



# The influence of anthropogenic activities on wetland integrity dynamics: a case study of the Rwampara wetland in Rwanda

Richard Mind'je<sup>1,2,3</sup> · Mapendo Mindje<sup>4</sup> · Patient Mindje Kayumba<sup>1,2,3</sup>

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## Abstract

Wetlands are prolific ecosystems in the world, and thus, information related to their change is pertinent for ecological monitoring processes. This study aims at informing anthropogenic activities and their effects on the health of Rwampara wetland distinctive with climate change effects. We assumed that these activities have led to a significant change in land use and land cover (LULC) which accelerated the disturbance of the wetland with corresponding changes to associated biological communities. Results revealed a change of Rwampara wetland over the past eighteen years where a remarkable decline in wetland area (from 58.6 to 20.7%) coincided with an increase in built-up areas (from 9.06 to 76.16%). The degradation of the area is attributed to human activities such as agriculture and waste dumping mostly practiced in and around the area. This degradation has also been indicated by the presence of plant bio-indicators (*Datura stramonium* and *Tithonia diversifolia*), animal species especially anurans (*Phrynobatrachus natalensis*, *Kassina senegalensis*, *Ptychadena* spp., *Hyperolius kivuensis*, *H. viridiflavus*, etc.), and Odonate species known to be excellent indicators inhabiting degraded ecosystems. Moreover, as to distinguish the assessed impacts of anthropogenic activities from those of climate change, the patterns of ecological structure unveiled a decline in the vegetation condition and water amounts as a result of the increasing temperature in the area. To rehabilitate and protect the integrity of the wetland, buffer zones creation and public awareness on the functions and benefits of wetland resources are highly recommended.

**Keywords** Anthropogenic activities · Bioindicators · Rwampara · Rwanda · Wetland degradation

## Introduction

Wetlands are one of the most prolific ecosystems around the world (Nora and Niels 2020; Tung and Dap 2020). They provide water, act as hubs for biodiversity, and are the

primary productivity for which numerous species of animals and plants depend for survival (Mitsch et al. 2015). Concerning the wetlands' convention (RAMSAR), researchers (Davidson et al. 2018; Xu et al. 2019) have demonstrated that approximately 87% of global wetlands (in regions with data availability) have degraded mostly in the 20th and early twenty-first centuries. Most threats are reported to emanate from anthropogenic activities that include crop and livestock farming, industrial actions, human settlements, irresponsible tourism, drainage structures, siltation, mining, and infrastructure development which have made them extremely vulnerable to changes in land use and management (Xu et al. 2019; Jamal and Ahmad 2020). Additionally, the accelerated level of the changing climate has added to the intricacy of preserving the functioning of wetlands (Gallant 2015; Ndayisaba et al. 2017). Meanwhile, and often as a consequence of anthropogenically derived changes, species associated with wetlands are facing increasing extinction risks which in turn makes conservation a more difficult task (Orimoloye et al. 2020).

✉ Richard Mind'je  
mindjerichard@gmail.com

<sup>1</sup> State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, 818 South Beijing Road, Urumqi 830011, Xinjiang, China

<sup>2</sup> University of Chinese Academy of Sciences, Beijing 100039, China

<sup>3</sup> Faculty of Environmental Sciences, University of Lay Adventists of Kigali (UNILAK), P.O. Box 6392, Kigali, Rwanda

<sup>4</sup> College of Agriculture, Animal Sciences and Veterinary Medicine, Center of Excellence in Biodiversity and Natural Resource Management, University of Rwanda, P.O. Box: 117, Huye, Rwanda

In most African countries, typical motives that intensify wetlands' stress are still the growth in population, poverty level, and economic strain (Phethi and Gumbo 2019; Xu et al. 2019). Even if numerous natural wetlands are remaining in Africa in comparison to Northern America or some parts of Europe, many of these wetlands are facing remarkable pressure (Gardner and Finlayson 2018). Hence, to support the management of wetlands, information from different scales (global, regional, and national) is necessary to lead policymakers in the planning and monitoring processes (Finlayson et al. 2017).

At the same time, advancements in Earth Observation coupled with analyses on the ground have given opportunities for the identification, description, and assessment of wetland status to facilitate its management (Rebelo et al. 2018; Wulder et al. 2018). Regrettably, the most important gaps exist in wetland inventory, inconsistencies in methods, attempts to evaluate the condition and extent of wetland deterioration, and decline through evaluations of the degree from uncertain assertions (Zuo et al. 2013; Gardner et al. 2015). With the lack of good and reliable data, the ongoing wetlands loss is of great concern to the Ramsar Convention through the Millennium Ecosystem Assessment that promotes the need to make available comprehensive information based on the status and trends of wetlands, their values, and the major drivers of change (Reis et al. 2017).

In Rwanda, approximately 14.9% of the surface area is covered by wetlands, of which 6.3% are marshes while 8.6% are lakes, rivers, and permanent or seasonal freshwater pools, such as Nyabarongo, Akagera, and Akanyaru (RoR 2006). In the city of Kigali, approximately 50% of the wetlands have been transformed by human activities such as tenure for agriculture, which is the predominant activity carried out in these wetlands (Beuel et al. 2016; Rwanyiziri et al. 2020). Among these wetlands, Rwampara has lost its integrity due to the adjacent cropland and inappropriate waste disposal from Gikondo Valley, which creates effluences along the channel moving directly into the wetland (Rajashekar et al. 2019; Baffoe et al. 2020). Most communities in Rwanda live with a limited understanding of strategies to conserve wetlands and the reason to protect them (Nsengimana et al. 2017). Various factors jeopardize these ecological systems and disrupt their natural integrity. Thus, unless serious conservation initiatives and policies are put in place, socio-economic activities will continue putting pressure on wetlands and the environment at large (Newton et al. 2020). In recent years, the Rwandan government has been fully aware of the significance of problems ensuing from damage to natural ecosystems. For this, the ministry of environment and natural resources in Rwanda argued that illegal activities in the wetland should be promptly restricted with strong policy enforcement and punishment regarding polluters. Unfortunately, Rwanda does not have a specified

policy for wetlands that preserves them from deleterious activities causing the loss of their integrity. These are currently being managed under the Environmental Organic Law and the Land Law only (TSINDA 2011; Heermans 2015). So, information on wetlands protection and conservation is pertinent for the promotion and normal functionality of wetlands.

Research that involves biological and acoustic assessment have been carried out globally to map the distribution of species and elucidate the ecological roles of species, such as the indication of changes in the health of wetlands (Pellet and Schmidt 2005; Frommolt and Tauchert 2014; Annich 2017; Frommolt 2017; Cameron et al. 2020). However, data on biological indicators such as anurans is still lacking to confirm the status of wetlands in Rwanda. This affects the scientifically-based decision-making on the effective management and conservation of wetlands in Rwanda. In Rwanda where the Rwampara wetland is located, only very few studies (Ndomba et al. 2010; Nabahungu and Visser 2011; Nabahungu 2012; Sinsch et al. 2012; Ndayisaba et al. 2017; Mindje et al. 2020; Rwanyiziri et al. 2020) have been conducted, with poor attention on the consideration of geo-spatial information using remote sensing (RS) techniques. For the detection of real wetland landscape change, RS holds great promise in Spatio-temporal data manipulation and visualization. This study serves as complementary work to the few existing studies within the same scope, in the provision of information on the status of wetlands. The results of this study aim to guide decisions on the management and conservation of wetlands in Rwanda. The objectives of this study are: (1) to compare the current and past LULC trends and their role on the natural change of the Rwampara wetland; (2) to analyze the status and the extent to which the Rwampara wetland has been degraded; and (3) to identify available biological indicators indicating Rwampara wetland degradation. We hypothesized that increased human activities have led to a significant change in LULC, which consequently have accelerated the disturbance of the Rwampara wetland with corresponding changes to associated biological communities.

## Materials and methods

### Site description

Rwampara wetland (Fig. 1) is situated in Kigali city of Rwanda, specifically in the central heart of three sectors namely Kigarama (in Kicukiro district), Nyarugenge, and Nyamirambo (in Nyarugenge district) (Jaganyi 2018). Referring to the lowest administrative unit in Rwanda, the wetland is surrounded by Rwampara, Bwerankoli, Nyarurama, Mumena, Agatare, and Kiyovu cells. This area is also

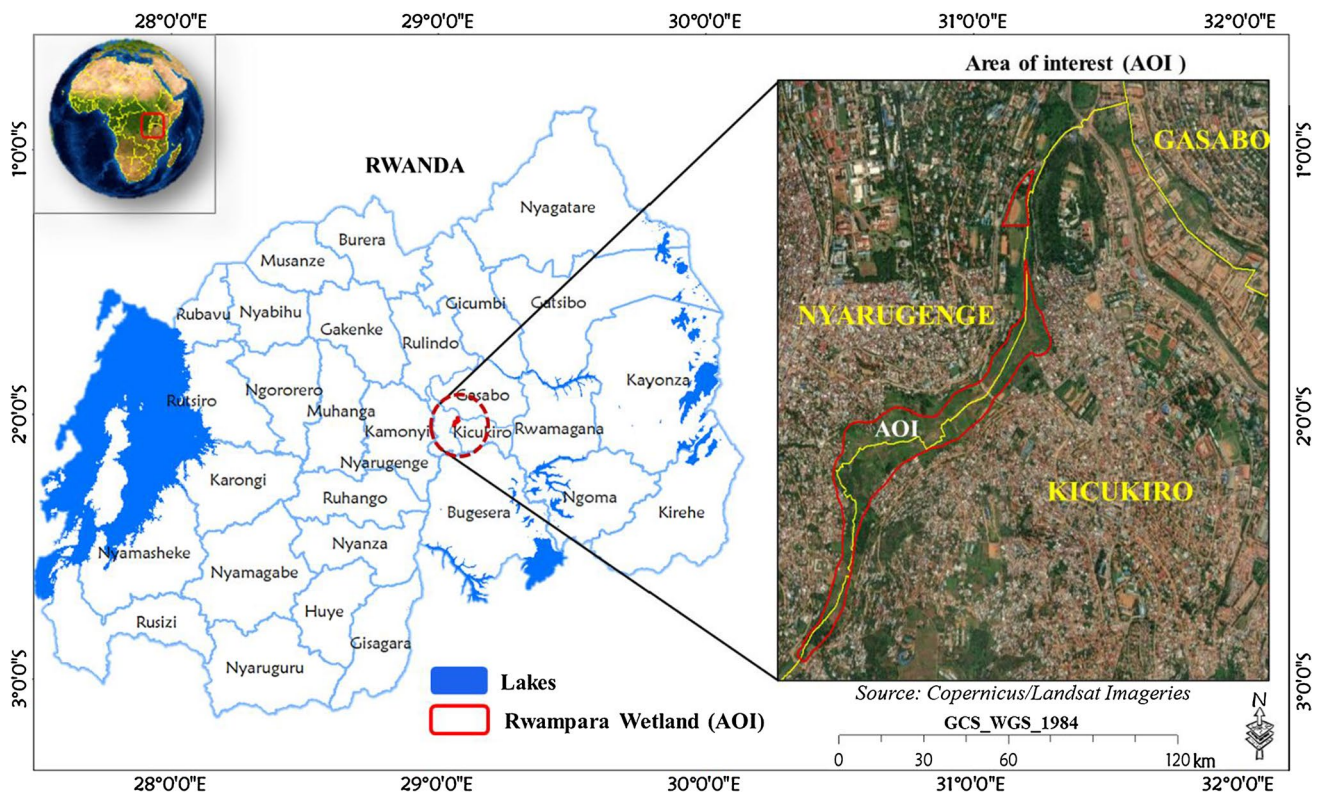


Fig. 1 Study area location

enclosed by some well-designed and constructed key distributor roads, households, and different business premises. Moreover, it is generally characterized by infrastructures, public services, and few organized systems for pedestrian circulation, and drainage (Perez-Molina et al. 2016). The site is partially dominated by agriculture and hosts a football ground. Given the terrain of Rwampara, sediments, storm-water flows, and flooding was reported to occur during the rainy seasons within the flood plain of river Rwampara (Rwanyiziri et al. 2020). The study area has a temperate tropical highland climate and experiences a bimodal pattern of rainfall, mainly driven by the progression of the Inter-Tropical Convergence Zone (ITCZ). Hence, the maximum rainfall seasons are remarkable in different months: March, April, and May (MAM) and then again in September, October, November, and December (SOND). Typical daily temperature ranges between 12 °C (54°F) and 28 °C (81°F) with little disparity throughout the year. The area is made of different vegetation coverage including shrubs, sparse trees, and grasses. Furthermore, the communities of plants include few natural papyrus canes in the regions that are permanently flooded, exotic plants (mesquite), water hyacinth spread over the surface of the water, and scattered herbaceous plants. As a highly disturbed ecosystem, Rwampara wetland has lost its regulating service as it currently fails to modulate flood occurrence by provisionally accumulating

water and gradually releasing stormwater during rainy seasons. Therefore, owing to the lack of management in stormwater and infrastructures to lodge peak runoff from upstream areas (Kiyovu, Nyamirambo, and Gikondo), Rwampara suffers extreme flash flood events during the rainy season (Rwanyiziri et al. 2020).

**Data and approaches**

The data used in this study were subdivided into different approaches; namely the quantitative, mapping, bio-acoustics, and visual observation based on the set objectives. To gain opinions from the community around the wetland, the quantitative approach was used to quantify data from the distributed questionnaires and transformed into useable statistics. The mapping approach was used to produce the periodic maps concerning the LULC for the years 2000 and 2018 to detect the changes of the wetland area over a certain period. The researchers relied on both observations, as well as biological and acoustics assessment in identifying the current status of the area based on the fauna and flora ecosystems. Finally, observation of some biophysical indicators (especially invasive plant species) and the current conditions (natural landscape) of the Rwampara wetland were conducted while assessing its status quo.

## Quantitative approach

With this approach, we were mostly interested in the respondent's demographic characteristics, human activities undertaken in and around the ecosystem, and the respondent's period of residence in the area. The targeted population involved the community and local leaders within the surrounding villages that border the wetland. Table 1 illustrates the number of people from the surrounding villages and the calculated sample size using the equation by Yamane (1967):

$$n = \frac{N}{1 + N(e)^2}, \quad (1)$$

where  $n$  represents the sample size;  $N$  represents the total Population;  $e$  represents the level of precision:  $e = 10\%$  margin of error,

$$n = \frac{12,325}{1 + 12,325(0.1)^2} = 99.91 \sim 100 \text{ people.}$$

Note: these people were chosen via a snowball technique of sampling, which is a non-probability sampling technique in which the samples have traits that are difficult to find as people were not that easy to recruit.

Besides the socio-demographic characteristics of the respondents, the questions used in this study are provided below:

(a) How long have you stayed in this area?

**Table 1** Sample size per village touching the Rwampara Wetland Source: (NISR 2012)

Villages	Total population	Sample size
Agatare	549	4
Akarekare	715	6
Amahoro	870	7
Amajyambere	591	5
Bwiza	1,229	10
Gacaca	910	8
Imena	645	5
Inyambo	598	5
Kiberinka	678	5
Kiyovu	609	5
Meraneza	439	4
Rugunga	638	5
Rwampara 1	1,396	11
Rwampara 2	678	5
Uburezi	415	3
Umuganda	936	9
Umurava	428	3
Total	12,325	100

(b) Tick in the appropriate box based on the activities undertaken in and around the Rwampara wetland using the following scale (mostly undertaken—moderately undertaken and least undertaken).

## Mapping approach

Concerning the first objective of the study, Rwampara was extracted from multi-spectral Landsat satellite imageries (Table 2) of Kigali city at 30 m spatial resolution acquired from the United States Geological Survey (USGS) Earth Explorer. To assess the spatial distribution in LULC dynamic, these imageries were processed and classified using the Maximum Likelihood classification (MLC) algorithm in ArcGIS 10.8 software (Mind'je et al. 2019; Nambajimana et al. 2019). Due to the accelerated probabilities of errors existing in digital imagery, accuracy assessment has become a vital process (Rwanga and Ndambuki 2017). Therefore, the accuracy of the classified LULC maps was also assessed in this study. For the year 2000, 123 ground truth points of data from all land-use types were sampled with 111 points as true tested values from an original source (online GIS-based higher-quality world imagery, version 2 tiling schemes), whereas 82 random points were sampled with a total ground correct samples data of 76 points for the year 2018. These points were all used to refine, verify, and validate the generated LULCs using the overall accuracy and Kappa statistical index given by Eqs. 2 and 3, respectively,

$$O.A = \frac{X}{X'} \times 100, \quad (2)$$

$$K = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_i + *x_{+1})}{N^2 - \sum_{i=1}^r (x_i + *x_{+1})}, \quad (3)$$

where, O.A stands from overall accuracy,  $X$  is the total number of correct samples,  $X'$  is the total number of samples,  $K$  is the Kappa index,  $r$  is the the number of rows in the matrix,  $x_{ii}$  is the number of observations in row and column  $i$  while  $x_i +$  and  $x + 1$  are the marginal totals of row  $i$  and column  $i$ , respectively, and  $N$  is the the total number of observations.

Further analyses were done to distinguish the effects of climatic change and those of human activities. Several studies (Erwin 2009; Hopkinson et al. 2020; Rokaya et al. 2020) stipulate that climate change, particularly the warming

**Table 2** Details of the Landsat data used in this study

Acquired date	Landsat number	Sensor	Path/row
08 Jul 2000	7	ETM+	172/61
20 Jul 2018	8	OLI/TIRS	172/61

temperature influence the patterns of ecological structure and attributes, including the vegetation condition and water amounts. To confirm this, temperature data were acquired from the Rwandan Meteorological Agency collected at the closest functioning meteorological station to the study area (Kigali airport station) for the trend analysis and evaluate the change in temperature over the past eighteen years (2000–2018). This was then followed by assessing the patterns of ecological structure of the wetland. The Vegetation Condition Index (VCI) and the Normalized Difference Water Index (NDWI) derived from the Landsat images, were used as effective indicators for the wetland's vegetation and water level conditions, respectively over some time (Tian et al. 2016; Kayumba et al. 2021). In percentage, VCI provides a reflection of the current vegetation condition compared to the historical trends using the observed values, whereby higher and lower values specify good and bad vegetation conditions, respectively. Furthermore, NDWI uses the green and the NIR bands; and it ranges from -1 to 1, whereby higher and lower values correspond to high and low water amounts, respectively (McFeeters 1996). Water stress is observed with the decrease in NDWI. These indices were also calculated in ArcGIS 10.8 using the below equations:

$$\text{VCI} = \left[ \frac{\text{NDVI}_j - \text{NDVI}_{\min}}{\text{NDVI}_{\max} - \text{NDVI}_{\min}} \right] \times 100, \quad (4)$$

$$\text{NDWI} = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}}, \quad (5)$$

where  $\text{NDVI}_j$  represents the year to be analyzed,  $\text{NDVI}_{\max, \min}$  denotes the multiyear maximum and minimum NDVI. Note that NDVI was computed by a ratio between the difference and sum of reflectance from green and NIR bands of remote sensing images, respectively.

#### Biological and Acoustics approach (Bioacoustics assessment)

The study adopted this approach in the identification of biological indicators for wetland quality change (third objective). The acoustic approach used vocalization produced by the males calling anuran species, whose advertisement calls were recorded using electronic recording equipment (LG Q6-Android smartphone) shortly after sunset (i.e., 6 p.m., 7 p.m., 8 p.m., and 9 p.m.). Acoustic surveys were digitally recorded and assessed with Raven Pro 1.6.1 (Center for Conservation Bioacoustics). This software was used to describe and sort signals according to their frequency, duration, intensity, and other related parameters through vocalization structure (Channing et al. 2016; Rocha et al. 2017; Moreno-Gómez et al. 2019). This allowed for anuran identification based on previous records of identified specimens and call

descriptions in literature (Du Preez 2015). The frequency of acoustic data was most effective in identifying the types of species recorded. The vocalization structures were illustrated by measuring call duration (ms), pulses per call, pulse rate (Hz), pulse duration (ms), interpulse interval (ms), and dominant frequency (Hz) (Sinsch et al. 2012; Mindje et al. 2020).

#### Specimen identification

In accordance with Raick et al. (2020), faunal bio-indicators (anurans and Odonate) were visually detected during three consecutive days of survey in a rainy period (from 3 h to 20 h pm) complemented by a further night for anurans' bioacoustics assessment (18 h–21 h). Collected anuran specimens were identified by morphological corroboration coupled with males' advertisement call structure identification based on literature (Orban et al. 2017; Mindje et al. 2020). For anurans that call exclusively under water, such as *Xenopus* species, whose call recording can be performed using a hydrophone which was absent during this study, the morphology was mostly implemented to identify the species. Since *Xenopus* species are fully aquatic, they were retrieved using a scoop net from mud holes or available ponds in the site. Moreover, besides anuran species used as bio-indicators, another aspect, plant and Odonate species known to proliferate in disturbed wetlands (Kati et al. 2006) were visually assessed by walking around in the wetland and identifying the observed species. Visualized plant specimens were sent to botanists at the Rwanda Institute for Conservation Agriculture (RICA) and the University of Rwanda to confirm their identification and ecology.

## Results and discussion

### Respondent's profile

Based on the scope of the study, the assessed socio-demographic profile of the respondents included the gender, length of residence around the study area, and the activities mostly undertaken around the study area.

In summary, among the 100 surveyed respondents, 58% were males and 42% were females. Even though this difference was not large, female participation in the study was lower than that of males due to cultural settings, where fear is reported as a paramount cause. Among these people, 76% lived around Rwampara for more than or equal to 6 years, whereas 24% have less than 6 years residing around the area (Table 3). In relation to different activities undertaken around the wetland (Table 3), the majority (91% of respondents) mentioned agriculture and irrigation followed by waste dumping (72% of respondents) as the two most

**Table 3** Gender of respondents, length of living in the area, and activities undertaken in and around the wetland

			Percentages	
Gender of respondents				
Male			58	
Female			42	
Total			<b>100%</b>	
Length of residence in the area				
< 6 years			24	
≥ 6 years			76	
Total			<b>100%</b>	
Human activities undertaken HP in the area	MP	LP	Total (%)	
Waste dumping	72	19	9	<b>100%</b>
Commercial	13	54	33	
Handcraft	28	41	31	
Fishing	0	0	100	
Agriculture and irrigation	91	7	2	
Recreation	41	39	20	
Car and motorcycle washing	52	26	22	

*HP* the activity highly practiced, *MP* moderately practiced, *LP* least practiced

highly practiced activities around the area. Moreover, activities such as handicrafts, recreational, and commercial are moderately practiced around the wetland as disclosed by 41%, 39%, and 54% of respondents, respectively. Lastly, 26% of all the surveyed respondents disclosed that car and motorcycle washing, and fishing, respectively were the activities least practiced. For the types of undertaken activities in the area, both genders were well represented in the survey, and not restricted nor favored activity was found to a particular gender. Thus, gender bias was neither practically nor statistically significant or considered for the general purpose of this study. Parallel to the aforementioned practiced activities in the area (Adekola and Mitchell 2011); and Uluocha and Okeke (2004) highlighted that human activities (depending on the nature and magnitude of the practiced activities in and around wetland's vicinity) put significant pressure on ecosystems and give rise to their ultimate degradation. The pressure on the Rwampara wetlands is similar in some respects to those commonly blamed to cause wetland disturbances globally (Adekola and Mitchell 2011), not excluding the extinction of some species (which justifies the total non-existence and exhaustion of fishes in Rwampara wetland).

### Comparison between the current and past LULC trends and their role on the natural change of Rwampara wetland

Several studies echoed that wetlands are threatened by the encroachment of other land uses (Perez-Molina et al. 2016;

Phethi and Gumbo 2019; Xu et al. 2019; Rwanyiziri et al. 2020). Therefore, to assess the trend in wetland change, it is necessary to gather past and current LULC information (Camacho et al. 2016; Rahimi et al. 2020). The analysis of previous studies (Rwanga and Ndambuki 2017; Sarkar 2018) indicates that the calculation of the overall accuracy and the kappa statistical coefficient estimated from the confusion or error matrix is necessary to test the precision of the classification procedure. Hence, the overall LULC classification accuracy levels for the two years 2000 and 2018 are 90.2% to 92.6% with Kappa coefficients of 86.6% and 87.6%, respectively (Table 4). These calculated accuracies were judged satisfactory for this study. Hence, they have been used to detect the change of the wetland over the past 18 years (Fig. 2).

The results of the classified images showed that from 2000 to 2018, Rwampara has undergone great changes. In the past, the LULC was made of five classes (built-up, forestland, wetland, grassland, and cropland areas) but currently, the area possesses only three classes (built-up, cropland, and wetland areas). The most noticeable LULC change in the area is a rapid decline in wetlands, and this is coincident with a rapid increase in built-up areas. In 2000, wetlands covered approximately 58.60% of the area but then decreased to 20.70% in 2018, while built-up area expanded from 9.06 to 76.17%. LULC change is a factor influencing the variation of the ecological system at a local, regional, and global scale (Tadese et al. 2020). While only a few landscapes in the world are remaining in their natural condition,

**Table 4** The confusion matrices of LULC classification (2000 and 2018)

LULC categories		Reference test information 2000					
		Wetland	Grassland	Cropland	Built-up	Forestland	UA (%)
Online GIS-based world imagery Classification	Wetland	<b>45</b>	2	0	0	1	93.75
	Grassland	0	<b>13</b>	1	0	1	86.67
	Cropland	1	2	<b>32</b>	0	1	88.89
	Built-up	1	0	0	<b>14</b>	0	93.33
	Forestland	0	1	1	0	<b>7</b>	77.78
	PA (%)	95.74	72.22	94.12	100	70	
	OA (%)	<b>90.2</b>					
K (%)	<b>86.6</b>						

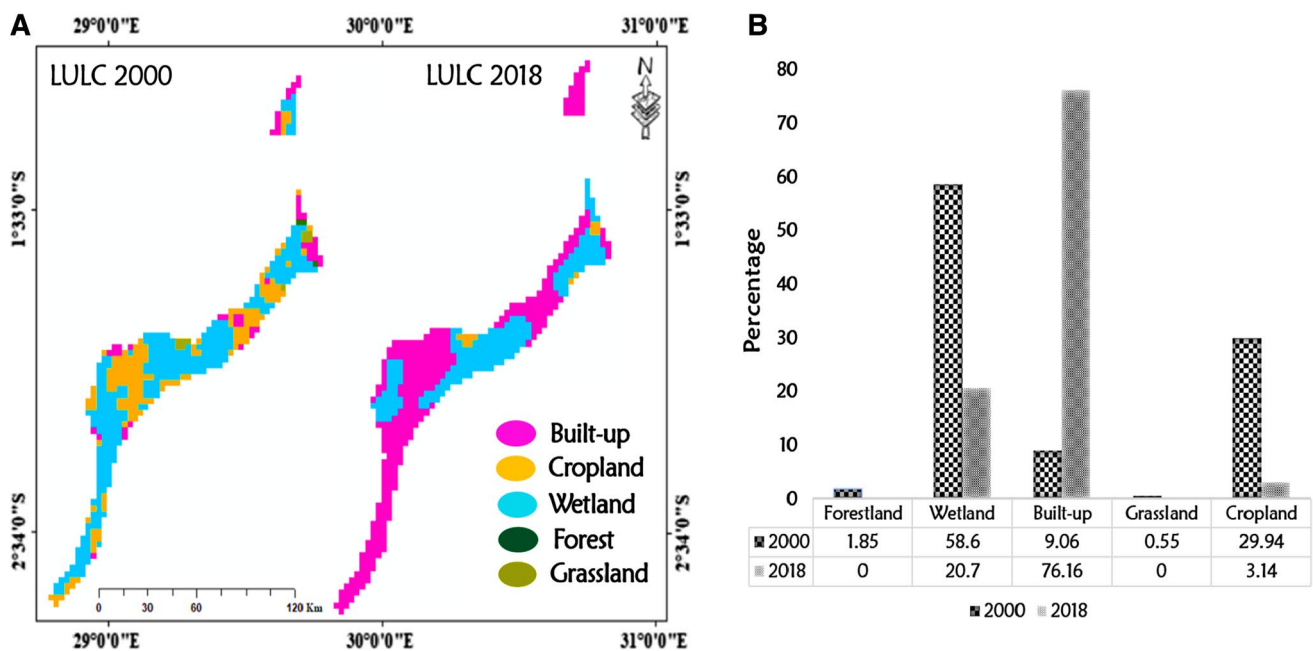
  

LULC Categories		Reference test information 2018			
		Wetland	Cropland	Built-up	UA (%)
Online GIS-based world imagery Classification	Wetland	<b>20</b>	2	1	86.96
	Cropland	2	<b>14</b>	1	82.35
	Built-up	0	0	<b>42</b>	100
	PA (%)	90.91	87.50	95.45	
	OA (%)	<b>92.6</b>			
K (%)	<b>87.9</b>				

PA producer accuracy, OA overall accuracy, UA user accuracy, K kappa statistical coefficient

wetlands in urban global landscapes are the most affected due to rapid urban growth. Similarly, in the study area, the

the rapid growth of the population and the amplified housing sprawl in connection to urbanization. Compared with the



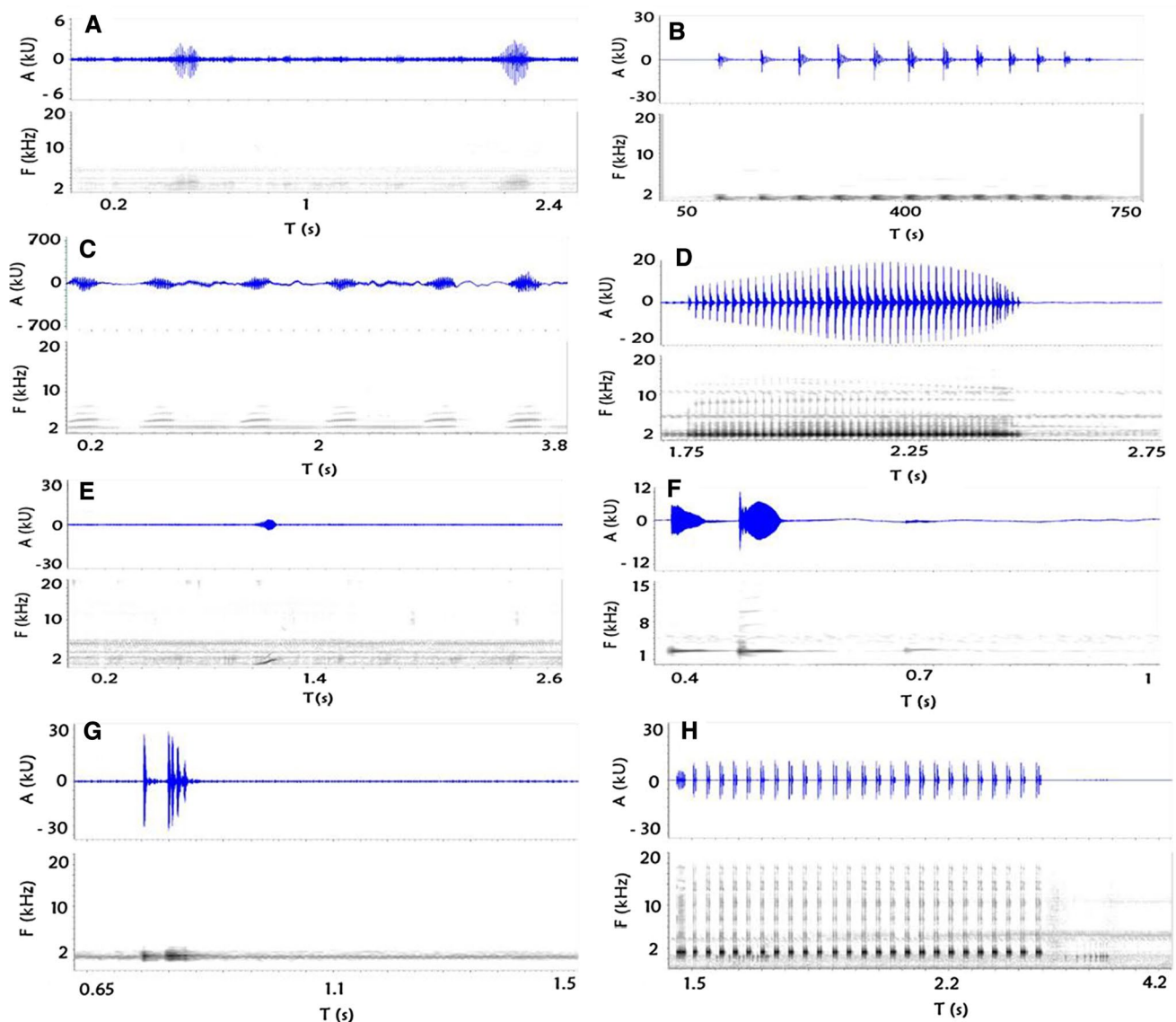
**Fig. 2** a Past and current land use and land cover change, b trends per each class

substantial decrease in wetlands and the related expansion in built-up areas were caused by human activities incurred by

past years, croplands have declined (from 29.94 to 3.14%). This trend was evident due to the strict implementation of

conservation/protection laws of Rwanda that subjected agricultural activities to the jurisdiction of the Rwandan Wetland Protection; but, the law is still being violated by some community members (The Newtimes 2020). However, even if the government has articulated its potential into environmental protection through the laws, national primacies such as the agricultural areas' expansion for food security and the resettlement of landless communities are still competing with the conservation of wetland areas, and thus, hastening wetland loss. Generally, farmers use the wetlands to expand their productivity in livelihood tactics (McCartney et al. 2015). Approximately, 92,000 hectares of entire Rwandan wetlands are used for traditional agriculture, where farmers

plant different types of crops on the borders of the wetlands (REMA 2009) and harvest papyrus used in their handcraft activities. In addition, the wetland is used as an irrigation site whereby sweet potatoes, cassava, yams, vegetables, and bananas (whose wastes were observed in the wetland) are the main irrigated crops. Similarly, Niu et al. (2012) verified that anthropogenic activities, mainly agriculture, alter the integrity of wetlands in terms of structure and composition. Rwampara wetland has been drained as farmland; for instance, the wetland has been affected by drainage and hence, deteriorated by the increase in irrigation, which alternates for its water supply functionality. These direct effects are also typically remarkable in areas with an amplified



**Fig. 3** Advertisement call differences among detected anurans: **A** *Ptychadena nilotica*, **B** *Sclerophrys regularis*, **C** *Ptychadena anchietae*, **D** *Phrynobatrachus natalensis*, **E** *Kassina senegalensis*, **F**

*Hyperolius viridiflavus*, **G** *Hyperolius kivuensis*, **H** *Afrixalus quadrivittatus*. Note that **F** denotes the frequency while **A** is the amplitude



built-up area (Fickas et al. 2016); which are prevalent around Rwampara (Fig. 2).

According to Mitsch et al. (2015) and Janse et al. (2019), a healthy wetland ecosystem is known to provide several services that benefit humans and other biodiversity. Among others, these include the absorption of pollutants, water quality improvement, flood pressure reduction, and ecological habitat for biodiversity. Kingsford et al. (2016) explain that human activities undertook around or in the wetland increase serious risk of damages to the wetland's health and integrity. In the Rwampara wetland, it was revealed that agricultural activities and waste dumping (Table 3) are the two most undertaken activities putting pressure on the services provided by the ecosystem.

### Status quo and the extent to which the Rwampara wetland has been degraded through a biological and acoustic assessment of available species around the wetland

Wetlands are believed to be more prone to invasion than other ecosystems. Moges et al. (2017) reported degraded wetland ecosystems to adjacently consist of more plant species of which the majority are invasive (Byun et al. 2018). Riparian and wetland environments are recognized as the most disposed to weed problems. The latter was observed in the area and some were invasive; which was an indication of the current status of the wetland. Through a field visit to compare the classified LULC and different opinions of the

surrounding community, who lived around the area for many years, it was found that the non-weedy vegetation coverage of the area has diminished, resulting in weedy vegetation dominance in the Rwampara wetland. Among weeds that are dominating the area, two plant species known to indicate degraded ecosystems were identified. First, the downy thorn apple (*Datura stramonium*) in the *Solanaceae* family. These plant species, particularly their seeds, are entirely toxic, their leaves produce an unpleasant odor when crushed, and their fruits are armed with spines (Disel et al. 2015; Verma et al. 2020). This latter aspect has an impact on the aesthetics of the area and when uncontrolled, *Datura* plants become invasive, competing with crops and indigenous species. The second identified specie was *Tithonia diversifolia* from the *Asteraceae* family, well known as tree marigold or Mexican Tournesol. According to the global invasive species database, *T. diversifolia* can reach 2–3 m high. It tolerates heat and drought; and can rapidly form a large herbaceous shrub (Akshatha 2015; Ayesa et al. 2018). The invasiveness of the plant species is mainly due to their tolerance to a disturbance within the wetland. This is manifested by the rapid production of substantial seeds that can quickly disperse and invade a wide area of the habitat, hence, creating stands and preventing the development of native species (GISD 2020). Adding to that, they are invasive weeds that compete with river flow and finally become a threat to the normal performance of aquatic life (Ndayisaba et al. 2017). This was evident for this study since the introduction of these plant species has been rapid with the ongoing degradation of the

**Table 5** Key identification for call structure (Niche partitioning in Afromontane frog)

Species	CD (ms)	P/C (n)	PR (Hz)	PD (ms)	InterPI (ms)	DF (Hz)
<i>Sclerophrys regularis</i>	719 (525–1011)	12 (8–17)	17.2 (13.3–19.9)	24 (13–37)	40 (24–58)	388 (301–510)
<i>Afraxalus quadrivittatus</i>	2855 (859–7598)	68 (17–138)	23.9 (15.5–9.9)	6 (3–8)	7 (4–11)	3251 (3078–3511)
<i>Hyperolius kivuensis</i>	75 (50–107)	5 (4–7)	64.1 (46.7–95.8)	3 (1–5)	7 (3–23)	2649 (2177–3124)
<i>Hyperolius lateralis</i>	27 (13–42)	6 (4–8)	250.0 (193.5–368.4)	3 (1–4)	1 (0–3)	3500 (3046–3854)
<i>Hyperolius sp. 1 (nasutus-group)</i>	139 (62–287)	18 (13–23)	129.5 (70.6–209.7)	3 (2–4)	2 (0–106)	4621 (4005–5272)
<i>Hyperolius sp. 2 (cinnamomeoventris-group)</i>	664 (550–2003)	6 (5–12)	9.0 (4.5–10.8)	3 (1–5)	0 (0–593)	3246 (3083–3992)
<i>Hyperolius sp. 3 (viridiflavus-group)</i>	47 (24–82)	1	–	47 (24–82)	–	2640 (2220–2917)
<i>Kassina senegalensis</i>	118 (58–159)	1	–	118 (58–159)	–	1076 (810–1421)
<i>Phrynobatrachus sp. 1 (mababiensis-group)</i>	374 (421–684)	22 (15–28)	61.5 (33.6–69.3)	7 (3–10)	9 (5–12)	3809 (3488–4306)
<i>Phrynobatrachus sp. 2 (natalensis-group)</i>	632 (501–821)	42 (34–58)	67.1 (56.4–79.6)	8 (6–10)	7 (4–9)	1490 (1292–1840)
<i>Ptychadena anchietae</i>	220 (110–278)	11 (7–14)	52.6 (36.4–64.3)	10 (8–13)	5 (3–8)	3359 (3014–3832)
<i>Ptychadena nilotica</i>	189 (72–281)	17 (8–26)	94.0 (74.1–111.1)	5 (3–7)	4 (2–6)	2239 (1772–2756)
<i>Ptychadena porosissima</i>	182 (100–262)	10 (5–13)	52.9 (41.3–84.4)	6 (3–12)	13 (7–20)	4091 (3660–4565)
<i>Amietia sp. 1 (anglensis-group)</i>	282 (65–633)	5 (2–10)	17.9 (13.1–30.8)	6 (3–14)	65 (52–87)	1421 (818–1765)

Source: (Sinsch et al. 2012)

CD call duration, P/C pulse per call, PR pulse rate, PD pulse duration, InterPI interpulse interval, DF dominant frequency

Rwampara wetland. On the other hand, anuran species are known to respond to the disturbance in wetlands structure as these alter the natural states of wetlands into more heterogeneous habitats. As a result, disturbed wetlands are invaded by disturbance-tolerant anuran species (Tumushimire et al. 2020). This study revealed that all anuran species detected in the Rwampara wetland are generalist species that occur only in heavily disturbed wetlands (Sinsch et al. 2012; Mindje et al. 2020). Moreover, the present study did not detect the occurrence of *Hyperolius lateralis* and *Hyperolius cinnamomeoventris*, which are known to co-occur in near-natural reed habitats, shrubs, or trees (Schick et al. 2005; Bell et al. 2015). This substantiates the fact that the absence of these species may be associated with the loss of the reed and papyrus vegetation that existed before the deterioration of the wetland. Further to this, a similar study by Mindje et al. (2020) investigated the impacts of wetlands' regeneration on the anuran community, and their results showed a positive response from the invasion of *H. cinnamomeoventris*, which confirmed the regeneration status of the investigated wetland. Hence, we can associate information from similar research to this present study and elucidate the status of the Rwampara wetland as one in a state of heavy disturbance. Below is the vocalization structure of identified anurans as recorded and analyzed (Fig. 3).

The detected anuran species were identified based on the key identification for call structure after analyzing their advertisement calls illustrated in Table 5.

In addition to anurans, other species indicators of wetland health, such as macroinvertebrates and birds were observed with the former indicating the degree of pollution (Sarah and Fortunate 2020; Ramírez et al. 2020). In our study, these species were visually observed and substantiated a certain degree of pollution in the Rwampara wetland. Similar results were also found in other studies in wetlands of the same condition in the country (Wronski et al. 2015; Dusabe et al. 2019; Uyizeye 2020), where the species were deemed to dominate wetlands that have been polluted and degraded.

Generally, a healthy wetland would mainly be made of Papyrus and other vegetation for natural wetlands (Irvine et al. 2014). Changes can be either due to strong disturbance (where the wetland has lost its natural vegetation, dominated by amphibians especially generalist anuran species, and invaded by weed vegetation); intermediate disturbance (where the area still retain patches of natural vegetation), and low disturbance (where the area still possess more of the natural vegetation). Table 6 summarizes and explains species used as bio-indicators of disturbances in Rwandan wetlands.

**Table 6** Floral and faunal indicators of disturbances in Rwandan disturbed wetlands

Taxa	Disturbance indicator and niche's partitioning	Dominant species
Amphibians (Sinsch et al. 2012; Mindje et al. 2020; Tumushimire et al. 2020)	Intermediate levels of disturbance can occur mainly in Rice fields, dry crops, irrigation channels with vegetation, flooded uncultivated meadows, reed swamps	<i>Africalus quadrivittatus</i> , <i>Ametia nutti</i> , <i>Kassina senegalensis</i> , <i>Hyperolius viridiflavus</i> , <i>Phrynobatrachus natalensis</i> , <i>Sceloporus regularis</i> , and <i>Hyperolius kivuensis</i>
	Intermediate level of disturbance and occurs mainly in dry crops, irrigation channels with vegetation, flooded uncultivated meadows, fish ponds	<i>Hyperolius rwandae</i> , <i>Phrynobatrachus kakamiko</i> , and <i>Ptychadena nilotica</i>
	Strong disturbance levels and occurs mainly in mud holes, shallow meadows, ponds, and often puddles	<i>Ptychadena anchietae</i> , <i>Ptychadena porosissima</i> , and <i>Xenopus victorinus</i>
	Low levels of disturbances and occurs mainly in near-natural reed habitats additionally including shrubs or trees	<i>Hyperolius lateralis</i> , <i>Hyperolius cinnamomeoventris</i>
Vegetation (Kati et al. 2006; Dai et al. 2021)	Strong disturbances and invade areas whose land becomes fresh or damp after heavy pollution	<i>Datura stramonium</i> and <i>Tithonia diversifolia</i>
Macroinvertebrates (Sarkar 2011, de Freitas Tallarico 2015)	Heavy freshwater pollution	<i>Heteroptera</i> such as members in the Nepidae family; <i>mollusks</i> such as <i>Biomphalaria</i> species and <i>Lymnae</i> species
Birds (Woldemariam et al. 2018)	Intermediate to strong disturbance levels and occurs in wetlands that are already altered	African Sacred Ibis ( <i>Threskiornis aethiopicus</i> ); African Spoon-bill ( <i>Platalea alba</i> ); Hadada Ibis ( <i>Bostrychia hagedash</i> ); Western Cattle Egret ( <i>Bubulcus ibis</i> ) and Hamerkop ( <i>Scopus umbretta</i> )

## Climate change consideration

In addition to anthropogenic drivers, climate change is a significant source of wetland ecological deterioration. As argued by Kingsford et al. (2016) and Mao et al. (2018), the pressures that endanger the interaction between the aquatic and terrestrial ecological function entail both human and naturally-induced drivers. However, identifying anthropogenic impacts on the functioning of aquatic ecosystems and certainly distinguish them from those accredited to climate change has become a puzzling task (Mills et al. 2017; Kayumba et al. 2021). Human factors speed up the degradation substantially, while natural factors such as climate change and related unceasing warming gradually degrade the wetland over some period rather than promptly. The non-climatic direct anthropogenic impacts have been more remarkable than impacts directly accredited to climate change. Serving as a background for wetland change, climatic elements such as precipitation and thermal regimes, are apparent in stimulating the evolution and deterioration of wetlands. There is an indication that climate change with its associated rising temperature is also occurring in the Rwampara wetland (Fig. 4). This last consideration has added to the intricacy facing the ecosystem.

Climate change impacts on wetlands, in this study, are in conjunction with those found in previous studies disclosing that the distinction between climate change and anthropogenic effects are mainly determined by the changes in the hydrological regimes and wetland vegetation conditions. For instance, Shen et al. (2019), Hou et al. (2020) and Guo and Li (2007) among others, used remote sensing techniques and climate data to evaluate the ecological deterioration and reported a significant decline in vegetation condition, blaming the increasing atmospheric temperature as the main driver. Accordingly, these earlier studies supported the results of the remotely-based assessment conducted in this present study, where a decrease in the vegetation condition

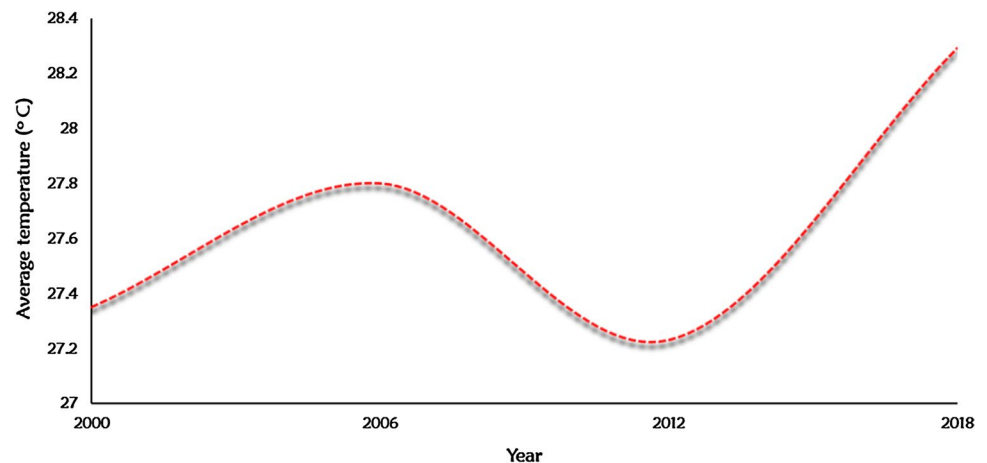
and the water amount (Fig. 5) has been detected. Thus, the increase in temperature has possibly intensified the evapotranspiration, thereby reduces the water level and lead to the insufficient water supply to the vegetation of the ecosystem. Consequently, this last resulted in the drying of land's portions, and the extirpation of aquatic organisms such as fishes (Table 3). Similarly, the increasing trend in temperature implicates a reduction in the soil moisture supply system and consequently demote the growth of vegetation around healthy wetlands by promoting the growth of heat-adapted plant species known to inhabit degraded wetlands. Latter justifies the observed greenness pixels in the 2018 VCI as they are more related to the dominance of weeds and invasive plant species around the ecosystem. Therefore, apart from the reported anthropogenic activities, the increasing temperature of the area has likely played a noteworthy role in the wetland alteration and influenced the habitat preference of the species.

In contrast, the driving forces of wetland changes were different from some earlier studies. Some of these studies unveiled the topographic and geologic factors with a leading role in the variation in wetland distribution (Merot et al. 2003), while Dong et al. (2016) found that the changes in wetlands can also be explained by geomorphic-related factors. These differences may be due to different considered approaches or differences between the locations and natural characteristics of the study areas.

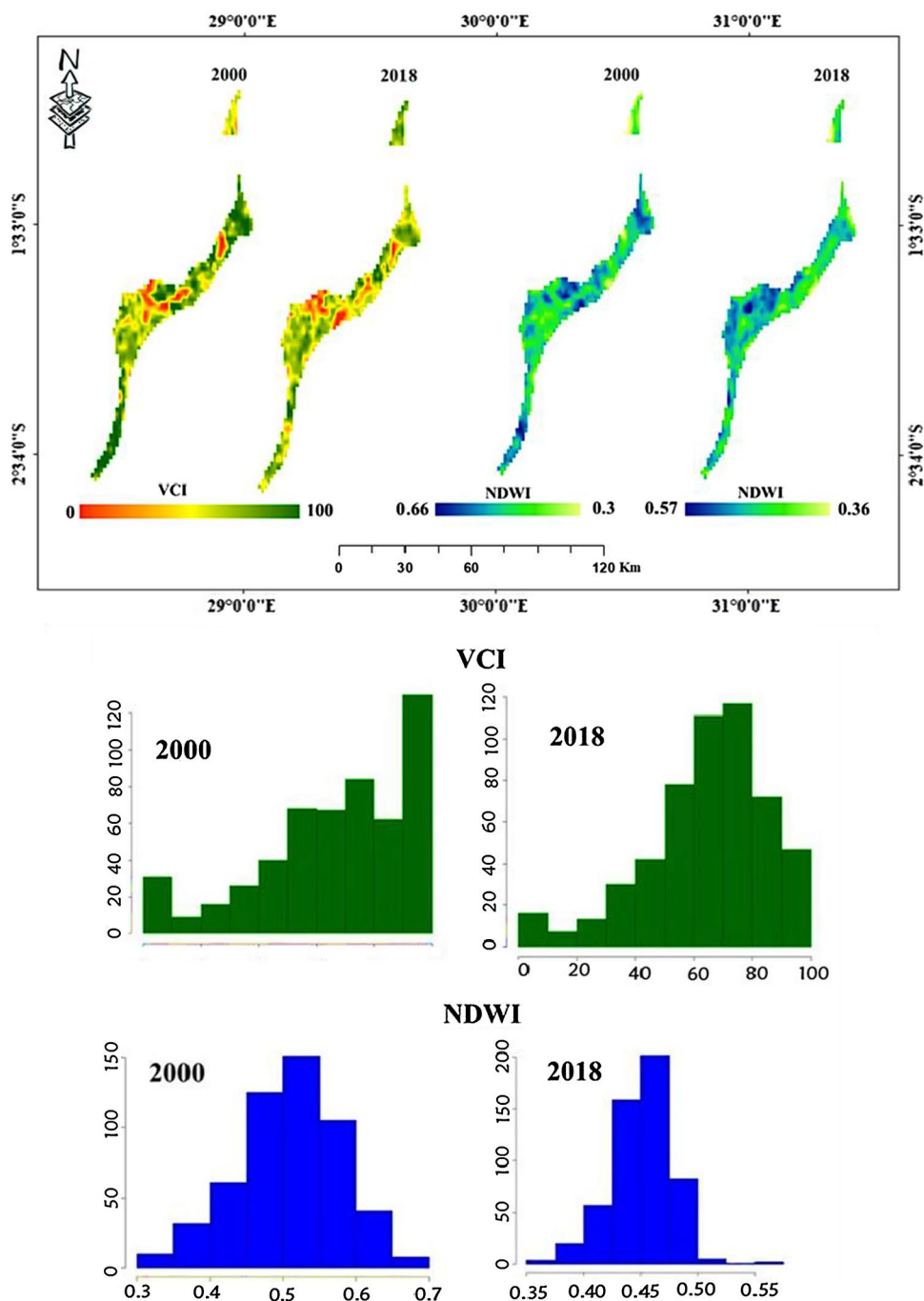
## Proposed protection scheme and restoration of the wetland

Different studies (Jabłońska et al. 2020; Walton et al. 2020) have evidenced the effectiveness of buffer zoning projects at a certain distance to form a transition between terrestrial and aquatic environments. These studies indicate that such zones are well-known to protect the ecosystems from pollutants and thus, their roles should be recognized in large-scale,

**Fig. 4** Trend in annual average temperature around Rwampara wetlands (2000–2018)



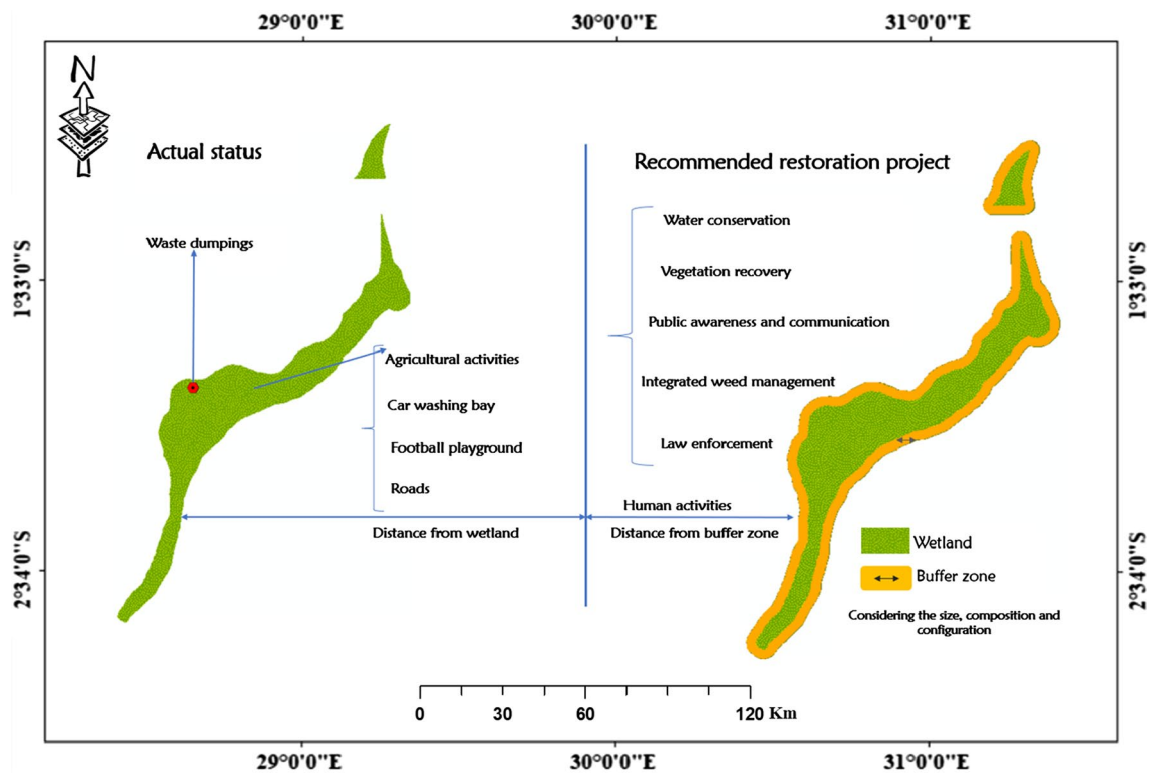
**Fig. 5** Changes in vegetation condition and water amount through the vegetation condition index and the normalized difference water index (2000–2018)



and long-term degradation management (Mester et al. 2020; Walton et al. 2020). The buffer zoning strategy can be the best for the management, rehabilitation, and restoration of the Rwampara wetland (Fig. 6).

From an ecological perspective, larger the buffer zone, better for the conservation (Ebregt and Greve 2000). However, size is not the only factor proving the effectiveness of the buffer, as it varies depending on the objectives, land availability, threats, and opportunities. Additional factors such as the composition and configuration of the

ecosystem (Li et al. 2018) also influence the determination of an effective buffer depending on its targeted function (Semlitsch and Bodie 2003; Walton et al. 2020), the spatial extent of the wetland (Miguet et al. 2016; Jabłońska et al. 2020), wetland characteristics and land use adjacent to the wetlands (Mander et al. 2017; Gene et al. 2019). Therefore, it is worth stressing that the mitigation process and protection schemes should not omit the spatial configuration and the composition within the ecosystem as they have an impact upon the functions produced by the



**Fig. 6** Rwampara wetland and recommended restoration project

wetland (Lovell and Johnston 2009). For this, the wetland mitigation strategy considering the function, size, composition, configuration, and connectivity of the wetland will be very significant in prioritizing and establishing an effective buffer zone. Various configuration mechanisms can be adopted in practice to support the effectiveness of the designed buffer in the Rwampara wetland. For instance, a fixed width buffer design composed of vegetation (forest) in a form of the greenbelt as a strip surrounding the area would be a prominent initiative to intercept the non-point-source pollution, and attenuating contaminants from anthropogenic activities than grassed buffers. From the suggested greenbelt approach, planted trees will consume a large amount of nutrients, and contaminants in overland movement, and thus, ensure wetland protection and increase the wetland functionality. Additionally, the vegetation will serve to reduce the speed of overland flow, thereby helping to prevent erosion and creating a better opportunity for the water to percolate into the soil.

Besides the proposed buffer zoning, the restoration of the site implies stringent feasible mitigation guidelines and protection by removing human-induced agricultural activities to minimize pesticides concentration, stopping livestock grazing, redirecting human pathways outside the wetland, eradicating invasive plants species

and non-degradable wastes such as plastics and wherever applicable, plantation of indigenous wetlands vegetation. Activities impeding the restoration of the ecosystem once reduced or halted would offer Rwampara wetland a resilience potential to restoration and thus, be defensive against flood or overflow plains, minimize maximal rates of flow during the rainy season, and sustain the relatively high flow rates during the dry season, as also argued by Ndayisaba et al. (2017). Beyond the Rwampara wetland, all wetlands should be prioritized by identifying the need of urgent conservation attention.

## Conclusion

The status of the Rwampara wetland was assessed through remotely sensed observations complemented by an assessment of biological indicators known to inhabit heavily disturbed wetland ecosystems in Rwanda. We further documented the effectiveness of qualitative respondent sampling to study human impacts on the changes in the integrity of the wetland. Findings revealed that increased anthropogenic activities accelerated the disturbance of the wetland with corresponding changes to associated biological communities. Besides human-induced changes to the

wetlands' integrity, the increasing atmospheric temperature and its effects on the patterns of ecological structure and attributes, have shown a reduction in the wetlands' hydrological regime leading to a decline in vegetation condition of the wetland. Since this study gave much attention to anthropogenic activities, future research should focus on the vulnerability of the wetlands to climate change and reconcile anthropogenic and climatic impacts on wetland degradation, as well as their implications by evaluating ecosystem services lost in response to these impact factors. The status quo of a particular wetland can effectively be assessed using similar approaches to obtain scientific-based information useful to guide the decision and policies on wetlands' management and conservation. However, disturbances on wetlands are expected to increase in Rwanda owing to the projected population growth. Thus, to preserve the wetland integrity and functionality, the initiation of restoration processes and development of buffer zones will be of importance to improve and sustain the resilience of the wetland to safeguard various products and services. Besides, contribution and support from the community, through campaigns of public education activities for wetland protection are needed to raise public awareness for the functions and benefits of wetland resources. This will reinforce the public's willingness in preventing ecological disturbances, and help in environmental monitoring, assessment and sustainability.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Author's approval** We ensure that all the authors mentioned in the manuscript have agreed for authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.

**Ethical approval** While collecting our data, all applicable guidelines and principles for the care of species were followed in accordance with the ethical standards while informed consent was obtained from all individual participants involved in the study by assuring their anonymity and were told about the purpose of conducting the research.

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