



# Factors driving utilization patterns of marshlands in the vicinity of South-Kivu urban agglomerations based on Rapid Assessment of Wetland Ecosystem Services (RAWES)



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## ABSTRACT

Marshlands are one of the most vulnerable ecosystems; being disturbed for several decades as the population density rises. These disturbances, due to anthropogenic activities, impact their ability to deliver important ecosystem services (ES). In this study, we analyzed the current state of marshes in the vicinity of South-Kivu urban agglomerations, in eastern Democratic Republic of Congo (DRC). Factors driving the utilization patterns of marshlands were also assessed in four selected marshes (Muku, Hogola, Chisheke, and Mudaka). The used methodology combined both analyses of satellite images and household surveys. Results showed that marshes' ecosystem utilization patterns in South-Kivu comprised of unsustainable farming practices, clay extraction for brick making, dwelling and settlement expansion, and aquaculture for fish production. The factors driving these utilization patterns combined both bio-physical and household socioeconomic characteristics. These include mainly reinforcement of restrictions for marshland use, the household head's age, income, and household size. Besides, the perception of marshes as wastelands is another driving factor on how people value and use marshlands in South-Kivu. These driving factors are to be considered in ensuring and maintaining marshland functions and ecosystem services (ES) to local communities that highly depend on marshes for livelihoods. As the population density increases substantially in the region, the demand for utilization patterns of marshlands for agriculture, aquaculture, brick making, and settlement and dwellings are also expected to increase in the near future. Therefore, both local communities and decision-makers should be involved in designing sustainable utilizations and conservation options to durably improve livelihoods of populations around these ecosystems.

## 1. Introduction

Marshlands are areas where water is at, near, or above the surface of the ground, and often enough for hydric soil formation and/or for wetland plants to grow. In general, wetlands include streams, ponds, bogs, marshes, swamps, floodplains, isolated lands subjected to flooding, wet meadows, land under lakes, coastal (shores) of river and lakes, among others (Robelo et al., 2010; Ramsar, 2018). Marshlands are also comprised of periodically flooded ecosystems, such as flooded forests, flooded grasslands, and seasonal shallow lakes and water bodies. Swamps and marshes can be distinguished; they include herbaceous swamps, swamp forests, and peat swamps (Mitsch and Gosselink, 2015).

Many studies showed that more than half (~64%) of wetlands, including marshlands, has disappeared since 1900, and this is mostly due to the anthropic pressure. In some regions of Asia and Africa, these losses are faster, mostly in the vicinity of urban areas (Davidson, 2018; WWT Consulting, 2018). Wetland degradation and losses have, in general, been perceived in developing countries, especially in Africa, due to poor institutional frameworks supporting marshland governance (Davidson, 2018).

In most African countries and in the eastern Africa (i.e. Kenya, Uganda, Burundi, Rwanda, etc.) particularly, there is still confusion in the definition and naming of wetland ecosystems; as all wetlands are locally referred to as marshes (WWT Consulting, 2018).

**Abbreviations:** HH, Household; DRC, Democratic Republic of Congo; GIS, Geographic Information System; RS, Remote Sensing; df, degree of freedom; MLR, Multinomial Logistic Regression; IITA, International Institute of Tropical Agriculture; PICAGEL, Projet Intégré des Crédits Agricoles dans la région des Grands Lacs; FH, Food for the Hungry; RAWES, Rapid Assessment of Wetland Ecosystem Services; Aw3, Tropical wet and dry or savanna climate; Cwb, Subtropical highland climate.

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The percentage of wetland areas in Africa has been estimated to range between approximately 1 to 16% of the total area of the continent. However, since 1900, more than half of the world's wetlands (including Africa) has disappeared (Barbier, 1993; Koohafkan et al., 1998). The land and water of marshlands have been converted into other uses such as agriculture and infrastructure development. While some marshland conversions have undoubtedly been in the best interest of the society, wetlands have too often been lost for very limited benefits and even at cost to the society. Reasons for marshland loss are many (Davidson, 2014; Hu et al., 2017); one major cause being the public domain nature of many marshland products and services.

Wetlands in general and the marshes particularly are one of the world's most productive ecosystems. They are vital for human survival and play a role in providing numerous economic, ecological, and well-being benefits (generally known as wetlands ecosystem services). Unfortunately, some uses are not consistent with the sustainability of these ecosystems. This further increases the pressure and degradation of these ecosystems. These pressure and degradation phenomena are observed in several regions and more particularly in the tropics where policies for the protection of these ecosystems are still poorly enforced. Thus, designing the proper maintenance of these ecosystems requires the knowledge of their current state (condition) and factors leading to changes in uses while thinking about their sustainability (Teferi et al., 2010; Gopal, 2013; Sjögersten et al., 2014).

In recent decades, marshlands in South-Kivu and specifically those surrounding cities and towns experience unprecedented modifications and degradations due to an anthropogenic pressure as a result of exponential population growth and migration. As the South-Kivu province develops, the demand for land has increased; leading to rapid marshland conversion. Five ideal conditions, provided by these marshlands for agriculture or any other activity, have favored the rapid conversion: (i) being unexploited public domain; (ii) high soil fertility and water content compared to uplands (Schyut, 2005; Sakané et al., 2011; Beuel et al., 2017); (iii) wetlands provide opportunity for off-season farming; (iv) they allow cultivation of water-demanding crops such as rice, sugar cane, vegetables; (v) marshlands harbor specific flora and fauna unique to these ecosystems such as *Raphia* spp., *Carex* sp., *Cyperus papyrus*, and other animals, birds and amphibians (Teferi et al., 2010; Gopal, 2013). Even though inland valley marshlands were under-utilized due to the high presence of water-borne diseases such as malaria, bilharzias, trypanosomiasis (sleeping sickness), onchocerciasis (river blindness), and dracontiasis (guinea worm), and also due to the difficult access (from road to settlements and markets) (Wood and Van Halsema, 2008; Chuma et al., 2021a, 2021b). For South-Kivu in the last few decades, these areas were under high utilization; they were exploited for crop production, brick making, aquaculture, settlement development, production of fibers, mats and pottery, fodder production, etc. This high pressure on marshlands near the urban agglomerations is leading to more acute ecological problems.

In South-Kivu, marshland is an essential ecosystem since it provides ecosystem services (ES) to local communities, and especially those living in their vicinity and in rural areas that strongly depend on agriculture and artisanary (Chuma et al., 2021a, 2021c). Healthy marshlands and wetlands, in general, provide direct and indirect benefits to communities through goods and services. Their contribution to human survival has been confirmed by the Millennium Ecosystem Assessment (M.E.A, 2005), which demonstrated the intricate relationships between these ecosystems and human livelihoods.

Water resources are found in many South-Kivu territories, eastern DRC. These comprised of marshes, ponds, swamps, and inland floodplains and lake shores (mainly the Lakes Kivu and Tanganyika). In South-Kivu territories, all the wetland types are locally referred to as marshes (locally called "Luziba"). Marshlands are currently exploited for many utilization patterns; two types of use were reported in previous studies and which comprised of brick making and agriculture (mainly for vegetable and rice production) (Chuma et al., 2021a, 2021c, 2021d).

Changes in terms of land use and land cover had been also reported in some marshlands, and mostly for the ones located in the vicinity of towns and cities. These changes were most linked to socioeconomic factors such as high income from marshland activities, presence of restriction, types of use, and the perception that wetland activities are more profitable than other local activities (Chuma et al., 2021a). Several biophysical and socioeconomic factors have been identified in several case studies as drivers determining the possible degradation of marshes (Russi et al. 2013; Ondiek et al., 2020; Chuma et al., 2021a). For crop production for example, to prevent perturbation of farming calendar in the sub-Saharan region, marshlands (at the watershed scale) provide alternative resources essential for human livelihood since the crop cultivation is largely dependent on vulnerable weather variables such as the rainfall and temperatures. Unexpected changes in the patterns of those weather variables negatively impact the crop yields. Therefore, marshlands are the only repository of moisture during dry periods, allowing farming activities when it is no longer possible in uplands. Thus, understanding the drivers of marshland use is necessary in determining the suitable land-use types to promote, and hence, contributing towards the attainment of Sustainable Development Goal (SDG 6)(Life below water and Life on land) and to promote the wise use of wetlands, referring to the Ramsar guidelines.

The state of marshes surrounding South-Kivu urban agglomerations has not yet been documented. Only a few studies mentioned the state of the wetlands in general and specifically in South-Kivu (DIOBASS, 2010; Chuma et al., 2021a, 2021c, 2021d). Tools and materials to assess wetlands' services are numerous and require many steps and time. The use of the Rapid Assessment of Wetland Ecosystem Services (RAWES) is an example of a cost-effective and pragmatic approach to assessing the multiple benefits that wetlands provide. It has been designed to provide a qualitative assessment of a comprehensive range of wetland ecosystem services (McInnes and Everard, 2017).

In this study, we focused on wetlands specifically marshes surrounding urban agglomerations in the South-Kivu province, eastern DRC. The motivation was to fill the research gaps on marshes as they represent the only ecosystems in the study area where bricks, vegetables, and rice are produced; thus participate in creating works/jobs for remuneration (pay) and/or livelihood support to local communities living in their vicinity. The overall objective of this study was to contribute to sustainable wetland ecosystem use. It assessed and critiqued brick making, settlement development, crop production, and aquaculture practices in vicinities of selected marshlands. It also analyzed the drivers that determine the patterns of marshland utilization in South-Kivu.

## 2. Materials and methods

### 2.1. Study area

#### 2.1.1. Location

In this study, we used case studies of four selected marshes. These four marshes are located in the vicinity of urban agglomerations (towns and cities) in South-Kivu: Hogola (at Nyangezi), Chisheke at Walungu Centre, Mudaka (at Mudaka), and Muku (near Bukavu and Muku). Bukavu City and other covered agglomerations of Kabare and Walungu territories are located along national roads. These selected marshes are well-known by local populations for their services to communities and mostly to rural households living in their vicinity and all other villages that benefit from services and products from these ecosystems (Chuma et al., 2021a). Fig. 1 presents the map of the four marshes selected for this study. These surfaces were obtained after digitization using very high-resolution images (CNES/Airbus) from Google Earth Pro. These images were then georeferenced and used to assess land use and land cover classes. Two of these marshes (Chisheke and Hogola) are currently under high anthropogenic pressure, leading to land use and land cover change (LULC) across years as documented by Chuma et al. (2021a, 2021c).

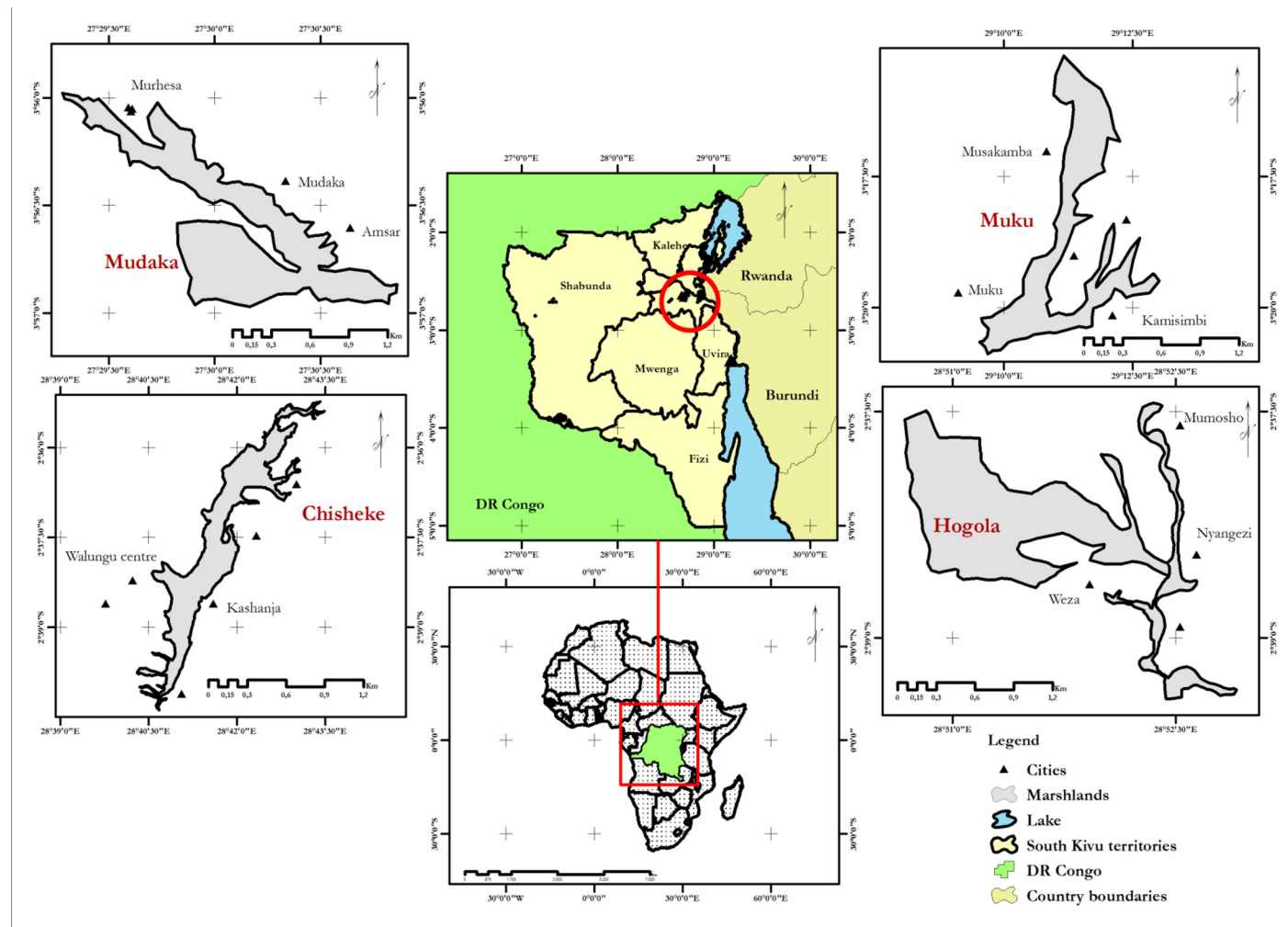


Fig. 1. Location of the four selected marshes (Hogola, Chisheke, Mudaka and Muku) in the vicinity of South-Kivu urban agglomerations (cities and towns), eastern DR Congo.

### 2.1.2. Climate, topography, and vegetation

The selected marshes are located in the same climatic zone and thus experience similar weather conditions (Mondo et al., 2019; Mugumaarhahama et al., 2021). Walungu and Kabare territories are characterized by humid tropical climates tempered with elevation (Chuma et al., 2021a). According to the Köppen-Geiger classification (Beck et al., 2018), the climate in this area varies from *Aw3* to *Cfb* types. The available data from INERA-Mulungu and Weza stations showed that the mean temperature is  $\sim 19.9^{\circ}\text{C}$  (min.  $13.5^{\circ}\text{C}$ , max.  $27.0^{\circ}\text{C}$ ) and annual rainfall of  $\sim 1446$  mm, with three months of dry season and nine months for the wet/rainy season.

The topography in the two territories is dominated by the Mitumba mountain range. The elevation varies from  $\sim 900$  m at the Ruzizi plain side to  $\sim 3200$  m above the sea level (masl) for the Mount Kahuzi in the Kahuzi-Biega National Park (PNKB). The four selected marshes are located at  $\sim 1720$  m,  $\sim 1560$  m,  $\sim 1780$  m, and  $\sim 2250$  masl for Chisheke, Hogola, Mudaka, and Muku marshes, respectively (Table 1). According to the land use and land cover, the vegetation is composed of natural forest vegetation (around the PNKB), farmlands, and secondary forests. Some plantations (tea, coffee, *Eucalyptus*, and *Grevillea* sp.) can also be observed in the area.

### 2.2. Methods

#### 2.2.1. Marshland uses in the vicinity of agglomerations in Kabare and Walungu territories, in South-Kivu

To analyze the different use types, four marshes were selected based on their accessibility and proximity to the main urban agglomerations in two South-Kivu territories. To identify these use types, pre-surveys combining questionnaire survey and individual interviews were firstly conducted in target areas to gain information on the main use types and the number of households involved. Questionnaires were administered together with semi-structured interviews conducted with key informants in the four marshes. From these pre-surveys' output, four use types were retained: agriculture for crop production, aquaculture, brick making, settlement and dwelling house development. Walungu and Kabare territories as well as the Bukavu City are currently supplied in vegetables by these four selected marshes (Chuma et al., 2021d). Since the total marshland users are unknown, a sample size of 368 users was randomly selected for data collection. Taking into account the relative importance in use and area covered by marshlands in Chisheke, Hogola, Mudaka, and Muku; 113, 200, 32, and 23 households, respectively, were selected for the survey. For each household, questions related to the type of use-

**Table 1**

Biophysical characteristics of the four selected marshes in the vicinity of urban agglomerations in South-Kivu Province.

Characteristics	Chisheke	Hogola	Mudaka	Muku
Elevation (m)	1720	1560	1780	2250
Territories/agglomerations	Walungu-Centre and Izege	Nyangezi	Mudaka, Bushumba and Konge I-II	Mudusa and Kamisimbi
Temperature (°C) (Min-Max)	12-27	16-26	17-25	13-27
Annual rainfall (mm)	1600	1300	1650	1650
Landscape unit	Inland valley	Inland valley	Lowland and depression	Lowland and depression
Water pH ( $\pm$ standard error)	6.7 $\pm$ 2.3	7.2 $\pm$ 1.8	7.1 $\pm$ 2.2	6.5 $\pm$ 2.6
Mean water depth (m)	0.5 to 1	0.5 to 1	<0.50	<0.75
Dominant land cover	Farmlands, herbaceous wetlands, and bare soils	Scour land by brick making and herbaceous wetlands	Farmlands and shrub wetlands	Farmlands and shrub wetlands
Hydroperiod	Seasonally and intermittently	Permanently	Permanently	Intermittently
Population size in the agglomeration	18,359	38,777	9,556	4,889
Mean distance to the national road (km)	<0.5	>1.5	<0.5	>1.5

lization, the starting year of exploitation, and constraints and opportunities of each marsh utilization patterns were raised.

### 2.2.2. Types of marshland use based on households' perceptions

To assess the households' perceptions on use of marshes, 368 selected households were interviewed using a semi-structured survey questionnaire on marsh utilization patterns. Since there was a difference in comprehension among marsh users for the definition of wetlands, the concept "marshland" was used to refer to wetlands, ponds, fens, swamps, marshes, peatland, etc. as it was also reported in the eastern African region (Amler et al., 2015). Two main questions were administered to marshland users: the first concerned the perceptions on the types of use that may lead to high degradation of such ecosystems; and the second assessed the perceptions of marshland users on the relevance of existing restrictions (policy enforcement measures) from decision-makers and which can assist with marshland preservation. In addition to the two previous questions, socioeconomic characteristics of surveyed households were also recorded on the questionnaire. The Likert-scale with three thresholds (Lewis and Erdinc, 2017) was used to assess the position of the respondents on the raised questions: 1: "I agree", 2: "I am neutral/I don't know", and 3: "I disagree". At the same time, questions on constraints and opportunities for each inventoried use were also assessed using the same likert-scale. The complete questionnaire used in data collection is presented in the **Supplementary materials**.

### 2.2.3. Factors affecting the use of marshlands either for settlement and dwelling, crop production, aquaculture, or for brick making in Kabare and Walungu urban agglomerations

To assess factors that predict the probability to use marshlands for one of the four main utilization patterns, a Multinomial Logistic Regression (MLR) was used. It helped to verify the effect of 13 variables on the types of use in marshes (either for agriculture, brick making, aquaculture, or settlements and dwelling). Of the 13 variables, three were continuous or numerical (number of persons per household, monthly income, and the starting year of exploiting marshlands) while the others (10) were categorical. The results were presented in tables that represented the iteration records for the baseline model. In particular, we have retained the initial log (-2LL) probability. The classification table has shown that prediction based on the most frequent category has correctly classified ~92.4% of participants. The pseudo R-squares based on the Cox and Snell, Nagelkerke, and McFadden tests were also assessed.

The Chi-square test was performed to assess the difference in -2 log-likelihoods between the final and the reduced models; the reduced model being formed by omitting an effect from the final model. The null hypothesis was that all parameters of that effect were 0. In our case, the reduced model was almost equivalent to the final model because omitting the effect did not increase the degrees of freedom (df). Based on the obtained results in the tables, the final model significantly improved the

probability of prediction. For each household, geographic coordinates of the activity location in the marshes were recorded and uploaded on the satellite images (CNI/Airbus with 30 cm spatial resolution) for validation, and the corresponding types of use were mapped. This allowed us to assess the spatial use diversity and cover in the four selected marshes.

### 2.3. Data treatments and analysis

Remote Sensing (RS) and Geographic Information System (GIS) were combined for marshes delimitation and map design. The images from Google Earth were downloaded and georeferenced to locate the different marsh utilization patterns. Land use and land cover (LULC) was assessed using the supervised classification in ArcGIS 10.7 software from Esri<sup>TM</sup> (Esri, California, USA). Data from the RAWES were combined with the survey output for data analysis, and the Multinomial Logistic Regression (MLR) was used to assess the relationship between the socioeconomic characteristics and the household heads' choices of involvement in marsh utilization, considered as utilization drivers. The independent variables that were hypothesized to affect the farmers' adaptation strategies are combined effects of various factors such as demographic, socioeconomic, and perceptions based on marshland restriction and perception of a wetland as wasteland by households. The hypothesized independent variables were evaluated for some statistical issues such as multi-collinearity. The multi-collinearity issue among the continuous explanatory variables was detected by the Variance Inflation Factor (VIF). The correlation matrix method was also used to detect the association degree/level among dummy explanatory variables. When the coefficient of correlation matrix was < 0.5, the variables were considered collinear while, if the correlation coefficient value was >0.5, it showed the presence of multicollinearity. Tools such as ArcGIS 10.7, R 4.2.1, and R Studio (R Core Team, 2020) were used for statistical analyses. The Chi-square test was also used to analyze the dependence/independence between perceptions factors and utilization patterns at the probability thresholds of 5%.

## 3. Results

### 3.1. State and utilization of marshes in the vicinity of Walungu and Kabare urban agglomerations

#### 3.1.1. Dwelling and settlement development in the vicinity of marshes

The combination of field data and observations, Remote Sensing (RS) data analysis and the survey made into the four selected marshes showed that four main marshland utilization patterns exist: crop production, aquaculture (fish production), brick making, and settlements and dwelling houses. The results obtained from the survey showed that besides these main utilizations, the four marshes also provide water for drinking, pasture for livestock grazing, and sometimes opportunities for

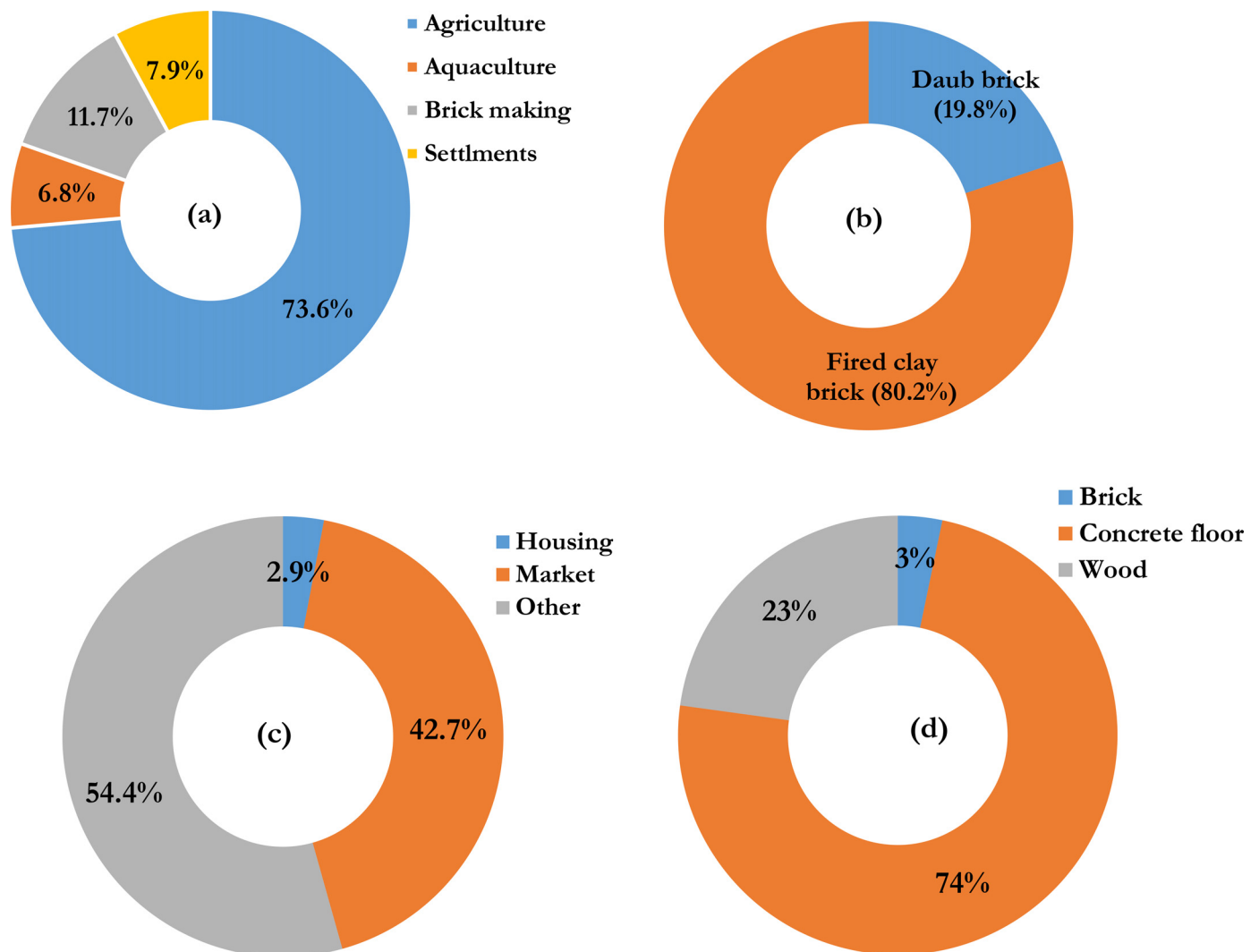


Fig. 2. Diagram for marshland use patterns (a), the types of bricks made in marshes (b), the types of utilization of built settlements(c) and built materials used for house making in marshes (d).

local academic excursions (mainly in Hogola at Nyangezi). From the results of the RAWES approach, only services and goods are recognized for marshlands, those related to recycling services, maintenance (carbon storage, erosion control, runoff, etc.) are not recognized by the local communities. Cultural and religious services linked to marshlands are not recognized by users, and/or even unknown by the local communities. The value of marshlands also includes the products that are derived from these natural resources, including rice and fish, thatch for roofing, fibers and local nets and mats, timber for construction, fuelwood, and medicines from leaves to name a few. The manufacture of pottery from marsh clay has also been reported.

In the Hogola and Chisheke marshlands, settlements are developed in their vicinities. Fig. 2 presents the types of marshland use (a), the types of bricks produced in the marshes (b), the types of use of houses built in marshes (c), and types of built settlements in the marshes (based on the nature of used materials) (d). Figs. 6 and 8 show and locate these utilization patterns on the map of two marshes (Hogola and Chisheke). The results showed that ~73.6% marshlands are exploited for crop production, brick making (11.7%), settlements (7.9%), and aquaculture (6.8%). This utilization trend varied significantly from one marsh to another ( $\text{Chi}^2=39.72$ ,  $\text{df}=9$ ,  $p < 0.001$ ). The aquaculture is only practiced in Chisheke (10%) and Mudaka (16%), while agriculture is the most observed utilization for the four marshes (Chisheke: ~62%, Muku: ~85%;

Mudaka: ~79%) except for Hogola where only ~13% land is allocated to crop production. Dwelling houses are in development in Hogola (~11%), Chisheke (~7%), and Mudaka (~5%). The houses primarily have two uses: either for workers' housing (~2.9%) or for the market (~42.7%), i.e., where crop producers, brick makers, or fish producers can discuss the price with potential buyers. These houses are on the concrete floor (74%) and in wood (23%); only 3% are in bricks (Fig. 2d).

### 3.1.2. Brick making in marshes

The second utilization of marshes is linked to brick-making activities (Fig. 6). Fig. 2b shows that for the two brick types, the fired clay bricks (~80.2%) are the most produced than daub bricks (~19.8%). Brick making is currently observed and practiced in Hogola (~76%), Chisheke (~22%), and Muku (~15%). While in Hogola (95%) and Chisheke (89.4%) fired clay bricks are currently produced; in Muku and Mudaka daub bricks are mostly produced (~84%). For the manufacture of bricks known as "cooked" or "fired", it is necessary to strip the ground, model, and cover with plant species (generally those growing in marshes). This significantly reduces the plant diversity in these ecosystems. These plant species are *Cyperus* sp., *Carex* sp., etc., and other hydrophilic grasses growing in these marshes. Subsequently, the trees located around marshes are also cut down to make firewood for bricks (Fig. 6).

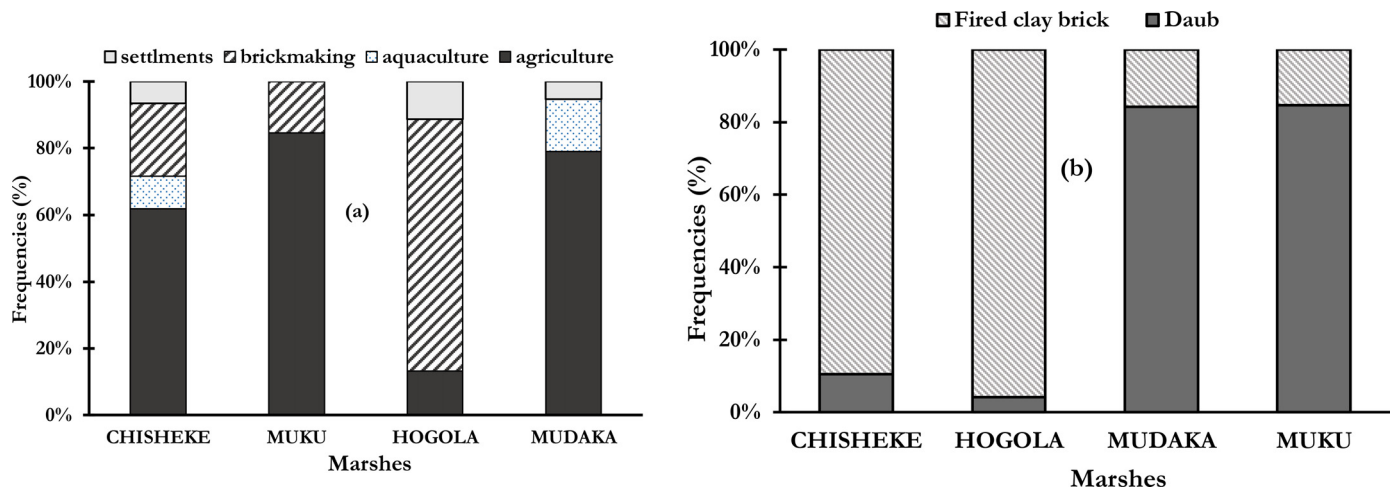


Fig. 3. Types of utilization (a) and type of bricks produced (b) in the four selected marshes in the vicinity of Walungu and Kabare agglomerations in the province of South-Kivu.

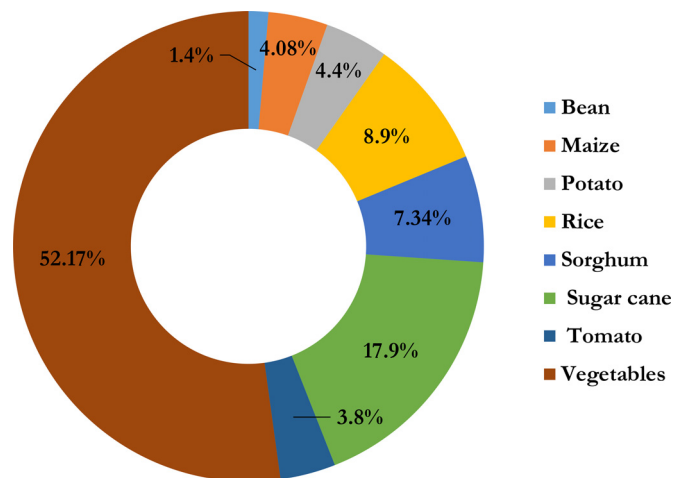


Fig. 4. Main crops produced in the four selected marshes of Kabare and Walungu in South-Kivu.

### 3.1.3. Crop production in marshes

Crop production is the main utilization of marshes in South-Kivu (~73.6%). Different crops are produced comprising vegetables (~52.4%) such as carrot, amaranths, celeries, onion, etc. Other crops such as sorghum (7.34%), rice (8.9%), and sugar cane (17.9%) are also currently practiced in selected marshlands (Fig. 4). For waterlogged marshes such as Hogola and Chisheke, drainage canals are made to evacuate excess water in the rhizospheric zones (Fig. 6). Unfortunately, due to lack of adequate knowledge, the drainage is sometimes accelerated such that some parts of the wetlands have become increasingly desiccated. Bushfire is also currently used in some of these areas to open up fields for crop production. Such practice destroyed plant (herbs) species growing on marshlands, and soil biodiversity (insects, fungus, and worms, etc.). Based on farmer perceptions, in the starting years after use of bushfire for field opening, due to the high concentration of ashes, the soil seems to be fertile but after a few cultural seasons, soil degradation occurs rapidly. Another degradation mentioned is due to the use of pesticides and fertilizers (mostly for vegetable production) that may affect fauna and flora diversity in wetlands. These farmers use much more organic manure than mineral fertilizers and pesticides.

### 3.1.4. Aquaculture (fish production)

Aquaculture for fish production has been in existence in these marshlands for a long time. In the past decades, the implementation of the

fish ponds was only reserved for waterlogged areas, but nowadays, it has been spread in all the wetland types. In ancient times, *Clarias* sp. (walking catfish) was the main species farmed in the study area, but nowadays, other species such as *Tilapia nilotica* are being farmed (Supplementary materials). The ponds are continuously managed, and fish production has been further developing in marshland. Even though marshes are dry, their soil types which are generally clayey soil with high water content, their topography characterized by inland valley with very low slope; the near river could be retained and oriented into the dry wetland to supply water in ponds (Fig. 5). Many young people and sometimes local organizations are currently helped (100%) by international organizations such as the International Institute of Tropical Agriculture (IITA), Integrated Agricultural Credit Project in the Great Lakes Region (PICAGEL), Food for the Hungry (FH), etc., working on the pond development in South-Kivu territories to contribute to food security. Fig. 5 and Supplementary materials present the fish production in Hogola and Mudaka where ponds are furnished water from rivers or marsh extension.

### 3.2. Factors affecting the marshes' utilization types in Walungu and Kabare territories

#### 3.2.1. Characterization of households involved in marshland use

Table 2 presents the socio-demographic characteristics of households involved in the four selected utilization patterns in marshes of Walungu and Kabare territories. According to Table 2, marshland users are typically 30-50 years old (76.1%), only ~13.3% are < 30 years old. These users are predominantly male (~68.2%). Five main activities are currently practiced by these users: agriculture (73.6%), brick making (11.4%), trading (mostly of vegetables or other food crops) (8.7%). Teachers and students are also currently involved in marshland activities as their secondary activities or as main activity (depending on whether this activity generates similar or higher income than teaching). The household members involved in marshes exploitation are mostly married (~92.7%). These households typically have > 8 persons/family members (61.7%), and 29.6% households having 3-7 persons per household. Concerning the education level, the majority of exploitants have secondary education level (82.3%). From activities practiced in marshes, most are considered to generate high monthly income; 36.4% of users have > 200,000 CF (Congolese francs) monthly and 46.5% have 50,000-200,000 CF; only ~17.1% have less than 20,000 CF (and these are typically crop producers/farmers). More than half (~56.3%) of households involved in marshland exploit less than 0.25 ha; only 12.2% exploit more than 1 ha. Wetland use experience by each household range from 5-15 years (49.7%).

**Table 2**  
Socioeconomic characteristics of households involved in marshland use in Walungu and Kabare in South-Kivu province.

Variables	Modalities	Number of respondents	Marginal Percentage (%)
Age (years)	<30	29	13.3
	30-50	315	76.1
	>50	19	7.9
	30-40	5	2.7
Sex	Female	117	31.8
	Male	251	68.2
Main activity	Agriculture	271	73.6
	Teaching	12	3.3
	Studentship	11	3.0
	Brick making	42	11.4
	Trading	32	8.7
Marital status	Married	341	92.7
	Single	19	5.2
	Widow(er)	8	2.2
Number of persons per household (HH)	<3	32	8.7
	>8	227	61.7
	3to7	109	29.6
Education level	Primary	39	10.6
	Secondary	310	84.2
	University	19	5.2
Revenue (income) in Kcf	<50	63	17.1
	50-200	171	46.5
	>200	134	36.4
Exploited surfacearea	<0.25 ha	207	56.3
	0.25-1.0 ha	116	31.5
	> 1.0 ha	45	12.2
Exploit starting year	< 5	107	29.1
	> 15	78	21.2
	5 to 15	183	49.7

Kcf: Thousand Congolese francs. At the time of the survey, 1 US\$ was 2Kcf.



**Fig. 5.** Aquaculture in Hogola (a) and Mudaka (b) marshes, ponds are furnished water from rivers or marshes extension.

These variables were integrated into the regression model to predict factors leading to various levels of marshland use by local communities involved in the four retained activities. The model fitting information obtained showed the -2 Log-Likelihood of 39.77 and a  $\text{Chi}^2$  test of 559.9 ( $df=93$ ,  $p < 0.001$ ). The pseudo R-squares of 0.78, 0.952, and 0.885 were obtained for Cox and Snell, Nagelkerke, and McFadden tests, respectively (**Supplementary materials**). Diagnostic tests through the Wald statistics showed that the model is globally significant, justifying

the use of the selected covariates to predict the response variable. According to the pseudo  $R^2$ , the retained variables are useful in predicting motivations/drivers for marshland uses.

According to the model, six variables explained the involvement in marshes activities: the number of persons per household (family size), the education level, the monthly income (in Kcf), the exploited surface area (ha), the perception that marshes are wastelands, and the starting year for exploiting marshland. Other factors such as the sex of the house-

**Table 3**  
Model fitting criteria and likelihood tests for the four marshland utilization patterns in Kabare and Walungu.

Effect	Model Fitting Criteria		Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model		Chi-Square	df	P-value
Intercept	39.776		0.000	0	
Age of the HH head	43.673		3.897	9	0.918ns
Sex of the HH head	41.317		1.541	3	0.673ns
Main activity	48.521		8.745	12	0.725ns
Marital status	39.813		0.037	6	1.000ns
Number of persons per HH	59.578		19.802	6	0.003***
Education level	1.877E3		1.837E3	6	0.000***
Income (Kcf)	93.737		53.961	6	0.000***
Exploited surface area (in ha)	83.074		43.298	6	0.000***
Perception of marshes as wastelands	76.502		36.726	6	0.000***
Presence of restriction policies	43.096		3.321	6	0.768ns
Starting year of exploitation	62.425		22.649	6	0.001***
Main crop produced in the marshes	71.642		31.866	21	0.060ns
<b>Wald Chi<sup>2</sup> (93)</b>	559.8				
<b>Prob&gt;Chi<sup>2</sup></b>	0.0001				
<b>Cox and Snell</b>	0.782				
<b>Nagelkerke</b>	0.952				
<b>McFadden</b>	0.885				

**Legend:** \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ , HH: Household, Kcf: Thousand Congolese francs, df: Degrees of freedom.

hold head, the main activity, and the presence of restriction policies in utilizing marshland resources did not affect the choice in utilization patterns (Table 3).

Table 3 presents the marginal effect of the four marshland utilization patterns by households involved and selected socio-economic drivers. From Table 3 and the Supplementary material, it is observed that different age groups utilize the marshes in different ways: younger users use wetlands for multiple purposes, whilst older exploitants (>50 years old) predominantly use them for agriculture. Based on the main activities, households involved in agriculture and brick making are those generally involved in crops (vegetables) and other goods trading, which significantly influence their choice of marshland use ( $p < 0.001$ ). Agriculture as the main activity of the household head significantly affects its involvement in marshes; such household is not only involved in activities such as brick making but also the construction of dwellings and settlements. Agriculture as main activity does not, however, affect motivation towards aquaculture. Marital status is also split between the single and married; married users are more likely to be involved in all the activities other than brick making. In contrast, single people are significantly interested in aquaculture and brick making. Households with < 3 people are more likely to be involved in crop production or dwellings and settlements rather than brick making and aquaculture; while those with > 8 members per household are more likely to be involved in agriculture or brick making. Heads of households who perceive the marshes as wastelands are likely to practice agriculture or aquaculture. While those who agreed with the presence of restriction policies were farmers and settlement and dwelling builders; they were contrasted on the effectiveness of these restrictions in conserving these ecosystems. The surface area exploited significantly affects ( $p < 0.01$ ) the choice of activities such as farming (generally by households exploiting areas < 0.5 ha for farming and house building). Farming on larger plots (> 1.0 ha) did not influence any of these four activities.

For agriculture, the main crop produced also affects the type of marshland use. Indeed, those practicing rice, tomato, and sugarcane mainly practice agriculture in the marshes but also build dwellings in the marshes mainly for storage and sale of the harvested products. Those who make tomatoes can also be involved in aquaculture and brick making. Those who practice sugarcane do both its production in the swamp and at the same time the brick making. Indeed, for a producer of the bricks and farmers, the sugarcane can be cut by the brick makers during the brick manufacturing and thus compensate for the expenses in terms of food for labor. The household head with a university-level tends to be involved in either farming or building houses and dwellings in the

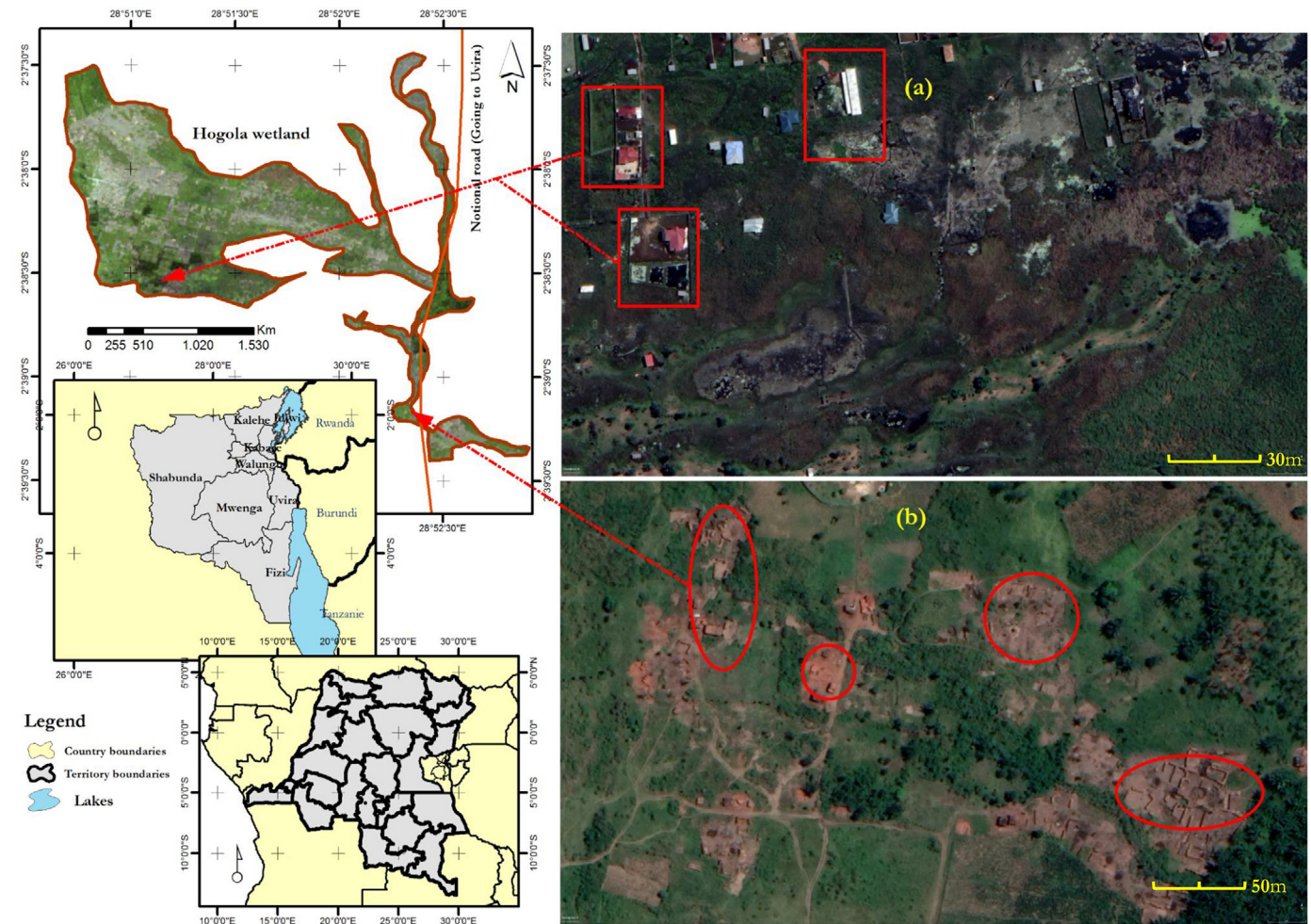
marshes, while those with a low level of education (primary and secondary) are more likely to be involved in other activities (brick making and farming).

### 3.2.2. Limitations and constraints in marshland utilization patterns

The results obtained from the survey, the focus groups with the users of marshlands, and validation from RS and GIS data certified that the greatest threats and causes of marshland loss are mostly associated with human activities. However, when approaching households living in the vicinity and working on these marshes and after the evaluations of costs and benefits of ecosystems, a distinction has been made between types of utilization for sustainable use ( $Chi^2=14.34$ ;  $df=2$ ,  $p=0.001$ ). Unfortunately, there is very limited capacity of the population to adapt to wise use practices, and there are no clear recommendations (and policies) on how these areas can be sustainably managed.

Based on discussions with users/exploitants during focus groups, the high rate of population growth (in both Kabare and Walungu) and much more in the cities, towns, and villages leads to high demands in terms of required lands (for housing and other services such as markets, schools, churches), and food demand that implies increasing crop production lands. The South-Kivu province and the entire African Great Lakes region experience a steady expansion of farmland and intensive agriculture. In order to increase crop production, farmers are used to do farmland expanding (and itinerant agriculture). Thus, farm activities continue to overexploit the land of the hills, which are already classified as "marginal", and begin to invade the wetlands, where there are still fairly good production conditions (fertility, accessibility to water even in dry season). One of the solutions suggested by users is a good management of the inland valley and marshes, taking into account the needs of the local population, the conditions of these ecosystems, their state as well as other provisioning services.

Fig. 7 presents the link between brick making utilization pattern and marshland degradation. Clay soil is exploited and used for brick making. In marshland scour land, this brick making is currently observed in most of the selected marshes. Herbaceous plants nearing these scour lands are degraded leading to reduced biodiversity as these species are cut and used to cover bricks during preparation processes. At the end, trees are also cut and used for firewood for brick firing/heating. According to survey results, brick-making needs  $\sim 1 \text{ m}^3$  of wood for  $\sim 7000$  fired clay bricks production (with  $\sim 9000$ – $15000$  bricks required for an average house of 3 to 5 bed rooms). Also, a lot of marshland grasses or herbs (mainly *Cyperus* spp. and *Carex* spp.) are currently being used to cover bricks during the firing process.



**Fig. 6.** Examples of settlement and dwelling development, brick making and farms in Hogola marshland, in Walungu territory eastern DR Congo (Image retrieved from CNIS/Airbus and georeferenced using ArcGIS 10.7).

## 4. Discussion

### 4.1. Marshland utilization patterns in Walungu and Kabare territories in the South-Kivu province

Survey results revealed that marshlands are used for different purposes (Fig. 2a); the majority of the households indicated four main marshland utilization patterns comprising agriculture, brick making, aquaculture, dwelling and settlement. Crop production and brick making are the dominant utilization patterns (with 73.6 and 11.7% users, respectively). These findings are similar to those found in many other wetland ecosystems located in the vicinity of cities, villages, and towns, mainly in tropical regions. These marshland utilization patterns significantly contribute to population livelihoods through the provision of food and opportunities for income generation (Dehnhardt et al., 2019). Cases where utilization of marshlands contributed to the welfare of surrounding populations are reported for many countries: Kenya (Ondienk et al., 2020); Zimbabwe (Gadzirayi et al., 2006), Rwanda (Nabahungu and Visser, 2013; Nabahungu, 2012), and South-Kivu in DRC (Chuma et al., 2021a; 2021c; 2021d; 2021e).

The marshland resource is first valued for crop cultivation, as the marshland provides water required for irrigated crops and deposits of sediments and nutrients that maintain soil fertility. This is not an isolated case for the South-Kivu province but common for the entire east African region (Schuyt, 2005; Chuma et al., 2021a). Crops such as vegetables, rice, sugarcane, etc. are mainly produced in marsh-

lands. Marshlands have been used mainly for vegetable production in several regions in Africa including in neighbouring countries such as Rwanda where marshlands are used for vegetable and rice production (Uwimana et al., 2018; Nabahungu and Visser, 2013; Tuyishime et al., 2020), fish production (Uwimana et al., 2018), and other human activities (Uwimana et al., 2018). Similar cases were reported in Burundi (Sawadogo, 1990; Cochet, 2004), Uganda (Van Soest, 2020; Kakuba and Kanyamurwa, 2021), and Tanzania (Munishi and Jewitt, 2019).

The second activity/use is the brick making; some marshes are almost solely exploited for brick making even if they are suitable for crop production. Thus, in these marshes brick making and crop production compete (case of Hogola and Chisheke) (Chuma et al., 2021a; 2021e). The conversion of marshland into residential areas (with a high rate of urbanization development) has a long history. Historical data such as the evidence of Bruneton et al. (1998); Segquier et al. (2009) confirmed these statements. These results are similar to those found throughout the world and mostly agree with the conclusion of Ajibola et al. (2016) and Adefioye and Ujoh (2012) in Nigeria that showed that building and settlement due to urbanization take over marshlands and result in a change in their spatial pattern; proportionally to increase in population that results in the takeover of wetlands for construction and agricultural activities. Changes observed by Hembra et al. (2017) were, however, classified as dangerous for ecosystem functioning because a continuous decline would lead to the extinction of marshlands and all the biodiversity they harbor. Although these phenomena have been reported elsewhere, they appear to be much more pronounced in the study area.

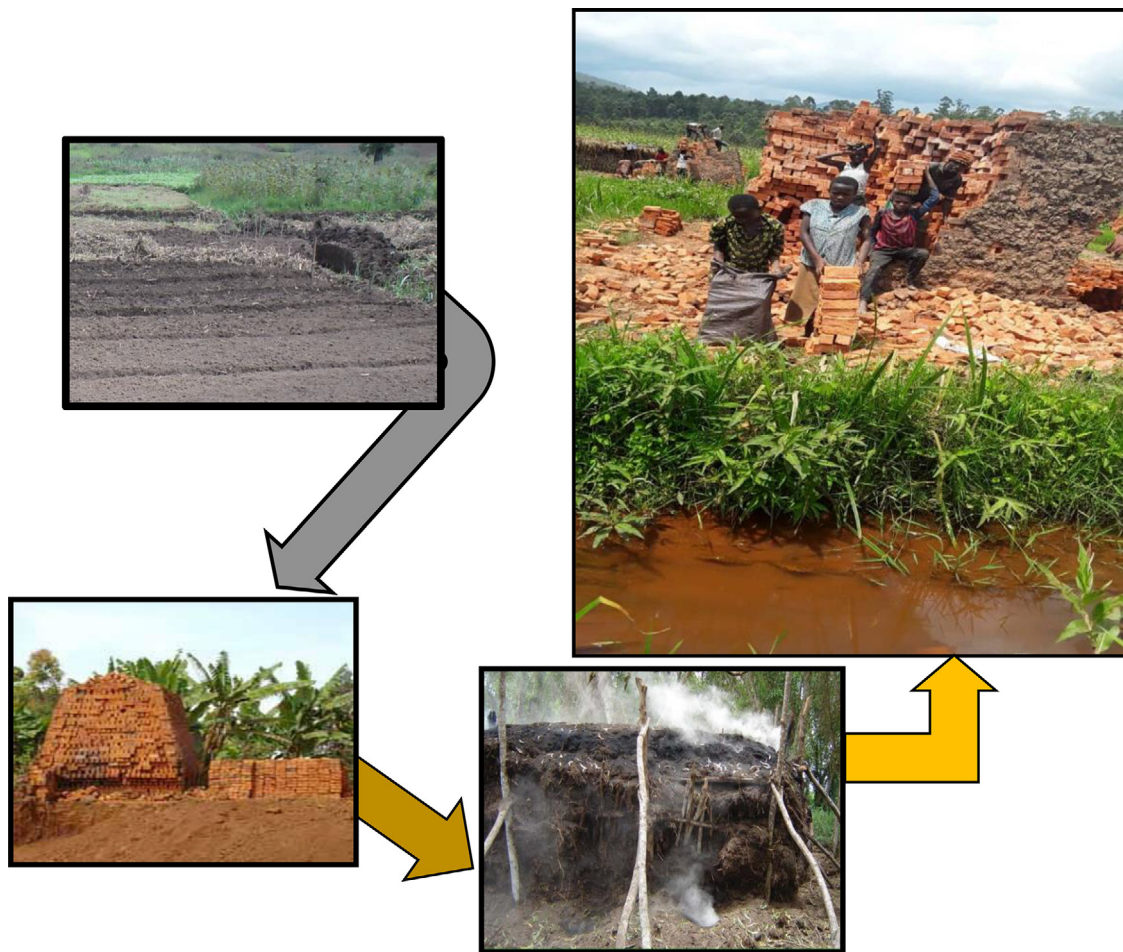


Fig. 7. Link between brick making for settlement, wood cutting for brick firing/heating and marshland degradation in South-Kivu.

For dwellings and settlements, a steady development of the brick making activity is currently observed and mostly on marshlands using clayey soil (Schuyt, 2005). This activity implies the preparation of a large quantity of clay harvested from marshes, formatted, burned/fired (with firewood) and protected by covering them with plant leaves harvested from marshes. Unfortunately, most times, the trees and shrubs are cut and used for bricks firing/heating process (Ogutu et al., 1997; Sampea and Pakiding, 2015). The brick making industry is traditional kiln that uses firewood as burning fuel, and have been assumed to be energy-inefficient and polluting. Besides, the brick making industry presents a negative influence on global warming and environmental sustainability (Dixon and Wood, 2007; Alam and Starr, 2009; Sampea and Pakiding, 2015). Fired clay bricks are one of the most important building materials in Africa and specifically in eastern DRC. Along with the increased economic and population growth, the demand for bricks by the construction sector had significantly increased in recent decades, leading to the creation of opportunities for establishing small brick making enterprises in marshlands. In South-Kivu, these activities are located as clusters in peri-urban and rural areas in the vicinity of major agglomerations (villages, cities, and towns) nearing marshes. These activities are mainly done on a small scale level and have become the source of the population livelihood as they provide employment, household income, and multiplier effect to the economy of the surrounding areas, as also reported in other regions (Schuyt, 2005; Buyinza et al., 2009). Daub brick types are mostly not durable, ineffective and are currently used by low-income households; the majority of the population prefers the fired bricks in construction. Unfortunately, the preparation of fired clay bricks has quite a significant environmental impact compared to the daub bricks.

All these activities undertaken in South-Kivu marshlands do not contribute to maintaining the good state of these ecosystems and their preservation from degradation. Two important factors can explain the aggravation of the ecosystem degradation in the context of eastern DRC: firstly, lack of regulating organization/institution specialized in the maintenance and enforcement of policies restricting destructive activities in these ecosystems; and secondly, no recognition of South-Kivu marshes (wetlands) by international regulating organizations; none of the marshlands in the province have been recognized as Ramsar sites. The only existing policies in the country relate to the peatlands of the western DRC without taking into account all other areas such as the eastern part of the country. Even though Ramsar sites are designated based on meeting at least 1 of 9 designation criteria (largely around wildfowl or endemism), these South-Kivu wetlands meet more than one of these criteria but still not interest both research and international wetland preservation objectives. The future management interventions could be guided by the Ramsar Wise-Use guidelines () or other tools developed for wetland wise-use such as the Wet-Health framework of South Africa (Melly, 2016).

A two-tiered co-operation plan should be considered first with local or national organizations working on the protection of biodiversity such as national parks, research institutions, and national reserves, but also with international and regional institutions to share expertise on wetland systems (as it is the case of CEPGL, SADC, FAO, UNESCO, etc). Another potential cause of human-induced wetland degradation is a lack of proper knowledge on how these complex systems function (Turner et al., 2000; Schuyt, 2005). The complexities of wetland systems and their link to the geography of the South-Kivu Province, and eastern DRC in general, are unfortunately not highlighted (elucidated).

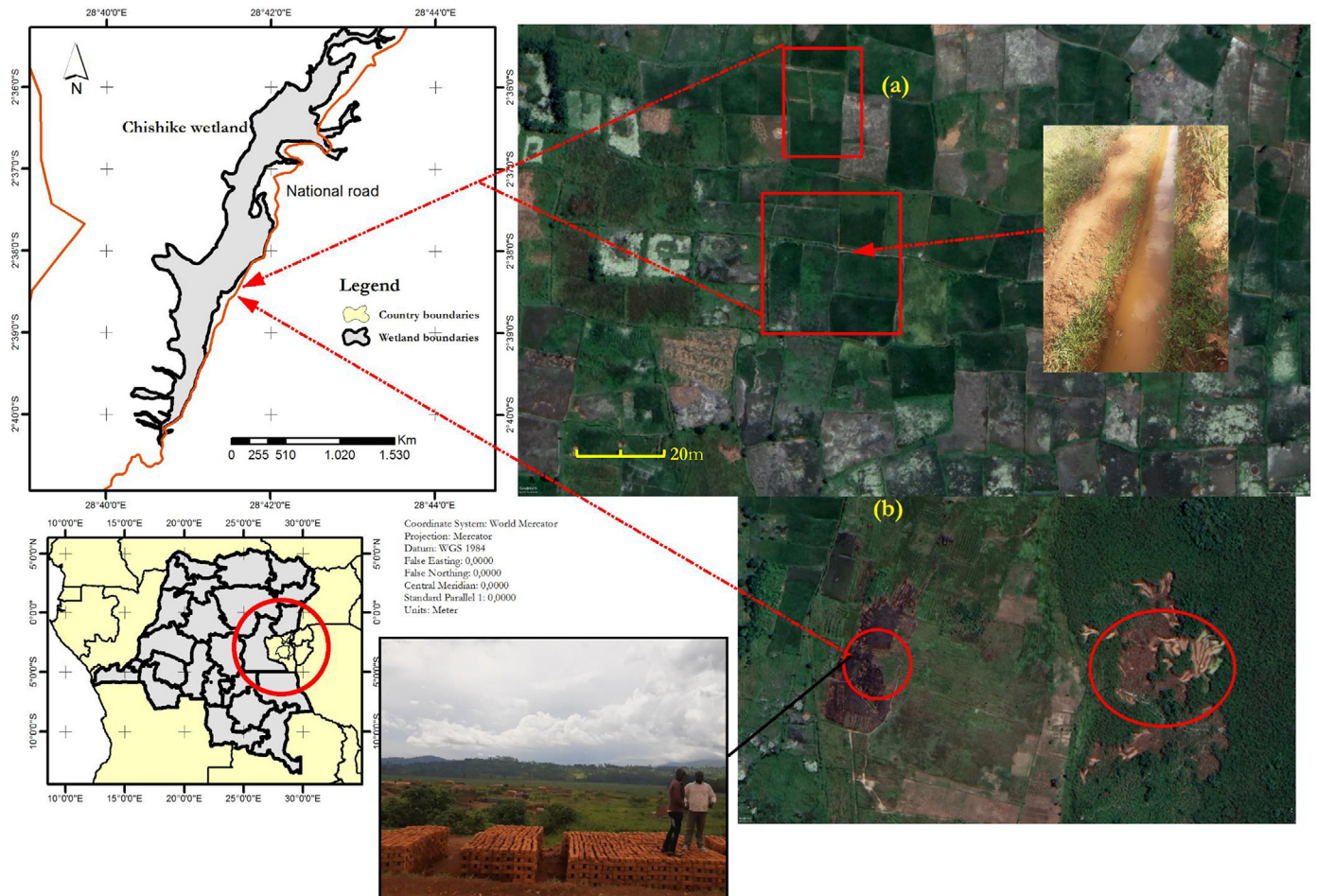


Fig. 8. Farm crops (a) and brick making in Chisheke wetland in Walungu territory, eastern DR Congo.

Future studies should consider a biophysical characterization based on a hydro-geomorphic framework of these areas.

Moreover, according to the local community's perception, these four selected marshes absorb excess rainfall water, reduce flooding and minimize subsequent infrastructure and economic damage in the area during storms. They also act as a filter for different pollutions (for water and air quality in the cities and towns surrounding them). Unfortunately, from the obtained results using the RAWES approach, only services and goods are recognized by communities for marshlands, those related to recycling, maintenance (carbon storage, erosion control, runoff, etc.) are not recognized by the local communities living in the wetland vicinity. As recommendations, we advise that special focus should be directed to: (i) determining the farming areas that should be regulated by policies for environment protection, (ii) defining which activities, when, and where (appropriate areas) to be subjected to use (or to enforce related policies), (iii) developing tools describing the permission process (regulatory provision) to community and decision-makers, (iv) increasing awareness on wetland resources and values, and (v) providing information on adequate agricultural practices and corresponding values.

#### 4.2. Which utilization type to be promoted in marshlands in the vicinity of South-Kivu urban agglomerations

An important component of sustainable use is understanding the spatial and temporal scales of the anthropogenic (and ecological) stressors on a system which should be part of spatially applicable decision-making processes. This does not only mean loss of livelihood options for local people but also means loss of biological diversity. The concept of sus-

tainable wetland management is enshrined in the Ramsar Convention that was adopted on 2<sup>nd</sup> February, 1971 in the Iranian city of Ramsar. Sustainable wetland utilization is defined as human use of a wetland in a way that it may yield the greatest continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations (Ramsar, 2018). Thus, any choice of marshland use should be made taking into account the local conditions with scientific evidence to guide decision-makers, while favoring low-pressure anthropogenic activities. If agriculture for example, it would be necessary to think of adequate agricultural practices for such areas (good water drainage, good fertilization practices reducing nitrogen and phosphate pollution). If intending to invest in the brick making industry, it would be necessary to develop regulations determining at what minimum level of degradation this type of use can be carried out. Also, we would recommend privatizing each use for each type of marshland for increased accountability.

#### 4.3. Determining factors and community perceptions affect marshland utilization patterns in the vicinity of South-Kivu urban agglomerations

Of the 13 factors studied, six significantly influenced marshland utilization patterns (Table 3 and Supplementary materials). These factors comprise the number of persons per household, the education level, monthly income, surface area exploited, perception of marshlands as wastelands, and the starting year of marshland exploitation.

In the model, many explanatory variables affect marshland utilization patterns. While the regression coefficients of the age, sex, main activities, number of persons per household, education level, income, and



**Fig. 9.** Marshland activities in the vicinity of Walungu and Kabare urban agglomerations: the pictures (a) and (b) represent the dwelling and settlement constructions, (c) represents water pollution in constructed areas of the marshlands due to waste deposit by runoff; (d) refers to pond for fish production in the Mudaka marsh, (e) and (f) relate to crop production in Mudaka marshland, the first activity being the opening of the land by bush burning.

start year for marshland exploitation have positively affected agriculture utilization at 5% *p*-value threshold; the exploited field area and the age of household head have negatively affected agriculture as marshland utilization pattern. The positive impact of the household size suggests that households with 3 to 7, and >8 are more likely to practice agriculture than other utilization patterns, a trend significantly different from aquaculture and brick making utilizations. The negative impact of the household size on brick making and settlement and dwelling maybe related to the fact that in the study area, household members are mostly used as workers in farms. This suggests that large families tend to rely greatly on agriculture than on other marshland utilizations. With limited incomes and higher unemployment, these families are likely to rely on environmental resources to meet the basic needs. These results are similar to the findings reported by Chuma et al. (2021a) in Hogola and Chisheke and in Uganda (Barbier 1996; Buyinza et al., 2009).

The age of marshland users has positively affected the brick making and aquaculture utilization patterns; younger people being more dependent on brick making and aquaculture in marshlands. This is also because these activities are sometimes perceived as illegal and only young people are willing to take such a risk. Besides, limited off-farm opportunities exist for these youths, and thus they rely more on brick making to meet their basic needs. Many studies in the region have confirmed these results that youths, and mostly in the rural areas are trapped in poverty owing to limited alternative economic opportunities. It is young people who are still energetic that can take such energy-demanding activities, brick making or dwelling (Buyinza et al., 2009).

The education level has also positively affected agriculture and aquaculture while the brick making and settlement and dwelling are negatively affected. Households with members of primary and secondary education levels are mostly exploiting marshlands for brick making and settlement and dwelling rather than agriculture and aquaculture. This seems obvious as crop and fish productions in such conditions (hydromorphic lands) require knowledge on water treatment and management that only educated households may have. The educated people have also greater off-farm employment opportunities in the study area (Mondo et al., 2019, 2020; Mugumaarhahama et al., 2021). In general, education is expected to open up diverse opportunities better than simple activities such as brick making and sales in marshes. Another aspect is that aquaculture in the South-Kivu marshes is generally practiced by a new generation of young people who have undergone university training or non-degree specializations in research institutes and non-governmental organizations (NGOs) working in these areas (Parker et al., 2018; Mushagalusa et al., 2019). In South-Kivu, fish production systems include cage aquaculture, fully commercialized cage aquaculture and mostly the ponds within smallholder farming systems (up to 1,550 smallholder farmers near Bukavu City are producing tilapia in such manner). These producers have been supported by IITA through extension services (providing training) and input supply. Unfortunately, their budget is unknown (and possibly overlaps across different initiatives). Scaling this beyond the current groups of farmers could be possible but would entail another magnitude of challenges of engaging across remote areas and the lack of skilled implementers.

In Africa, marshland use changes in general are linked to common factors that increase pressures on marshlands: demographic growth, rising poverty, and severe economic stress. Also, the benefits of wetlands are often not shared by relevant (competent) bodies. A further underlying cause of much wetland degradation is information sharing failures, resulting in limited awareness of wetland exploitants on ecological implications of their activities. Information sharing failures relate to the complexity and invisibility of spatial relationships among groundwater, surface water, and wetland vegetation (Buyinza et al., 2009; Nabahunu, 2012).

The rising human population and the need for increased agriculture and industrial activities' expansion have led to substantial pressure upon the marshland's resources. People destroy marshland because they generate low or less tangible benefits than they think makes economic sense

for them. The case of the River Niger (Dugan and Dugan, 1990) where one of the most fundamental drivers for the conversion of marshland utilization patterns is the lack of appreciation of the extent, to which these ecosystems are important and are used by local communities that are adjacent to them. Even Barbier et al. (1996) showed that activities that lead to marshlands utilization patterns are often poverty-related. Wetlands and marshlands' utilizations, in general, are mostly influenced by fundamental economic forces (Schuyt, 2005).

Figs. 6 and 8 present the location of houses (buildings) in the Hogola and Ciske marshlands (Fig. 6a) and soil scoured by brick-making activities. Deep holes are visible in the satellite image (Fig. 6b) showing areas of heavy exploitation of clay for the manufacture of bricks. Fig. 8a shows the lines of the drainage channels on marshlands to practice different crops. The difference even in terms of the crops grown in the marsh fields can be seen in terms of changing color patterns on the satellite image. This also shows the variation in water level (moisture content in the marshland plots).

Fig. 9 shows the various other pressures suffered by wetlands in the Kabare and Walungu territories. We can see in the Fig. 9 (a and b) that the houses were built in these areas even though the water table remains superficial. Wastes are deposited in these ecosystems considered as dumping boxes for these houses, so its waters become polluted. Fig. 9 (e) and (f) show the bushfire for the field opening activities in these areas, and a sugar cane field under full exploitation.

The role of Walungu and Kabare wetlands on biogeochemical cycling, flood control and aquifer recharge needs to be reinforced in the future studies. Unfortunately, the data-scarcity in South-Kivu province and in eastern DRC is a challenge to informing the wetland custodians on adequate practices and attitudes vis-à-vis these ecosystems. This should be considered as key recommendations for targeted approaches to the landscape and catchment management (e.g. through a global restoration focus such as through the Global Environment Facility). Studies such as those of Sekane et al. (2011) and Musasa and Marambanyika (2021) reported that the age of household head increases dependency on marshland utilization for food security, while and Ramsar (2018) observed that increased age of the household head broadens the spectrum of resources available for marshland utilization. Households headed by females had limited access to this fragile resource due to lower access to natural resources including wetlands. In South-Kivu agglomerations, diversification of horticultural activities has been necessary and sustained by the emergence of external markets. In some cases, vegetable products are exchanged for maize, sorghum, sugar cane, etc. in periods of drought through barter trade which improves the food security status of local communities.

## 5. Conclusions

Marshlands in the vicinity of Walungu and Kabare urban agglomerations are constantly changing due to anthropogenic pressure from four main activities: crop production, aquaculture, brick making, and dwelling and settlement constructions. These activities cause the wetlands to constantly transform. Important changes are currently observed in these ecosystems and mostly the reduction of the water level. These marshes still produce vegetables to satisfy the increasing population needs in the neighboring urban agglomerations, clay quarrying for brick making for construction, but they also sustains other crop productions such as sugarcane, rice, and sorghum. The small houses built in these areas are used for selling products from marshes (crops, bricks, fish, and other goods) and, contributing significantly to land use and land cover changes. Based on households involved in these activities, demographic, economic and perception factors are determinants for the utilization patterns. However, crop production and brick making are the main uses of marshlands in the study area. Future research should emphasize on the environmental effects of each of these utilization patterns while making sustainable monitoring of these ecosystems to support decision-making. Application of sustainable agriculture and integrated

water and nutrient management techniques, and continued monitoring, research, and capacity building to support adaptive management are to be taken into consideration in the future perspectives. Improved management implies also coordination at the provincial level between territories and local organizations intervening in these areas while implementing a strong policy framework dealing with wetland issues. Building capacity among stakeholders should be part of this effort and linked to the governance framework. Co-learning on wetland sustainable management and restoration have to be tested. Continued monitoring of the marshland ecosystems and researches into the trade-offs between provisioning and regulating ecosystem services are also to be promoted in the study area. Ecosystem services have been rapidly assessed; this study suggests that both qualitative and quantitative ecosystem services assessments are needed in the area in order to fill the gap in understanding the hydrological and pedological provision and regulating services of these resources and similar wetland systems Fig. 3.

### Declaration of Competing Interest

No conflict of interest.

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### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2021.100297.

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