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Geospatial assessment of ecosystem health of coastal urban wetlands in Ghana

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ABSTRACT

A comprehensive assessment of ecosystem health of wetlands is needed to guide protection and restoration activities. However, the conventional methods used in evaluating ecosystem health of wetlands largely rely on field observational data which often do not provide spatio-temporal perspectives to the assessment. Geospatial assessment of remotely sensed data has enormous potentials for assessing ecosystem health of wetlands at different temporal and spatial scales. This study employed geospatial techniques to assess ecosystem health of Densu Delta, Sakumo II and Muni-Pomadze Ramsar Sites over a 32-year period using structure, function and resilience indicators. Landsat satellite images of 1985, 2002 and 2017 were obtained for this study. Analytic hierarchy process (AHP) was used to weight the indicators. The importance of the ecosystem health indicators in decreasing order was as follows: Structure > Resilience > Function. The findings of the study also indicated that ecosystem health of the wetlands progressively deteriorated in 2002 and 2017 compared to the reference year of 1985. In 2002, the Densu Delta experienced the least decline (11.8%) from the 1985 state among the three wetlands and Sakumo II recorded the highest deterioration (38.0%). Unlike 2002, in 2017 the health of the Densu Delta experienced the worse deterioration (46.3%) whereas Sakumo II recorded the least decline (26.2%). Ecosystem health of Muni-Pomadze Ramsar Site deteriorated at a similar magnitude, 27.0% and 29.1% in 2002 and 2017, respectively. The critical underlying factor for the degradation of the wetlands is urbanization largely due to increase in human population which led to the expansion of built-up areas in the wetlands, fragmentation of natural land use and land cover (LULC) classes and reduction of vegetation cover.

1. Introduction

Wetlands are among the most important productive ecosystems on earth and provide a wide range of essential services to humanity (Wu et al., 2018; Zhang et al., 2013). Wetlands serve as habitats for some vital species that are essential for human survival and their degradation affects ecosystem services they provide (Daryadel and Talaei, 2014). Notwithstanding their essential functions, the world has lost about 50 percent of its wetlands since 1900 and continues to lose it at a faster rate of 3.7 times in the 21st century (Davidson, 2014). Globally, more than 50 percent of coastal wetlands have been lost (Li et al., 2018) and the primary cause associated with the loss is urbanization propelled by rapidly increasing human population in coastal areas (Hinrichsen, 1999; Nicholls, 2004).

To change the narrative, the Ramsar Convention Secretariat (2008), called on all contracting parities to review the state of their urban and peri-urban wetlands and take appropriate measures to protect them. In view of this, the theme for World Wetlands Day 2018 was “Wetlands for a Sustainable Urban Future”. This theme was chosen to sustain the discourse on the deplorable state of urban wetlands and also raise awareness on the important contributions of urban wetlands to the future of sustainable cities. The degradation of urban wetlands cannot be overemphasised but the focus now is on restoration and protection. Assessing ecosystem health of wetlands has been identified as an important activity that precedes any remediation and restoration activity (Fennessy et al., 2009). A comprehensive assessment of wetland

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ecosystem health is needed to guide protection and restoration plans (Zheng et al., 2012). However, the conventional methods used in evaluating wetland ecosystem health largely rely on field observational data (Chen and Wang, 2005) which cannot be applied on a large spatial scale. Furthermore, it is difficult to provide some spatio-temporal perspectives to the assessments (Kerr and Ostrovsky, 2003).

Novel approaches or methods are required to undertake a comprehensive assessment of wetland ecosystem health. Data from geospatial techniques such as Remote Sensing and Geographic Information System (GIS) have enormous potentials for assessing wetland ecosystem health at different temporal and spatial scales (Kerr and Ostrovsky, 2003). Geospatial techniques have proven to be effective in assessing wetlands particularly, at large scales (Fritz et al., 2017). It has numerous advantages over the conventional methods, especially, it is comparatively cost-effective and timely. It is also suitable for repeated studies and capable of acquiring images from inaccessible places which is typical of wetland areas (Mahdavi et al., 2017). The information obtained from remotely sensed data (such as satellite images) can be used when there are no or limited resources to support field data collection (Weller et al., 2007).

Comprehensive assessments of wetlands have been done in developed regions particularly United States of America (Dahl, 2006), China (Zheng et al., 2012) and Europe (EEA, 2011). However, not much has been done in developing countries such as Ghana. In the past, wetlands in Ghana were considered as waste lands and were dredged to facilitate drainage of water, reclaimed for other uses, or simply considered as dumping sites for municipal solid waste (Ministry of Lands and Forestry, 1999). In recent times, rapid urbanization and industrialization as a result of increased population in coastal cities have led to detrimental changes in the extent and functioning of coastal urban wetlands in Ghana (Ryan and Attuquayefio, 2000). The problem has been exacerbated by constant influx of migrants from the interior which contributes to rapid population growth and urbanization of coastal urban areas (Reed et al., 2010). Data from the Ramsar Sites Information Service database (https://rsis.ramsar.org/) indicates that in Ghana, biological resource use and human settlements are the most reported threats to wetlands and climate change/severe weather and water regulation are the least reported threats.

Most studies on wetland ecosystem health in Ghana have mainly used the conventional method of field data collection (Fianko et al., 2009; Kyerematen et al., 2014; Nonterah et al., 2015) which limits the spatial scale and also makes it difficult to provide spatio-temporal patterns and the processes that produced them. This gap is largely due to lack of historical data on wetlands. Adade et al. (2017) used geospatial techniques to study fragmentation of Songhor Ramsar Site over a period of 25 years (1990–2015). Geospatial techniques enable characterisation and quantification of wetland ecosystem health indicators to minimise the subjectivity of the assessment. There is a pressing need to understand and monitor the spatial heterogeneity of ecosystem health for better conservation strategies (Liu et al., 2016). Hence, this study sought to undertake a comprehensive assessment of ecosystem health of coastal urban wetlands in Ghana over a 32-year period using geospatial techniques. The objective of the study was to assess ecosystem health of Sakumo II, Densu Delta and Muni-Pomadze wetlands in 2002 and 2017 using structure, function and resilience indicators. The ecosystem health of the wetlands in 1985 served as the reference year.

2. Materials and method

2.1. Study area

The study was conducted in three coastal urban wetlands; Muni-Pomadze, Densu Delta and Sakumo II Ramsar Sites. There are more coastal urban wetlands in Ghana than were considered for this study. However, these wetlands were selected for the following reasons; among the six wetlands designated as wetlands of international importance in Ghana, they are the ones that are located in urban areas. Several studies have reported that these wetlands are threatened by anthropogenic activities (Attuquayefio and Wuver, 2003; Nartey et al., 2011; Wuver and Attuquayefio, 2006) and moreover, these wetlands have well defined boundaries that enable spatio-temporal studies.

2.2. Densu Delta Ramsar Site

The Densu Delta Ramsar Site is located in Accra, the capital city of Ghana. It encompasses the lower part of the Densu River water course and its confluence with the Atlantic Ocean. The total area of the wetland is about 46.2 km^2 (Gbogbo and Attuquayefio, 2010). The main five habitats found in the wetland are coastal savanna grassland, marsh, delta and sand dunes and thickets (Ntiamoa-Baidu and Gordon, 1991). It lies between latitude 5°30′0″-5°36′0″N and longitude 0°18′0″-0°24′0″W (see Fig. 1). The main livelihood activities of the fringe communities are fishing, peasant farming and commercial salt production (Ntiamoa-Baidu and Gordon, 1991). The area has bimodal rainfall pattern with mean annual rainfall of about 800 mm and mean temperature ranges from 24.2 °C to 31 °C. The site serves as a favourable grounds for feeding, roosting and nesting of seashore birds (Ntiamoa-Baidu and Gordon, 1991). Densu Delta Ramsar Site is a habitat for several species of resident and migratory birds. It serves as home for about 57 species of seashore birds with an estimated population of 35000 and about 15 species of finfish belonging to 14 genera and 9 families with *Sarotherodon melanotheron* and *Tilapia zilli* as the predominant fish species (Ntiamoa-Baidu and Gordon, 1991).

2.3. Sakumo II Ramsar Site

Sakumo II Ramsar Site is found at south-western part of Tema, an industrial city in Ghana. It lies between latitude 5°36′0″-5°42′0″N and longitude 0°0′0″-0°6′0″W (see Fig. 1). The total area of the wetland is about 13.4 km^2 (Gbogbo et al., 2012). The wetland is made up of floodplain, lagoon, marsh and coastal savanna grassland/thicket. The primary livelihood activities of the neighboring communities are farming, fishing and industrial works. The lagoon used to be a closed lagoon until a sluice was constructed in 1953 to link it to the sea during the construction of the Accra-Tema Beach Road (Ofori-Danson and Kumi, 2006). Two main rivers flow into the Sakumo II lagoon; Gbagbla Ankonu and Mamahuma, with an estimated catchment of about 222 km^2 (Ntiamoa-Baidu and Gordon, 1991). The dominant plant species are *Bothriochloa bladhii, Sesuvium portulacastrum, Imperata cylindrica* and *Typha domingensis* (Ntiamoa-Baidu and Gordon, 1991). The open water is periodically covered with floating water lettuce, *Pistia stratiotes*. Sakumo II Ramsar Site provides habitat for several seashore birds, a total of 66 species and recorded population of 32,500 (Ntiamoa-Baidu and Gordon, 1991).

2.4. Muni-Pomadze Ramsar Site

Muni-Pomadze Ramsar Site is the largest wetland considered for this study. It is located at the outskirt of Winneba Township. The western part of the wetland falls within the Gomoa West District and the eastern part belonging to Effutu Municipalty. It is about 55 km from Accra and has a total land area of about 95 km^2 (Gordon, Ntiamoa-baidu & Ryan, 2000). It is situated between latitude 5°18′0″-5°18′0″N and longitude 0°36′0″-0°48′0″W (see Fig. 1). It is bounded at the south by the Atlantic Ocean, west by the Yenku Forest Reserve and Winneba Township at the east. It is occupied by four major habitats; forest, floodplain grassland/thicket, open water, the degraded forest and scrubland (Ntiamoa-Baidu and Gordon, 1991). To enable easy management of the Ramsar Site, it has been divided into five zones; land use management area, core area, controlled zone, traditional hunting grounds and settlements. The mean annual bimodal rainfall is about 854 mm and mean temperature ranges from 24 °C in August to 29 °C in March; and relative

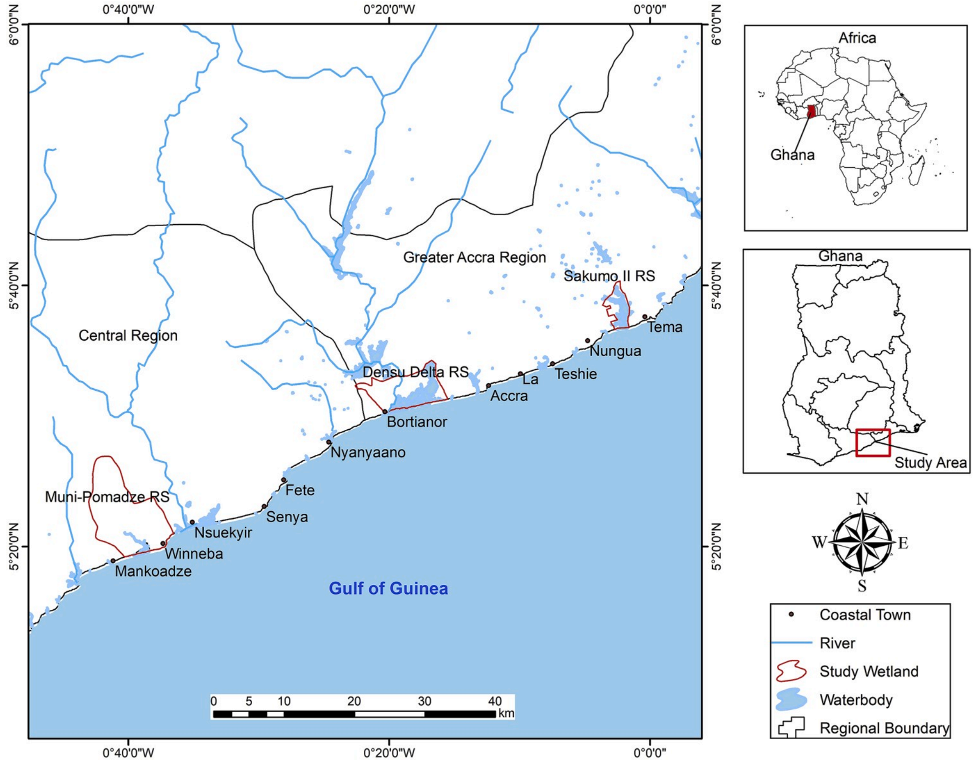

Fig. 1. A map showing the location of study wetlands.

humidity ranges between 75 and 80% (Wuver and Attuquayefio, 2006). The banks of the lagoon are occupied by *Sesuvium portulacastrum, Paspalum virginicum* and *Sporolobus virginicus* and the sand bar vegetation is dominated by *Alternanthera maritima, Canavalia rosea, Cyperus maritimus* and *Remirea maritima* (Gordon et al., 2000). *Cocos nucifera* has been planted on the sand bar. The predominant grass species include *Andropogon gayanus, Hetero-pogon contortus, Panicum maximum,* and *Sporobolus pyramidalis* and the portion that falls within the Yenku Forest Reserve was converted into Eucalyptus, Neem, and Teak plantations (Wuver and Attuquayefio, 2006).

2.5. Data collection and analysis

2.5.1. Landsat satellite image acquisition and classification

Landsat satellite images for the years 1985, 2002, and 2017 were obtained from the United States Geological Survey website (https://earthexplorer.usgs.gov). The 1985 image is a Landsat 5 TM, 2002 image is a Landsat 7 ETM+ and 2017 image is a Landsat 8 OLI/TIRS. After radiometric and atmospheric corrections were done, maximum likelihood algorithm of supervised classification in ENVI v.5.3 was used to classify the satellite images. The boundary of the wetlands were delineated using Ramsar Site maps from Ntiamoa-Baidu and Gordon (1991). Old topographic maps of the wetlands served as reference data for classifying 1985 and 2002 satellite images. Training samples collected from unmanned Aerial Vehicle (UAV) images, Google Earth images and GPS coordinates from ground truthing served as reference data for the classification of the 2017 satellite image. Densu Delta and Sakumo II Ramsar Sites were classified using one classification scheme but Muni-Pomadze Ramsar Site had different schemes due to the prevailing conditions. Densu Delta and Sakumo II Ramsar Sites were classified into four classes: water, built-up/bareland, thicket and marsh. Muni-Pomadze Ramsar Site was classified into forest, cultivated land, water, built-up, shrub/-grassland and burnt land. Even though burnt land is not known to be a LULC class, due to its significant persistence in the wetland during the dry season, it was included. Cultivated land encompasses a mosaic of crop and fallow lands.

2.5.2. Ecosystem health indicators

A plethora of indicators have been used to assess wetland ecosystem health for different purposes. The goal of this study is to employ geospatial techniques to assess the ecosystem health of coastal urban wetlands. It implies that all the indicators selected should be measured and analysed using geospatial technologies. The ecosystem indicators adopted for this study are structure, function and resilience. These indicators are similar to the ecosystem health indicators proposed by Costanza and Mageau (1999); vigour, organization and resilience. In this study, vigor and organization were modified into function and structure respectively.

2.5.3. Ecosystem structure

National Research Council (2005) defined ecosystem structure as both the composition of ecosystem and the physical and biological organization. Skidmore et al. (2015), proposed ten variables that can be monitored by satellite towards the tracking of Aichi biodiversity targets. Under ecosystem structure, four variables were proposed; ecosystem distribution, fragmentation and heterogeneity, land cover and vegetation height. In this study, LULC change and fragmentation were considered. Landscape Deviation Degree (LDD) was computed to represent LULC change. LDD quantifies the extent to which anthropogenic activities have changed the natural landscape (Chunxiao et al., 2008). The formula for calculating LDD is:

$$\text{LDD} = \text{the sum of all artificial surfaces/ total area of land} \tag{1}$$

Fragmentation refers to the breaking up of a habitat into smaller patches (Cairns et al., 1992). To identify the appropriate landscape metrics for the study, thirty-nine (39) class metrics were computed in FRAGSTATS v.4.2. Spearman correlation was run to eliminate high correlating indices. One of the indices with Spearman's Correlation Coefficient above 0.8 or less than −0.8 were eliminated to reduce redundancy. Detailed descriptions of the landscape metrics and the formulae used in calculating them are found in the FRAGSTATS user's guide (Mcgarigal, 2015). Principal Component Analysis (PCA) was then carried out to determine the indices that explain much variation in the dataset. Components that had eigen value of 1 or more were retained. For each retained component, high loading indices (absolute score of 0.8 and above) were selected. The high loading indices in each of the components were selected to represent fragmentation in the ecosystem health analysis.

2.5.4. Ecosystem function

Ecosystem function refers to the processes that take place in an ecosystem as a result of the interactions of plants, animals, and other organisms or their environment (National Research Council, 2005). The study considered two of the four variables proposed by Skidmore et al. (2015). The variables used in the study were vegetation phenology (variability) and inundation.

Vegetation phenology is a key indicator for observing changes in the natural environment (Richardson et al., 2013). It is commonly detected from multispectral remote sensing data by computing for the Normalized Difference Vegetation Index (NDVI) (Wu, 2018). NDVI indicates plant vigour and potential productivity (Walters and Scholes, 2017). The formula for calculating NDVI is:

$$NDVI = (NIR - \mathrm{Red}) \,/\, (NIR + \mathrm{Red}) \tag{2}$$

NIR and Red represent the spectral reflectance values acquired in the near-infrared and red portion of the electromagnetic spectrum, respectively. NDVI values range from −1 to +1. NDVI values from −1 to 0 indicate no vegetation whereas values close to +1 indicate the highest concentration of green vegetation.

Among all wetland indicators, hydrology is a critical factor because, it affects the formation and functions of wetlands (Wu, 2018). Inundation was estimated using the Normalized Difference Water Index (NDWI). NDWI is efficient in detecting surface water and is used in delineating open water features and enhancing their presence in satellite images (McFeeters, 1996). The formula for calculating NDWI is:

$$\mathrm{NDWI} = (\mathrm{Green\text{-}NIR}) \,/\, (\mathrm{Green} + \mathrm{NIR}) \tag{3}$$

NIR and Green represent the spectral reflectance values acquired in the near-infrared and green portion of the electromagnetic spectrum, respectively. NDWI values range from −1 to +1. Positive values indicate water features whilst negative to zero values indicate soil and terrestrial vegetation features.

2.5.5. Ecosystem resilience

Resilience is the capacity of an ecosystem to withstand external pressures and return to its pre-disturbance state over time (Yan et al., 2014). Resilience was assessed by quantifying the extent of wetland loss. Wetland loss was quantified by estimating the impervious surface. Impervious surface was calculated by summing up all areas occupied by built-up. Another variable considered under Resilience was persistence of the wetland LULC. Persistence was computed by subtracting the sum of areas of the wetland that experienced changes from the total area of the wetland.

2.5.6. Weighting of ecosystem health indicators

Analytic hierarchy process (AHP) was employed to design a decision framework for assessing ecosystem health of the wetlands. AHP is an effective mechanism for quantifying opinions of experts that are based on knowledge and personal experience to develop a consistent decision framework (Pecchia et al., 2013). It provides a systematic and robust means of eliciting and quantifying subjective judgments (Schmoldt et al., 1995). The first level of the hierarchy represents the goal; wetland ecosystem health assessment. The second level is the criteria which are the three ecological indicators considered in this study (structure, function and resilience). The third level of the hierarchy represents the sub criteria which are a set of variables that feed into a specific criterion (see Fig. 2). The weights of the criteria and sub criteria were calculated using the steps outlined in Saaty (1987). In all, 20 experts with diverse backgrounds were involved in the weighting of the indicators.

Among all the climatic factors, rainfall is critical to wetland productivity. It was therefore necessary to determine whether rainfall in the study wetlands had undergone some changes that might affect the health of the wetlands. Rainfall data were obtained from the Ghana Meteorological Agency. The population data obtained from the 2010 Population and Housing Census National Analytical Report (Ghana Statistical Service, 2013) were also assessed to identify trends that could be relevant to the study.

3. Results

3.1. Rainfall

The rainfall data for the study areas from 1982 to 2012 from Ghana Meteorological Authority (GMA) were analysed to determine if the amount of rainfall differs across Ramsar Sites and also, if there have been significant changes that could affect the health of the wetlands. The rainfall data for the cities in which the wetlands are located were used but for Muni-Pomadze, Winneba, which did not have GMA station, Saltpond GMA data were used because it was the closest station to Winneba. Analysis of variance (ANOVA) statistics presented in the supplementary material (Table S1) indicated that the mean annual rainfall for Accra and Tema from 1985 to 2012 were not statistically different but Saltpond recorded higher mean annual rainfall compared to the other two locations. In addition, Mann Kendall Trend Test analysis was performed to examine the rainfall pattern in the study areas from 1982 to 2012 but the result provided in the supplementary material showed no trend (Table S2).

3.2. Population

Population data for the three cities, Accra, Tema and Winneba were obtained from the Ghana Statistical Service (2013). The population of the three cities has steadily increased over the years from 1984 to 2010, when the last census was carried out. Winneba had a population of 27, 105 in 1984 and 57,015 in 2010. Accra Metropolis population was 969, 195 in 1984 and 2,070,463 in 2010. Tema had a population of 100,052 in 1984 and 139,784 in 2010. The population of Accra and Winneba doubled from 1984 to 2010 and that of Tema also increased significantly.

3.3. Landscape Deviation Degree (LDD) of wetlands

The overall accuracy for the Land cover classification for the study sites were all above 80 percent with the exception of Sakumo II Ramsar Site (2017) and Muni-Pomadze Ramsar Site (2002) which were 79.0 and 77.5 percent respectively. The results of landscape deviation degree (LDD) analysis of the wetlands are provided in Table 1. In the Densu Delta Ramsar Site, saltpans areas which form part of the water class were considered as artificial surfaces and in Sakumo II Ramsar Site, portions of the lagoon that were covered by Pistia plants were also captured as thicket. These classification errors affected the accuracy. Sakumo II Ramsar Site had the lowest LDD throughout the three time points and Densu Delta had the highest LDD in 1985 and 2017 but had the same LDD as Muni-Pomade Ramsar Site in 2002. The deviation degree for all the three wetlands increased progressively over the study period.

3.4. Wetland landscape fragmentation

Out of the 23 components from the PCA, 6 components had Eigen value of 1 or more and were retained. The 6 retained components explained 85.56 percent variation in the dataset. In all, eleven (11) class

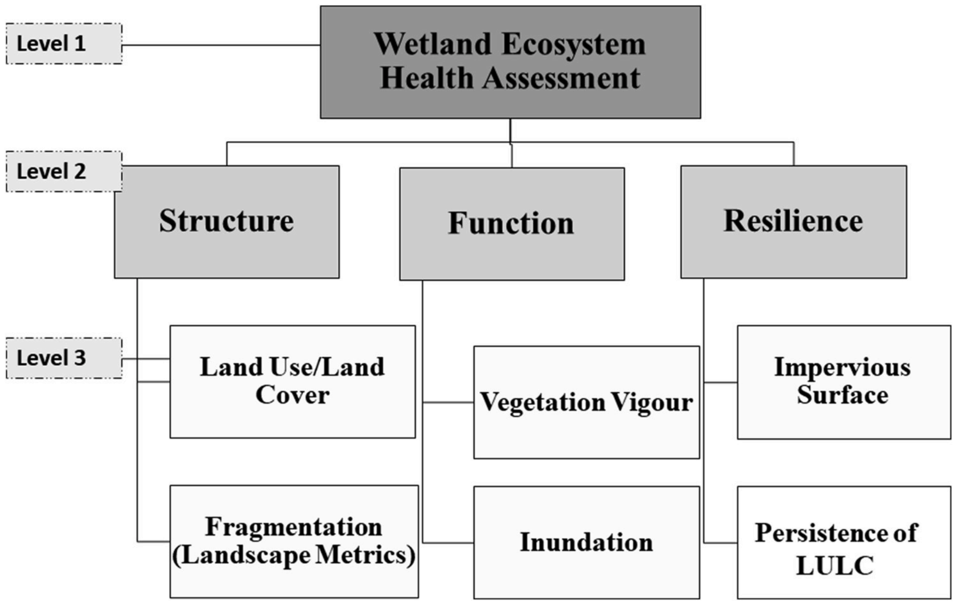

Fig. 2. Analytic hierarchy process for wetland ecosystem health assessment.

Table 1
Wetland ecosystem health sub-indicator values (%).

	Densu Delta			Sakumo II			Muni-Pomadze		
	1985	2002	2017	1985	2002	2017	1985	2002	2017
LDD	39.09	47.01	71.13	10.02	18.07	39.03	33.17	46.99	61.44
Built-up	25.07	28.01	50.63	10.02	16.39	33.98	11.45	16.66	26.29
Persistence	84.00	82.68	53.59	84.00	81.52	46.78	84.00	72.38	55.41
NDVI	54.62	45.91	30.23	80.13	59.88	65.33	83.81	62.00	65.10
NDWI	8.70	16.16	17.10	3.99	3.85	4.59	1.39	1.66	4.59

indices were selected based on the criteria. The values of the fragmentation indices are provided in the supplementary material (Tables S3–S5). The definition of the indices from Mcgarigal (2015), are summarized below:

- Largest Patch Index (LPI) quantifies the percentage of total landscape area occupied by the largest patch. It describes dominance of a particular class in the landscape.
- Core Area Percentage of Landscape (CPLAND) is defined as the sum of all core areas of each patch of a class expressed as a percentage of the total landscape.
- Total Edge (TE) is the sum of all edge segments of a particular patch type (class).
- Landscape Division Index (DIVISION) refers to the probability that two randomly selected pixels in a landscape are not found in the same patch of the corresponding patch type.
- Splitting Index (SPLIT) is defined as number of patches with a constant patch size when the corresponding patch type is subdivided into S patches, where S is the value of the split.
- Mean Edge Contrast (ECON_MN) at the class level, it quantifies the average edge contrast for all patches in a landscape.
- Edge Density (ED) quantifies the sum of all edge segments of a particular patch type expressed as a percentage of the total area of the landscape.
- Contrast-Weighted Edge Density (CWED) standardizes edge to a per unit area basis to allow for comparison among other landscapes with varying sizes.
- Patch Density (PD) is the number of patches of a particular patch standardize by the total area of the landscape.
- Patch Fractal Dimension (FRAC_MN) is a shape metric that quantifies the complexities of patch shape at the patch, class or landscape level.
- Similarity index (SIMI_MN) is the sum of particular patch type in a specified radius divided by the number of patch type.

3.5. *Ecosystem productivity*

NDVI maps of the three wetlands are provided in Fig. 3 and NDWI maps are presented in Fig. 4. There were some disparities in the values which could be attributed to the differences in the sensors used in acquiring the images in different years. The maps were reclassified to quantify the extent of vegetation and water expressed as percentage of the total area of the wetlands (see Table 1). NDVI value of 0.2 and above were classified as vegetation and positive NDWI values were classified as water.

Areas of high NDVI values at Densu Delta significantly reduced progressively over the study period. In Sakumo II and Muni-Pomadze, areas of high NDVI values reduced in 2002 and increased in 2017. The increase observed in 2017 at Sakumo II could be largely attributed to the taken over of the Sakumo lagoon by Pistia plants. The gains made in 2017 at Muni-Pomadze could be as a result of plantation activities by the Forest Service Division and Wildlife Division.

Areas of high NDWI values at Densu Delta significantly increased over the study period. Construction of saltpans accounted for the increase. Part of the wetland has been given out for commercial salt production. Sakumo II and Muni-Pomadze Ramsar sites experienced similar trend, areas of high NDWI values reduced in 2002 and increased in 2017. The increase seen in 2017 in Sakumo II could be attributed to sea erosion. In the previous years the shoreline was found outside the boundary of the Ramsar Site but in 2017 the shoreline was within the

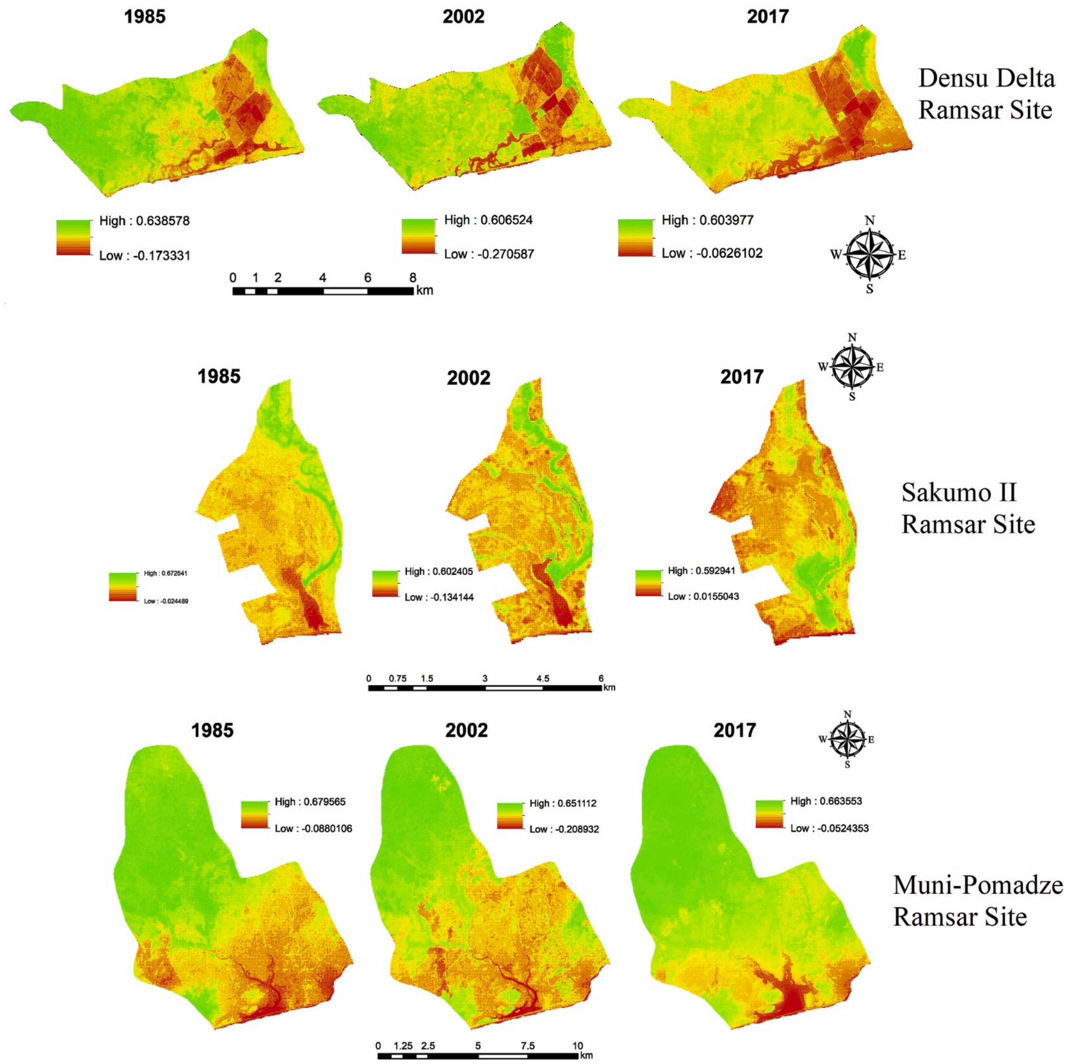

Fig. 3. NDVI maps of the wetlands for 1985, 2002 and 2017.

boundary of the site. The increase observed in 2017 in Muni-Pomadze could be attributed to a flooding incident that occurred in 2016 which expanded the surface area of the lagoon. In addition, saltpans construction could also partly account for it.

3.6. Wetland ecosystem health assessment

In this study, wetland ecosystem health was assessed using three indicators; structure, function and resilience. The sub-indicators for structure were LULC change and fragmentation. LDD (Table 1) was the measured variable for LULC. Fragmentation was assessed using the eleven landscape class metrics that loaded strongly in the PCA. Each index was given equal share of the weight assigned to fragmentation from the AHP. The sub-indicators for function were NDVI and NDWI (Table 1). Impervious surface and persistence of LULC were sub-indicators for resilience. The area of impervious surface and persistence of LULC are presented in Table 1. The change for 1985 was not measured in this study. A change value of 16 percent reported by Hu et al. (2017) for wetlands in Africa was used. The state of the wetlands in 1985 was considered healthy to which the state of the wetlands in the other years were compared.

Among the sub-indicators, LULC represented by LDD and impervious surface were considered negative. This implies that an increase in their values indicates deterioration of the wetland ecosystem. NDVI, NDWI and persistence were regarded as positive sub-indicators indicating that an increase in their values improve the health of wetland ecosystem. With regards to fragmentation, LPI, CPLAND and SIMI_MN were positive and the remaining eight indices were negative. From the AHP, structure was assigned the greatest weight among the indicators and function had the least weight. Table 2 presents the weight of the wetland ecosystem health indicators evaluated using AHP method.

Table 3 provides the health status of the three Ramsar Sites in 2002 and 2017 as compared to 1985. The values range from 0, being the worst state and 1, the healthiest state. The health status value in 1985 was regarded as 1. From the evaluation results, the health of all the wetlands deteriorated with time. In terms of magnitude, in 2002, the Densu Delta wetland experienced the least decline from 1985 state among the three wetlands and the Sakumo II wetland recorded the highest deterioration. Contrary to 2002, in 2017 the health of the Densu Delta wetland experienced the worst deterioration whereas the Sakumo II wetland recorded the least decline.

4. Discussion

The health of the wetland ecosystems was assessed using structure, function and resilience indicators. AHP method was used to assign weight to the indicators. From the AHP results provided in Table 2, ecosystem structure received the highest weight followed by resilience. Ecosystem function was assigned the lowest weight. Bofu et al. (2016), also assigned a higher weight to ecosystem structure than function

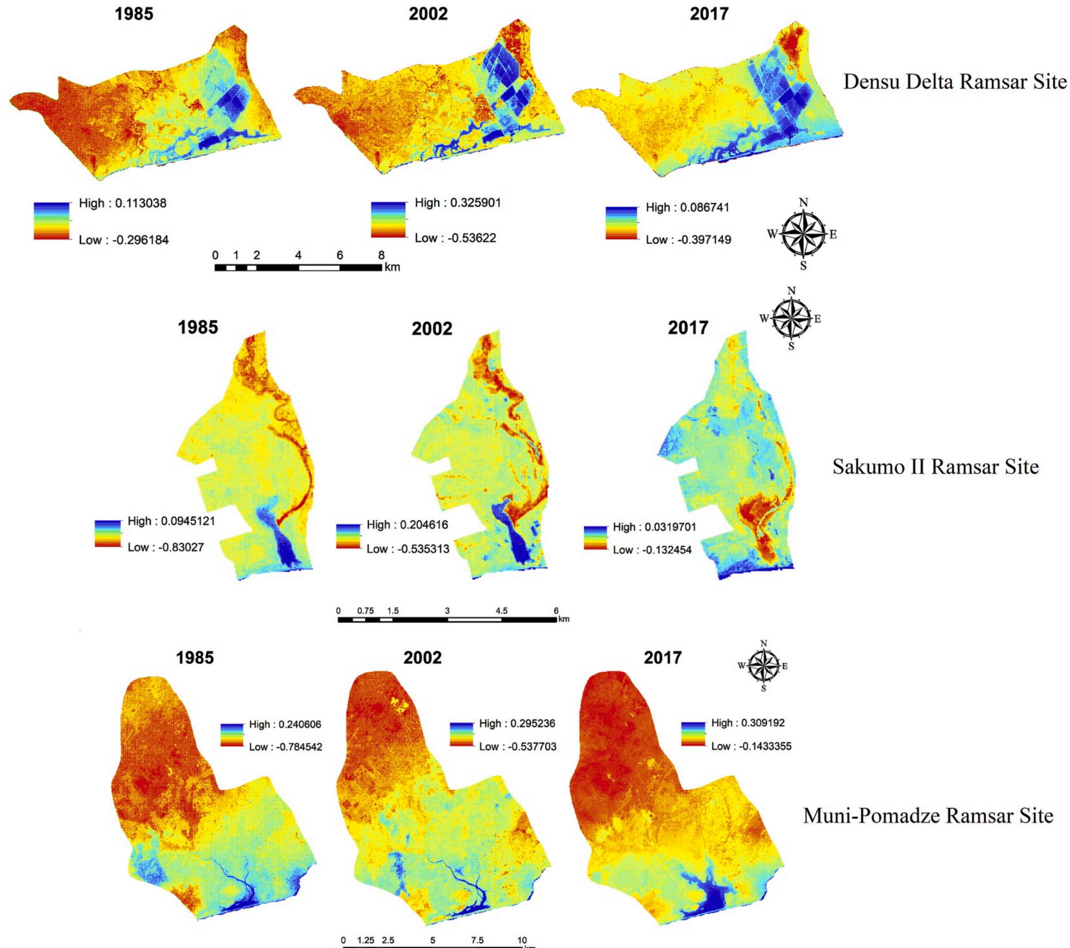

Fig. 4. NDWI maps of the wetlands for 1985, 2002 and 2017.

Table 2
Weights of wetland ecosystem health indicators.

Goal	Indicator	Weight	Sub-indicator	Relative Weight	Overall Weight
Wetland Ecosystem Health	Structure	0.381	LULC	0.833	0.281
			Fragmentation	0.167	0.099
	Function	0.246	NDVI	0.875	0.156
			NDWI	0.125	0.090
	Resilience	0.374	Impervious Surface	0.800	0.263
			Persistence	0.200	0.111

Table 3
Ecosystem health status of the wetlands.

Ramsar Site	Year		Change	
	2002	2017	1985–2002	2002–2017
Densu Delta	0.882	0.419	−0.118	−0.463
Sakumo II	0.620	0.358	−0.380	−0.262
Muni-Pomadze	0.730	0.438	−0.270	−0.291

however, resilience was assigned the highest weight in their work unlike in this study. The differences may be attributed to the different variables considered under each ecosystem indicator and the method used in weighting the indicators. Ecosystem structure is very important because the other two indicators depend on it. Any activity that alters the composition and organization of an ecosystem directly affect the functioning and the stability (resilience). The breaking up of patches and changes in the pattern of patch types affect the distribution and exchange of energy and matter which are key functions of an ecosystem.

The findings of this study (Table 3) indicate that the health of the wetlands has deteriorated in recent times compared to the health of the wetlands in 1985. The primary cause of the deterioration was the expansion of the built environment. It is also evident in the LDD values recorded for the wetlands in 2002 and 2017. LDD quantifies the extent at which human activities have changed the natural landscape (Chunxiao et al., 2008). This is a clear indication of increasing anthropogenic activities in the wetlands. Built-up expansion is as a result of urbanization and this eventually leads to the replacement of vegetated surfaces with impervious surfaces (Shuster et al., 2005). This explains the reduction in areas covered by vegetation in 2002 and 2017 as indicated by the NDVI maps (Fig. 3). Expansion of impervious surfaces substantially reduces the infiltration capacity of landscapes which increases runoff (Hsu et al., 2000). This eventually leads to flooding in the affected areas. Residential areas close to Densu Delta and Sakumo II wetlands are known to be flood prone areas. Expansion of built environment also pollutes the wetlands through the discharge of domestic effluents and industrial contaminants into the waterbodies. For instance, the Sakumo lagoon has been invaded by Pistia plants because of high nutrient levels.

Fragmentation is regarded as one of the important drivers of biodiversity loss (Cosentino and Schooley, 2018). It decreases the size and increases the isolation of habitats and population (Lienert and Fischer, 2003). The fragmentation results show that the wetlands are becoming more fragmented with time. Out of the eleven indices, eight of them were indices that described disaggregation of the wetlands and the remaining three were aggregation indices. The values for the disaggregation indices for natural classes increased with time whilst the aggregation indices decreased. Fragmentation of natural habitats is an indication of urbanization (Liu et al., 2016) which leads to the expansion of artificial surfaces. This explains why the values for aggregation classes for built-up/bareland increased. In effect, whilst the natural classes were being broken into smaller patches and isolated, built-up/bareland was expanding.

Densu Delta and Muni-Pomadze Ramsar sites had some commercial salt production activities on-going during the study period. Saltpans were not identified in 1985 and 2002 at the Muni-Pomadze wetland but were present in 2017. Area covered by saltpans in Densu Delta became larger in 2017 compare to 2002. This accounts for the increase in water areas of positive NDWI values in 2002 for Densu Delta and 2017 for both Muni-Pomadze and Densu Delta. This is an indication of increasing salt production activities in recent times in the wetlands. Gbogbo (2009), found out that population densities of water birds feeding exclusively on benthic macroinvertebrates were significantly lower in the salt production wetlands than wetlands which had no saltpans. This means that salt production affects the ecosystem functions of wetlands.

Agricultural activities had significant contribution to the deterioration of the Muni-Pomadze Ramsar Site in 2002 and 2017. Even though in both 2002 and 2017, the percentage of built-up area did not increase substantially like what happened in the other two wetlands, the LDD values recorded were close to the values recorded in the other two wetlands. This underscores the fact that some other human activities also contributed to the high LDD. One major human activity in the Muni-Pomadze Ramsar Site is farming and it is the main livelihood activity for the rural communities around the wetland. Among all the anthropogenic activities carried out in the Ramsar Site, Wuver & Attuquayefio (2006), reported that farming, wildfires and hunting posed significant threats to the wetland ecosystem.

Currently, about 55 percent of the world's population lives in urban areas and it is predicted that the shift from rural to a predominantly urban population will continue with close to 90 percent of this increase occurring in Africa and Asia (United Nations Department of Economic and Social Affairs Population Division, 2019). The three study areas experienced rapid human population growth from 1984 to 2010. The population of Accra and Winneba almost doubled between 2002 and 2010 (Ghana Statistical Service, 2013). The rapid growth of human population reflected in LDD and built-up areas. Both LDD and built-up areas also nearly doubled between 2002 and 2010. Expansion of built environment increased fragmentation of natural LULC classes of the wetlands and reduced the vegetation cover. It implies that the underlying factor that is driving the degradation of urban wetlands is increase in urban population. It can be predicted that the ecosystem health of coastal urban wetlands will continue to deteriorate since it is projected that by 2050, about 68 percent of the world population will live in urban areas (United Nations Department of Economic and Social Affairs Population Division, 2019).

Notwithstanding the numerous benefits urban dwellers obtain from wetlands, their activities continue to degrade these essential ecosystems. The wetlands considered in this study are Ramsar Sites and are designated as protected areas by law. Ordinarily, these wetlands are not supposed to encounter threats such as built-up encroachment, commercial salt production, farming, wildfires and pollution. It shows that even if people know the value of wetlands, they may flout regulations if their livelihoods essentially depend on it. Three interventions are critical in restoring urban wetlands. People need to be educated on the importance of wetlands in order to change their minds from the notion that wetlands are waste lands. Education remains an integral part of restoration strategies of any natural habitats such as wetlands, which have other competing uses and generate socio-economic benefits. The second intervention strategy is enforcement of laws. Ghana became a signatory to the Ramsar Convention on 22nd June 1988 and subsequently designated 6 sites as wetlands of international importance in 1992. The Forestry Commission is mandated to protect the Ramsar Sites in collaboration with the law enforcement agencies and other relevant institutions (Water Resources Commission, Land Use and Spatial Planning Authority). Until law enforcement agencies begin to sternly punish those whose activities are inimical to the ecosystem health of the wetlands, no restoration effort will be successful. The third intervention is for policy makers and local government authorities to create alternative livelihood opportunities for riparian communities to reduce dependency on the wetlands (Armah et al., 2009, 2010).

4.1. Study limitations

Even though physicochemical parameters are important in evaluating ecosystem health of wetlands, they were not considered in this study. Physicochemical parameters could not be extracted from the Landsat satellite images used in this study. Besides, the time intervals between the study years were not equal. Although Landsat satellite images have been available since 1972, some of the images did not meet the criteria set for this study. Distorted images and images with clouds covering the study areas were not considered. High resolution satellite images would have improved the accuracy of the land cover classification however, such images of the study area were not available for all the 3 years considered in this study. The available high resolution images were captured recently.

5. Conclusion

The ecosystem health of Densu Delta, Sakumo II and Muni-Pomadze Ramsar Sites was assessed using structure, function and resilience ecosystem indicators. From the AHP, ecosystem structure received the highest weight followed by resilience. Ecosystem function was assigned the least weight. The findings of the study indicate that ecosystem health of the wetlands deteriorated in 2002 and 2017 compared to the health of the wetlands in 1985. The extent of deterioration in 2002 was far less than that of 2017 for the Densu Delta and Muni-Pomadze wetlands however, Sakumo II Ramsar Site experienced the worse deterioration in 2002. In terms of magnitude, in 2002, the Densu Delta wetland experienced the least decline (11.8%) from 1985 state among the three wetlands and Sakumo II recorded the highest deterioration (38%). Contrary to 2002, in 2017 the health of Densu Delta experienced the worse deterioration (46.3%) whereas Sakumo II recorded the least decline (26.2%). Ecosystem health of Muni-Pomadze Ramsar Site deteriorated at a similar magnitude, 27 percent and 29.1 percent in 2002 and 2017 respectively.

The underlying factor for the degradation of the wetlands is urbanization largely due to increase in human population which led to the expansion of built-up areas in the wetlands, fragmentation of natural LULC classes and reduction of vegetation cover. These explain the higher values observed in LDD for 2002 and 2017 for all the wetlands. Higher LDD is an indication of growing interference of human activities in the wetlands. This implies that without any new urban wetland protection interventions, the ecosystem health of the wetlands will continue to deteriorate since it is projected that the shift of human population from rural to urban areas will intensify in the coming years especially in developing countries like Ghana. Interventions that seek to protect coastal urban wetlands should include ways to minimise influx of people into urban areas. In addition, measures should be put in place to efficiently manage the limited urban residential lands. Multiple land use planning should be integrated into urban planning policies and byelaws. The Forestry Commission, Water Resources Commission, Land Use and Spatial Planning Authority and the law enforcement agencies should endeavour to enforce the laws that protect wetlands in Ghana to ensure the success of restoration efforts.

Declaration of competing interest

The authors declare that they have no known conflicts of interest to disclose.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2020.105226.

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