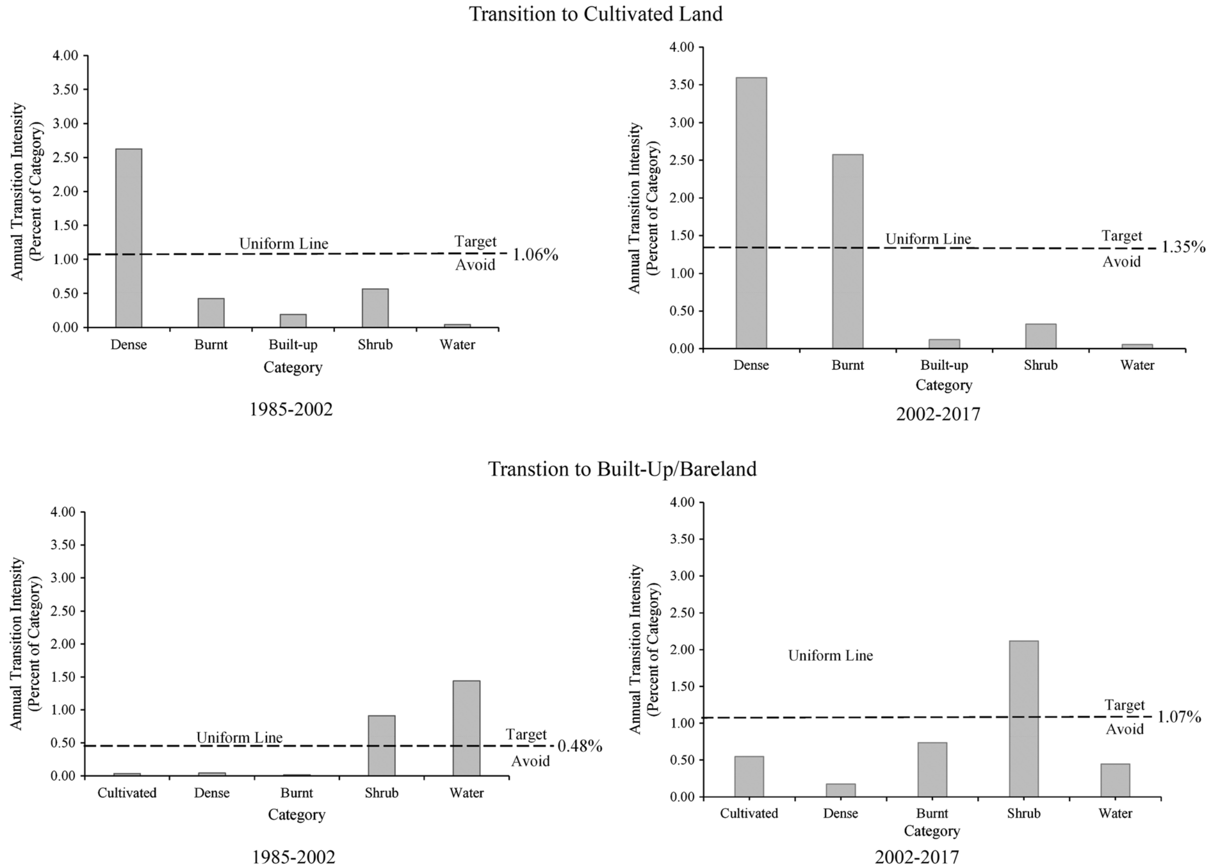

Fig. 6 Transition to cultivated land and built-up/bareland at the Muni-Pomadze Ramsar Site for 1985–2002 and 2002–2017 time intervals

research strategies are warranted at the national and sub-national levels. From the big picture perspective, however, the current science on wetland impacts from anthropogenic activities presents a compelling case to support greater local regulation and management of wetlands and their contributing drainage areas. The corpus of literature on indirect impacts to wetlands in Ghana and beyond has been generated by a constellation of different academic disciplines that rarely interact with each other. Urban wetland research has been published by geographers, hydrologists, herpetologists, landscape ecologists, botanists, wildlife managers, conservation biologist, toxicologists, stormwater engineers and wetland scientists. It is recommended that a national network be launched to improve communication among the diverse research community currently working on the topic of direct and indirect impacts of LULC to urban wetlands.

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