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Impact of climate change and human actions on the turbidity of water from wetlands in Rukiga district in Uganda: implications for health and community involvement

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Abstract
Climate change has been a serious issue in many countries, including Uganda, and has led to water contamination, pollution, and even water scarcity. Wetlands have shown their capacity to maintain water quality and safety for the population's health through their filtering function, but they are highly susceptible to agricultural activities and destruction. This study aimed to determine the status of fifteen wetlands in the Rukiga district and the impact of climate hazards and human activities on water quality in the area where a conservation project was implemented by three organisations. Eighteen-month records were obtained, and readings were taken to determine the turbidity level of the water from the different wetlands. The reading mean of each wetland was used to determine three water source categories: clear or non-turbid (read > 80), less turbid (read 50–80), and very turbid (read 0–50). Analysis was performed with SPSS V28.0, which included univariate and bivariate analyses. Observation and conversation notes with project staff and community members were taken. The study showed that 93.33% of the water sources from wetlands were turbid, and for some, the turbidity did not oscillate stably from one category to another. Only one water source (6.67%) was still clear (non-turbid) for 18 months. These communities mostly contain wetlands as the main sources of water, which is collected from streams. Wetlands are more susceptible to agricultural activities, and hills are deforested exposing to soil erosion leading to water contamination. In conclusion, most wetlands are destroyed and have lost their filtering capacity and exposing people to consumption of unsafe water. Climate hazards and agricultural activities contributed the most to this issue. Interactions between NGOs and communities are helpful in responding to this threat.

Keywords Water clarity · Wetland · Conservation · Health · Turbidity · Diseases · Community · Climate change · Environment

1 Introduction

The importance of safe and readily accessible water for public health has been demonstrated for drinking, domestic use, food production, and other recreational purposes [1]. It has been documented that making clean and safe water accessible to the population when needed from an improved water source helps boost the country's economy and contributes to reducing poverty [1]. Access to safe water in sufficient quantity, affordable, and physically accessible for personal and domestic use has been recognized by the UN assembly as a right to everyone worldwide [1, 2].

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Water turbidity is an indicator of poor water quality and affects the health status of humans and animals [3, 4]. The WHO has recommended a turbidity level of less than 4 NTU (nephelometric turbidity units) for drinking water, which is equivalent to a reading distance of more than 85 cm measured by using a clarity tube [4]. If the distance is less than 85 cm, then the turbidity is more than 5 NTU; under these conditions, further actions to clear water are recommended before use [5]. The same observations were made by researchers at the Penn State Agriculture & Environment Center, who reported a level of less than 5 NTU for recreational use of water [6].

In addition, access to clean, safe water and sanitation is the target 6 of the Sustainable Development Goals, and a call for action was launched because the goal is far from being achieved by 2030 [1, 2, 7]. Hence, there is a need for governments to increase their efforts and access resources to progress toward achieving universal access to safe water [2]. It has been documented that 5.8 billion people worldwide have access to safe water, while 2 billion people still lack access to safe, protected, and reliable water sources [1, 2]. Among these 2 billion people, 1.2 billion use basic services (those with improved water sources located at a distance of 30 min in a round trip), 282 million use limited services (those with improved water sources requiring more than 30 min in a round trip), 368 million use water from unprotected wells and springs, and 122 million use untreated surface water from lakes, ponds, rivers, and streams [1, 8]. The 2 billion people live in water-stressed countries, and this stress is expected to exacerbate in some regions as a result of climate change and population growth [1]. Globally, 2 billion people with water stress use water sources contaminated with feces; are exposed to a high risk of illness due to microbiological contamination; and can experience diseases such as diarrhea, cholera, dysentery, typhoid, hepatitis A, and polio, which cause 485,000 deaths every year worldwide [1, 2].

There is a large need to quadruplicate efforts toward universal coverage of basic drinking water services because the world is still not on track to achieve SDGs 6.1 and 6.2 by 2030, and fragile countries may unevenly accelerate progress [1, 2, 8]. According to the WHO guidelines, water sources should be monitored regularly for quality checks, and joint efforts and coordination between the actors involved, including governments, civil societies, and local populations, are needed [9]. A regular quality check for drinking water is a public health indicator that requires particular attention, and testing should be planned and organized [2, 7, 9].

Climate change has been a serious issue not only for livelihoods and food production but also for water sources, leading to a loss of quality water and, sometime, a loss of water sources due to declining rainfall and increasing demand [10, 11]. Floods are reported to significantly contribute to water source destruction, and urgent actions are needed to reduce the climate risk to protect the population's health. It is important to incorporate measures of climate resilience in water safety plans and improve the management of water resources [11]. Prolonged drought and changes in temperature impact the quality of water in diverse ways, including increasing water salinity and contamination, especially in surface water [10, 12].

Climate change is known to be a major contributor to water scarcity and impacts the health and well-being of populations in diverse ways, including increasing water-borne diseases [13]. Approximately 80% of illnesses are caused by the use of unsafe drinking water, especially in low- and middle-income countries (LMICs) [13]. The water supply is directly linked to food security, sanitation, and hygiene, which are direct contributors to the global burden of diseases, revealing that the impact of climate change on the water supply has negative consequences on human health [14, 15]. Several African countries are facing challenges in sustaining adequate water supply systems due to climate change [14].

The role of wetlands as contributors to water supply, wildlife habitat, flood protection, and filtering functions to maintain human and animal health has been demonstrated in numerous studies [16–21]. A study conducted in the United States of America showed that water from lakes that contained large quantities of particulate matter, solids and organic particle-bound nutrients was free of these substances after passing through wetlands via a hydraulic performance system [18]. Another study conducted in Australia emphasized the value of wetlands as filtration systems for reducing the cost and burden on people's health; artificial filtering costs more than the natural filtering provided by wetlands [21]. The study showed that almost 90% of the wetlands have been destroyed by industry (only 500 ha remain out of 5700), leading to a loss of filtration function in the wetlands and exposing people to unsafe water [21]. Another similar study showed that reconstructing wetlands helps to improve water quality by reducing significantly the quantity of particles from water [22].

Climate change has affected the African continent, especially Sub-Saharan Africa, where a large number of people have no access to improved water sources and use surface water that is affected by irregular rainfall, giving it a muddy, acidic, and turbid appearance [23]. Uganda has experienced the effects of climate change on water sources in diverse ways. A study conducted in Uganda at the household level showed that 30% of the population did not have access to safe water sources, and some decided to migrate to other places as a coping mechanism [24]. Another study showed that people living in remote areas of Uganda are exposed to the constant threat of floods and landslides, resulting in water source loss affecting themselves and their crops [25].

The government of Uganda recognized that wetland degradation has serious consequences for the lives of both people and animals and may even impact energy production systems by decreasing the water supply in the Kisizi Fall, where a 300 kW energy plant was constructed in 2008 [26]. In Uganda, 3 drivers of wetland destruction have been identified. First, Uganda has experienced a rapid population explosion, which has increased pressure on land availability, leading to a high demand for wetland use.

The second factor is economic pressure due to a low level of job availability and poverty. Third, rapid industrial development expresses the need for land for agricultural activities (e.g., tea plantation in the Mulehe wetland, as shown in Fig. 1 below) [26].

In an effort to respond to climate change crises such as soil erosion and flooding, many studies have suggested Napier grass plantations [27–33]. It was demonstrated that Napier grass plays a critical role in protecting gardens against soil erosion and increasing soil fertility and is included in pest management strategies [31]. Moreover, increasing productivity and soil stability can occur when Napier grasses are mixed with leguminous schrubs or Calliandra plants [30]. Planting Napier grass in gardens contributes to soil health and prevents environmental degradation [32]. Napier grass has shown efficacy in preventing crises such as landslides in addition to floods [29, 30, 32, 33].

The Napier plantation process was known by Ugandan farmers many decades ago but was abandoned due to ignorance [29]. The human action of deforestation has made the effects of climate change worse in Uganda, particularly in the Rukiga district [29, 33]. The Rukiga district is among the most vulnerable zones in Uganda and is prone to crises from landslides and floods [29, 33].

It is important to note that farmers in the Rukiga district and even in the Kabale district are now conscious and willing to make positive changes in terms of environmental protection and responding to these chronic crises in the respective areas. Many farmers have decided to plant Napier grasses on deforested hills and in their respective gardens to avoid landslides and soil erosion [29]. An example of Napier grass planted in one of the farmers' gardens is shown in Fig. 2. Most importantly, Ugandan government officials have supported farmers in their efforts to plant Napier grass to respond to these crises by providing Napier grass seeds for some occasions [33].

It is known that wetlands have the natural capacity to filter water to remove sediments, toxic products, organic particles, and heavy metals to protect people's life [17, 20] given that destroyed wetlands lose the ability to filter water to protect people [17, 20]. However, there are gaps in detail on the status of particular wetlands in particular settings and what local actions affect them, hindering the provision of clean water to people and animals. Information about how responders and local communities interact to protect wetlands is still lacking. This study contributes to filling these gaps and provides insight into potential solutions for sustaining and maintaining healthy wetlands. These findings also reveal areas that need further research and interventions in terms of wetland protection and water source cleaning.

The aim of this study was to explore the status of fifteen wetlands in terms of turbidity level as the main source of water for the populations of the Rukiga district in Uganda and how human actions impacted these water sources and to determine the contributions of the conservation project implemented in the district. Hence, our research questions are

Fig. 1 Tea plantation growing in Mulehe wetland [26]

Fig. 2 Napier grasses were planted in one of the gardens in the Buhara subcounty, Kabale district [29]

as follows. First, how has the turbidity status evolved over time for the different water sources in the project catchment area of the Rukiga district? Second, how do human actions impact the level of water turbidity in the Rukiga district where the project was implemented? Third, what are the contributions of the conservation project in protecting wetlands and keeping the water source non/less turbid?

2 Methods

2.1 Study setting

This study was conducted in the zone where a conservation project was implemented to understand the impact of the project on community change behavior for environmental conservation. The conservation project was implemented in some parishes of the Rukiga district to protect human and wildlife health by conserving and sustaining the environment, more specifically, wetlands. The project is implemented mainly by the International Crane Foundation (ICF) in conjunction with Margaret Pyke Trust (MPT) and Rugarama Hospital. The Rukiga district is known as a very hilly place in Uganda with many wetlands. The district is composed of 25 parishes with a population of 123,821 people from 27,258 households. The project was implemented in 13 parishes of the district, with 15 sites identified for water turbidity testing. It is noted that in most of the 15 sites with 15 wetlands identified for the testing process, the populations have wetlands as the main source of water that they use for drinking, food production, domestic activities, and recreational use. Only a few other sources of water, such as tap water and/or spring water, were identified in some of the 15 areas. Surveillance to check the quality of water in these wetlands (water sources) has not been performed regularly, and the project has initiated a monthly check to test the turbidity of water from the 15 water sources. This provides a window for discussion with community members to involve them in conservation and create a spirit of ownership for protecting wetlands for both humans and animals. Notably, water safety tests were not performed for these wetlands to confirm the pollution level in terms of the presence of microorganisms, toxic products, heavy metals, and other organic particles. Rukiga district populations do not have (or have less) access to safe or improved water sources, most people fetching water from streams in wetlands. Only a few of them have access to tap/spring water that they access mostly after traveling a long distance, and most of the springs are frequently exposed to floods during the rainy season, leading to destruction of the water sources.

It is important to note that the project has initiated, as part of its activities, supporting community members to plant Napier grass on the hills around the wetlands. This helps to prevent contamination of wetland water by sediments coming from hills caused by soil erosion during heavy rains. The project has distributed Napier grass plants to the large population that has gardens and has trained them in making trenches and terraces to prevent soil erosion. This approach has the main objectives of protecting wetlands from contamination and protecting community members from soil erosion to maintain fertile soil in gardens, leading to an increase in agricultural productivity. The project has divided the supported sites into two groups: those that are integrated and those that are not integrated (commonly called parallel sites). The integrated sites receive support for both health and environmental conservation issues, while the parallel sites receive support only for health issues.

2.2 Study design, data collection, and analysis

This study is descriptive and comparative and involves mixed methods (quantitative and qualitative). This retrospective and cross-sectional study collected data from past reports and from conversations with participants (NGO staff and community members) and from observations of water sources (wetlands) in the Rukiga district. For the quantitative part, the author explored the project reports of the monthly water turbidity monitoring and the data reported and stored from October 2021 to March 2023 (18 months). The author collected the data from reports during the period beginning on 21 July to 27 October 2023 and collected additional data from observation and conversation notes. Water quality monitoring was performed using a specific graduated tube (graduated from 0–100 cm) with a magnetic device that helps to determine the turbidity (clarity) level visually. The reading is performed by looking through the tube filled with water from the swamp/stream. The reading is performed from the side of 0 graduation, and a second person moves the magnetic device in the opposite direction until the device stops being seen. The word turbidity will be more used in this manuscript than clarity which can be used to mean non-turbid and is related to the visual aspect of the water source. The level of turbidity for that water source is where the device disappears from being seen. As the process is performed by the human eye and to minimize errors, the reading is performed 3 times for the same water source and by different people. The mean of the 3 readings is taken as the value for that month as the monitoring is performed monthly. This measuring process was informed by the Gokce Capital guiding lecture, which explains the causes of turbidity, its levels, and how to measure it [34]. The adopted classification for turbidity was informed by findings from research conducted by Azis et al. [35], who classified turbidity into four levels as follows. The first level is fairly turbid, with a turbidity measure of 15–25 NTU; the second level is turbid, with a turbidity measure of 25–35 NTU; the third level is moderately turbid, with a turbidity measure of 35–50 NTU; and the fourth level is very turbid, with a turbidity measure of more than 50 NTU. Another guideline from the DataStream Initiative [36] classifies the three levels as follows. Level one is low turbidity with a turbidity less than 10 NTU; level two is moderate turbidity with a turbidity between 10 and 50 NTU; and level three is high turbidity with a turbidity greater than 50 NTU. Combining these two guidelines and considering the guide from the WHO [4], water turbidity was classified as follows (the reading was performed by transparency tube graduated in cm): the sources with a reading between 0 and 50 cm (more than 10 NTU) are classified as very dirty/turbid, those between 50 and 80 cm (05 and 10 NTU) are classified as less dirty/turbid, and those above 80 cm (less than 05 NTU) are considered clear/not turbid. The equivalences from cm and NTU were extracted from the research findings conducted by Elizabeth Myre and colleague [5]. For this study, 15 wetlands and water sources were considered for comparison. To facilitate this classification, the monthly mean (average) reading was calculated for each wetland for the 18-month period from October 2021 to March 2023.

People who had planted Napier grass were recorded at their respective locations. These data are collected through monthly monitoring and completed. People who did not plant these grasses were also recorded. The conservation project was implemented at two groups of sites. First, integrated sites in which interventions for both health and agriculture are implemented. Second, parallel sites in which only interventions for health are implemented. This implementation process aimed to assess the impact of a multidisciplinary approach (environmental conservation-health). These records were considered in the analysis, especially to determine how integration has impacted the understanding and willingness of community members to plant these grasses in their gardens. The impact of integration on water turbidity was also assessed.

Regarding the qualitative part, we used additional information from observation notes, narrative reports, and conversations with project staff and community members. The author organized a visit in the field to collect these data from the 18-month reports and collect additional qualitative data. All participants who were involved in the conservation of the data collection signed consent forms. This approach was used to obtain additional insights into what the quantitative data cannot provide, such as the status of wetlands (cultivated or not), community behavior toward water sources (e.g., washing motorcycles in the stream), and the presence of improved protected water sources such as spring or tap water. SPSS V28.0 and Excel were used to develop the databases and analyse the data. The analysis was both univariate and bivariate. The on-sample p value test was used to determine the significance of differences between categories for univariate analysis. For bivariate analysis, the chi-square test and paired-sample t-test were used for significance. Thematic analysis was used for qualitative data and was performed inductively.

2.3 Data presentation

For univariate analysis, the data are represented in graphs that are in line format for trends and in bar charts for percentages or counts. For bivariate analysis, the data are presented in graphs and tables with counts and/or percentages.

2.4 Ethical consideration

This study was approved by the ethics committee of the London School of Hygiene & Tropical Medicine (LSHTM), reference number 24031. At the country level, the study was approved by the Institutional Review Board (IRB) of Makerere University (reference numbers: MAKSS REC 10.20.447/CR and MAKSS REC 10.20.447/CR2) and the Uganda National Council of Science and Technology (UNCST) (reference number: HS1137ES). The study is largely approved for both quantitative and qualitative data collection, including interviews, focus group discussions (FGDs), and observation notes. In-depth interviews and FGDs were not considered for this manuscript, as they were part of another manuscript in development. All the quantitative data did not involve human participants and were collected from the project reports; they are about measures of water clarity (turbidity) from the 15 water sources and were considered for the retrospective part of the study. The data were collected in accordance with the country regulations and guidelines.

2.5 Study limitations

This study has used reported figures measuring water turbidity using graduated clarity tube (in cm). The conversion from cm to NTU was guided by the guideline from WHO and from the publication of Elizabeth Myre and colleague [5]. There no specific device to measure turbidity in NTU. In addition, this research did not consider investigating the level of wetlands' water pollution to check the presence of microorganisms, heavy metals, agricultural nutrients because the conservation project did not have the capacity to perform this kind of test. This is an important field for future research.

3 Results

In this section, we describe the level of water turbidity according to three levels of classification (non-turbid, less turbid, and very turbid), determine the status of wetlands (fully, partly, or not cultivated) and determine what human actions contribute to this degradation of water quality. We determine also the interventions initiated by the consortium to mitigate this issue of water turbidity and its impact on environmental sustainability, how people access water for daily life and how people are exposed to turbid water from wetlands.

3.1 Classification of wetlands in the study area according to turbidity level

This section shows the trend of turbidity for the 15 wetlands (water sources) for a period of 18 months of project implementation. It was observed that, among the fifteen wetlands, only one maintained its clarity during the 18-month period of the project. This wetland is Kabimbiri-Kyerero. Other water sources are between 50 and 80 cm for some (less turbid) and between 0 and 50 cm for others (very turbid).

Figure 3 below shows the 3 categories of water sources from the 15 wetlands: clear or non-turbid (left), less turbid (middle), and very turbid (right). This classification was supported by the calculation of the average reading for each wetland for the 18 months of the project. Those for which the average reading fells in the interval 0–50 were considered "very turbid", those within 50–80 were considered "less turbid", and those above 80 were considered "non-turbid" according to the three levels of classification.

The trends of the 3 groups of wetland water sources are shown in Figs. 4, 5, and 6.

Figure 4 shows how this wetland water source evolved over time during the 18 months of project implementation. Its clarity was maintained during this period of the project, except for the month of March 2022, when the reading value dropped to 36 without clear reason. Our investigations provided tentative explanations, as detailed in the discussion section.

Fig. 3 Water sources from wetlands (from left to right: non-turbid, less turbid, and very turbid)

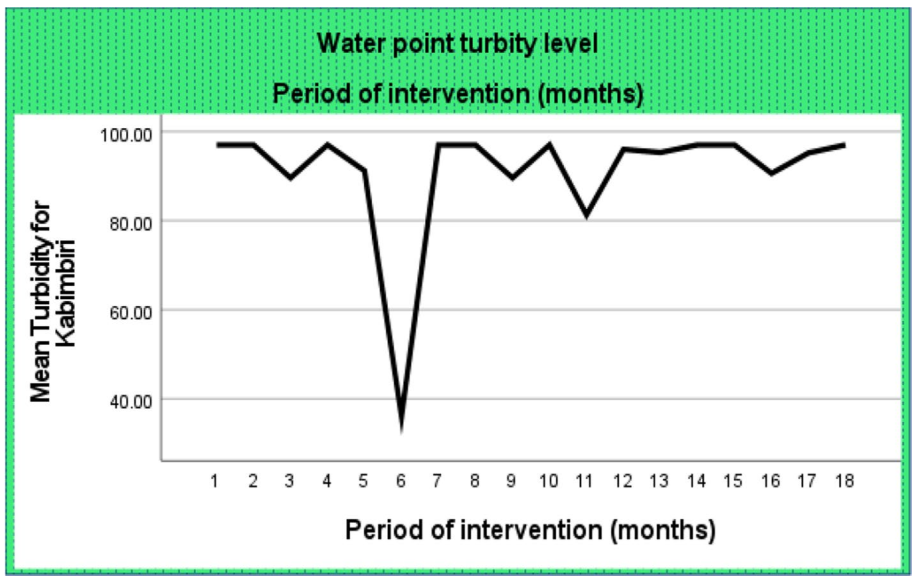


Fig. 4 Trend of Kabimbiri-Kyerero wetland water sources over an 18-month period (from October 2021 to March 2023)

Figure 5 shows the trends of 5 wetlands with less turbid water sources in the project implementation area.

As shown in this graph, these wetlands exhibited readings mostly between 50 and 80 cm with a considerable number of sporadic oscillations under 50 and sometimes above 80.

As previously explained, August is the month when all the wetland readings had decreased, and the same observations were made in March, May, and November of the study period. This can be explained in part by five main reasons. First, these months coincide with the periods of active agricultural activities and heavy rain. Second, the farmers use streams for washing feet and other materials after working in their gardens. Third, local community members wash their motorcycles and bicycles in streams. Fourth, hunting activities in the wetlands were performed. Fifth, pastoral communities bring their animals to streams to drink water.

The wetlands of the very turbid water sources exhibited almost the same trend as did the less turbid wetlands during the 18-month project period. This is shown in Fig. 6.

This figure shows that these nine wetland water sources were very turbid during most of the entire 18-month period, with small pics of oscillations above the reading of 50.

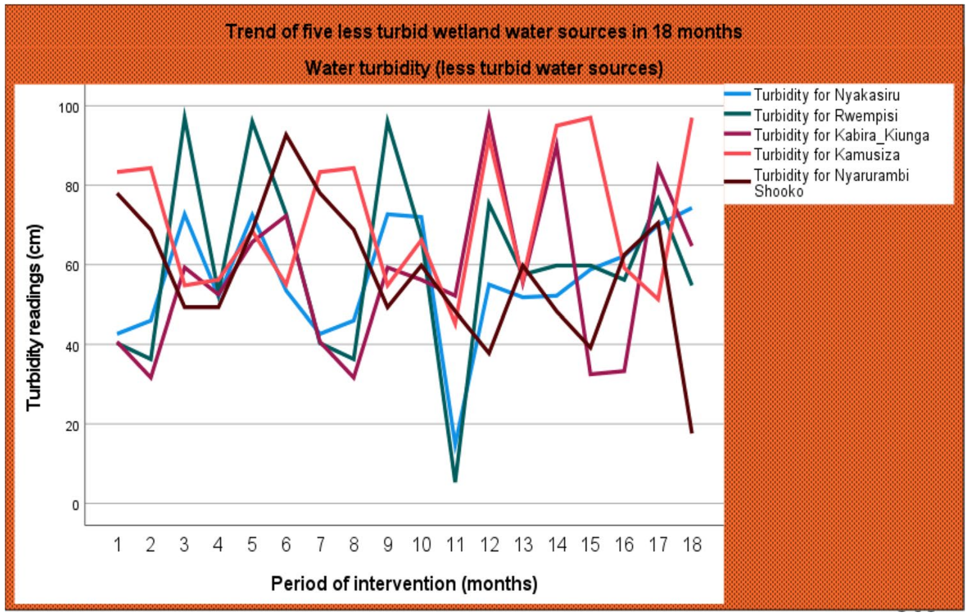


Fig. 5 Trends of the five less turbid wetland water sources over an 18-month period (October 2021–March 2023)

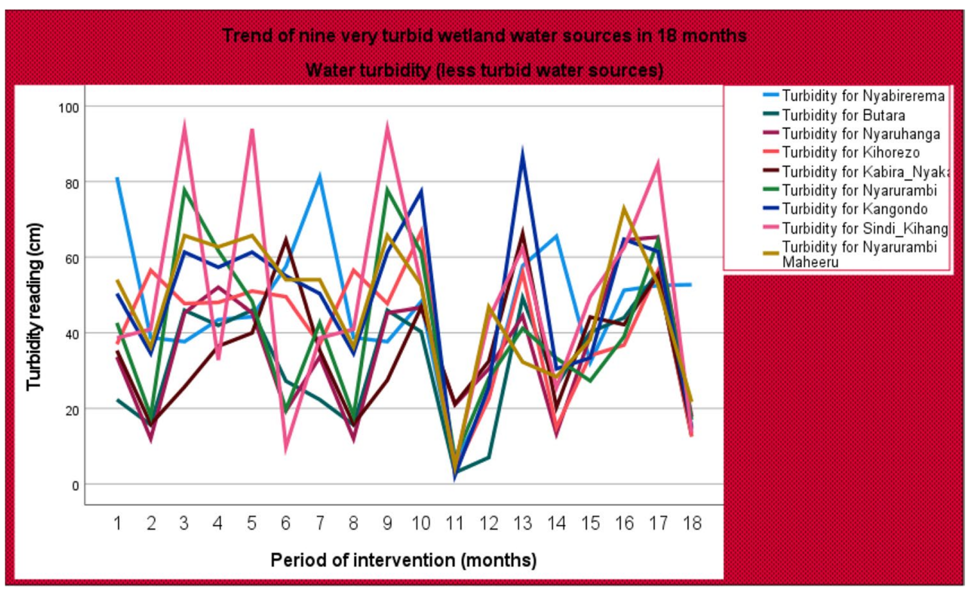


Fig. 6 Trends in the water sources of nine very turbid wetlands over an 18-month period (October 2021–March 2023)

3.2 Wetlands and water turbidity level

In this study, we explored the level of water turbidity among the 15 wetlands that are present in the conservation project implementation area. This is shown in Fig. 7. Only 6.67% of the wetlands had non-turbid water, 33.33% were less turbid, and 60% were very turbid. This leads to 93.33% turbid wetland water sources, which likely

have lost the ability to filter water for the benefit of both humans and animals. This difference was statistically significant according to the one sample test (p = 0.041). This shows that the most wetlands in the area have very turbid water than those which have less or non-turbid water.

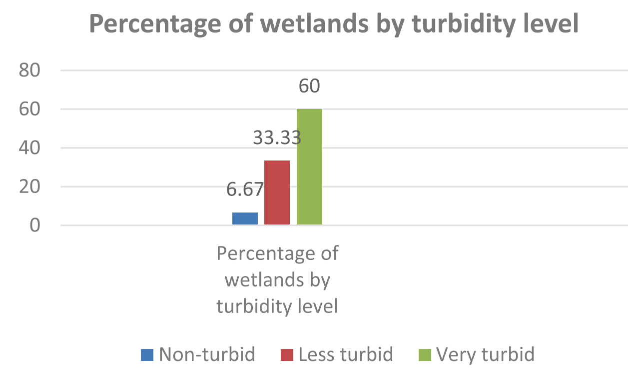


Fig. 7 Percentage of wetlands according to turbidity level of 15 water sources in the project area

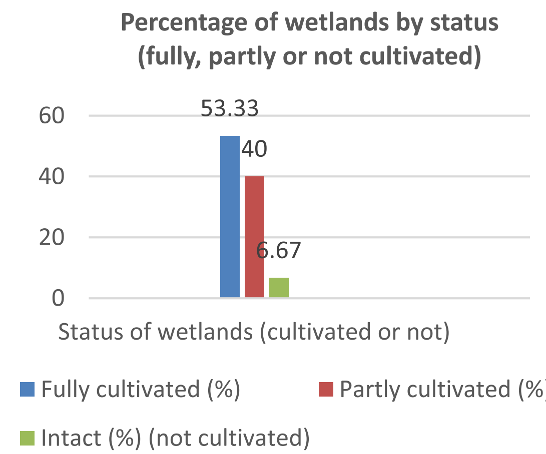


Fig. 8 Percentage of wetlands by status (fully, partly, or not cultivated)

Table 1 Water turbidity level by wetland status

		Water turbidity (clarity) level			Total	Chi-Square & p value
		Clear	Less turbid	Very turbid		
Wetlands' status	Fully cultivated	0 (0%)	4 (50%)	4 (50%)	8 (100%)	$X^2 = 16.778$; $p = 0.002$
	Partly cultivated	0 (0%)	1 (16.7%)	5 (83.3%)	6 (100%)	
	Intact (not cultivated)	1 (6.7%)	0 (0%)	0 (0%)	1 (100%)	
	Total	1 (6.7%)	5 (33.3%)	9 (60%)	15 (100%)	

3.3 Status of wetlands

It was important to understand the status of each of the 15 wetlands in the project implementation area. The findings of our investigations are summarised in Fig. 8.

Among the 15 wetlands in the project implementation area, 8 (53.33%) were fully cultivated, 6 (40%) were partly cultivated, and 1 (6.67%) was still intact. Most of the wetlands are cultivated by the local population seeking to increase their land productivity given that the soil has lost its fertility in the hills.

This is because the area is seriously affected by floods and soil erosion that erode the fertile soil from the hills to the wetlands.

3.4 Water turbidity level and status of wetlands

It was interesting to understand the association between wetland status and the turbidity level of the water they contained. Therefore, a bivariate analysis was performed, and the findings are shown in Table 1.

Fig. 9 Population fetching water from the 3 categories of wetland water sources

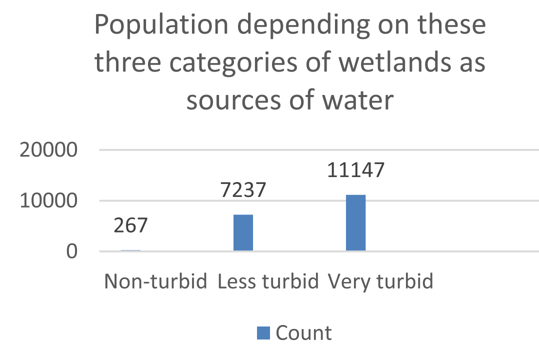
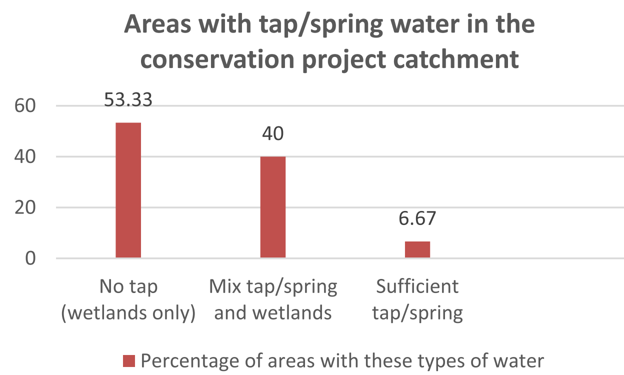


Fig. 10 Percentage of areas with tap/spring water



This table shows that among the 8 fully cultivated wetlands, none had clear water, 4 (50%) had less turbid water, and 4 (50%) had very turbid water. Among those that were partly cultivated, none had clear water, 1 (16.7%) had less turbid water, and 5 (83.3%) had very turbid water. Only 1 wetland (6.7%) had clear water. The difference between these observations was statistically significant; chi-square = 16.778, p = 0.002. This means that the water sources in the wetlands become more turbid when the wetlands are more cultivated. The fully cultivated wetlands have more turbid water than do the partly cultivated wetlands. The one that is still intact has clear (non-turbid) water.

3.5 Population dependence on wetlands as sources of water by category of wetland

The author was interested in understanding the proportion of the population depending on each of the 3 categories of wetland sources of water. The results of this investigation are summarised in Fig. 9. 267 people (1.43%) fetch water from a clear (non-turbid) source in the wetland; 7,237 people (38.8%) fetch water from less turbid sources in the wetlands; and the majority of people, 11,147(59.77%) fetch water from a very turbid source of water in the wetlands. There was a statistically significant difference between these observations; d = 0.533, 95% CI [0.183–0.758]; p = 0.02.

This means that the proportion of people using very turbid water is very high, which constitutes a public health risk for these people. This shows that the vast majority of the population in this area is using unsafe water sources for domestic and recreational use. The development of frequent diseases, more specifically, outbreaks, is a public health risk for these populations. There is a real need for improved water sources accessible to these populations.

3.6 Presence of tap and/or spring water in the area

It was interesting to understand whether the populations had access to tap and/or spring water in addition to wetlands as sources of water for their daily life. Figure 10 shows the results of our investigations.

The majority of the areas covered by the conservation project did not receive tap or spring water, accounting for 8 out of the 15 areas (53.33%).

By those areas that have few taps/springs, 7 out of 15 (40%) put the population in a situation of using a mix of tap/spring and wetland water, and finally, only 1 area out of 15 (6.67%) had sufficient tap/spring water for the population.

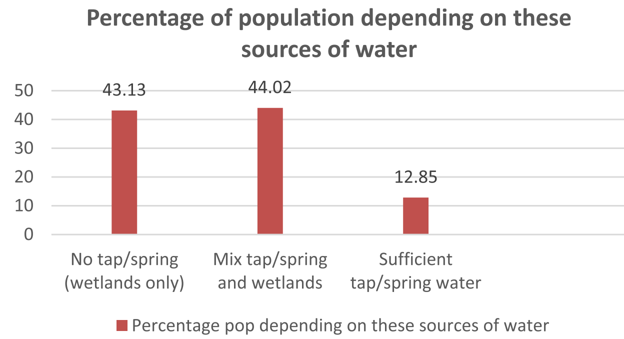


Fig. 11 Percentage of people fetching water from tap/spring or wetlands

Table 2 Nappier plantation with integrated and parallel sites

		Nappier grass planted on hills around the wetlands		Total	Chi-Square & p value
		No	Yes		
Integrated sites?	No	7 (70%)	3 (30%)	10 (100%)	$X^2 = 6.563$; $p = 0.010$
	Yes	0 (0%)	5 (100%)	5 (100%)	
	Total	7 (46.7%)	8 (53.3%)	15 (100%)	

This shows that the populations have no option to use water from the wetlands even though they have shown a higher level of turbidity, as they do not have (or have very little) other points of water available in their areas. According to our conversations and observations, before the implementation of the ongoing conservation project, the population has not received sufficient awareness of this risk. This has left them ignorant for a long period. Hence, conservation projects have taken this seriously to educate populations on environmental conservation and health, encouraging them to adopt non-risk (or low risk) behaviors, such as boiling water before use, planting Napier grass in gardens around wetlands, and getting WASH facility in households, as well as making trenches and terraces in gardens to prevent soil erosion.

3.7 Population depending on tap/spring and wetland water

The author has investigated the proportions of people fetching water from tap/spring and those depending entirely on the wetlands' water. The findings are shown in Fig. 11.

These investigations showed that 44.02% of the people in these areas use both tap/spring water and wetland water. Almost the same proportion is observed for those who use only wetlands as a source of water (43.13%).

Only 12.85% of people had access to sufficient tap/spring water. This shows that there is a pressing need to concentrate efforts to provide improved and safe sources of water in these different areas.

3.8 Nappier grass planting at the integrated and parallel sites

It was important to explore the impact of site integration on the willingness of community members to plant Napier grasses in their respective gardens as a mechanism to protect soil and respond to the soil erosion crisis. The findings of this investigation are summarised in Table 2.

These findings showed that community members in all the integrated sites had Napier grasses planted in their gardens, while only 30% of the parallel sites had Napier grasses planted and 70% of the parallel sites had not yet planted them. There is a significant difference between these observations (chi-square = 6.563; p = 0.010). This shows that members of the integrated sites respond better to consortium mobilisation in terms of preventing soil erosion and conserving wetlands than do those in parallel sites. Many efforts are still needed at parallel sites to bring 70% of the people on board for community action toward environmental conservation. This can be partly explained by the fact that community members at parallel sites were less exposed to awareness messages regarding environmental conservation.

Table 3 Turbidity of water from wetlands by integrated and parallel sites

		Water clarity level			Total	Chi-Square & p value
		Clear	Less turbid	Very turbid		
Integrated sites?	No	1 (10%)	4 (40%)	5 (50%)	10 (100%)	$X^2 = 1.4$; $p = 0.497$
	Yes	0 (0%)	1 (20%)	4 (80%)	5 (100%)	
	Total	1 (6.7%)	5 (33.3%)	9 (60%)	15 (100%)	

3.9 Turbidity of water from wetlands at the integrated and parallel sites

It was also important to explore the impact of integration on the water turbidity in these wetlands. These findings are presented in Table 3.

These results showed that there was a greater proportion of less turbid wetlands in parallel sites than in integrated sites. This trend was the opposite for the very turbid wetlands, which had a greater proportion of integrated sites than parallel sites. The difference between these observations is not statistically significant. This means that integration has not had an impact on the water turbidity in these wetlands.

3.10 Turbidity of water from wetlands by the Napier plantation process

The impact of the Napier plantation process on the water clarity/turbidity in the wetlands was explored in this study. The findings of this investigation are presented in Table 4.

These results showed that there was a greater proportion of less turbid wetlands in parallel sites than in integrated sites. The opposite situation occurred for the very turbid wetlands, which had a greater proportion in the integrated sites than parallel sites. The difference between these observations is not statistically significant (chi-square = 2.143; $p = 0.343$). This means that the Napier plantation did not have an impact on the water turbidity in the wetlands. There are several reasons for this, which are explained in the discussion section.

4 Discussion

The wetland located in Kabimbiri-Kyerero has kept its clarity during the 18-month period. However, almost all wetlands, including the Kabimbiri-Kyerero, had drop in their reading values in the month of March 2022. It is important to note that this is the only month among the 18 when this wetland had a lower reading, while it has kept, for the rest of the period, the readings above 80. There are thoughts that there was an error in reading for this water source in March 2022, as the reading for March 2023 was still above 80. Moreover, for other wetlands, it is important to understand the factors that affected all the wetlands in March 2022, as this was repeated again in March 2023. The same observations were noted repeatedly in May, August, and November for most of the wetlands. According to the World Health Organization (WHO), the turbidity level should be greater than 85 cm (< 4 NTU) for water to be used for drinking [4]. This wetland, as source of water, in Kabimbiri-Kyerero is the only wetland that fulfills these criteria among the 15 wetland sources in the project catchment area in the Rukiga district.

August showed the greatest decrease in all the wetlands. It is important to further explore the influencing factors that make water sources more turbid during this month of the year and plan interventions accordingly. A tentative

Table 4 Turbidity of water from wetlands by the Napier plantation process

		Water clarity level			Total	Chi-Square & p value
		Clear	Less turbid	Very turbid		
Napier grasses planted on hills around wetlands	No	1 (14.3%)	3 (42.9%)	3 (42.9%)	7 (100%)	$X^2 = 2.143$; $p = 0.343$
	Yes	0 (0%)	2 (25%)	6 (75%)	8 (100%)	
	Total	1 (6.7%)	5 (33.3%)	9 (60%)	15 (100%)	

explanation is that this period coincides with the highest solicitation period during which the population or heavy rain season brings sediments from hills to wetlands.

There is a real need for a new project focusing on wetland restoration. This can be another phase or a new filial of the current project to ensure that people's and animals' lives are protected. One wetland providing clear water out of 15 is a silent disaster and needs urgent attention. It is important to develop best practices from elsewhere that can help in the restoration phase to further support the current project. Wetlands play a crucial role in removing toxic products (e.g., arsenic and uranium from waste rocks) and minerals such as heavy metals (e.g., cadmium) from water before being used by populations [20]. Land use policy and current management practices should be oriented toward wetland conservation for both humans and wildlife, revealing the value of promoting wetland plants for environmental conservation and sustainability [19].

Most importantly, given that water safety for these wetlands in Uganda is not known, further research is needed to test the pollution and contamination levels of microorganisms and organic substances to understand the acceptability level for consumption. These areas are urgently needed because, in these regions, people have wetlands as main water sources for their daily life with high levels of water stress.

As the wetland in Kabimbiri-Kyerero has kept its clarity for 18 months and is the only one that keeps its clarity for a sufficient period of time, it is important to raise awareness about this wetland and engage the community in its protection and reinforcement measures to sustain its status for the health of humans and animals. The water clarity for this wetland can be explained by the fact that it is still intact and not yet cultivated by local populations. This highlights the importance of the conservation project implemented by the consortium ICF/MPT/Rugarama Hospital, as each partner plays an important role in maintaining wetlands. Here, there is an opportunity to structure a clear message to both local communities, which are the direct and first beneficiaries of what wetlands offer, and to governments and donors/stakeholders, who are accountable for the health of populations (both humans and animals). It is important to note that governments and donors have the advantages of keeping wetlands intact and natural rather than funding projects aiming to treat and filter water and treating patients when they become sick or respond to an epidemic/outbreak originating from contaminated water. Studies conducted in Canada and Australia have shown that the destruction of wetlands leads to a large loss of economy in terms of water provision and accessibility [17, 21]. Another study conducted in Canada (Ontario) showed that the conservation of natural wetlands allows saving a mean of 4.2 billion dollars per year in filtering water and that efforts should be made to protect the existing wetlands as naturally as possible [17].

Among the five less turbid wetlands, some have shown instability in reading, with oscillations above 80 and below 50 for some months. This shows that their turbidity level is not stable, ranging from less turbid to non-turbid or from less turbid to very turbid for some months of the 18-month period. This can be explained partly by certain number of human activities in the wetlands that can be intense for some months and less intense for others. These are the five reasons explained in the Results section on page 15 (agricultural activities and heavy rain, washing feet and other materials, washing motorcycles/bicycles, bringing animals to the stream to drink water, hunting activities). Similar studies conducted in Spain and Australia have shown the same results where turbidity increases during intense agricultural activities and for cultivated wetlands [19, 20, 37].

Among the nine very turbid wetlands, some had oscillations with readings above 50 for several months. The turbidity level of these wetlands can be explained by the reasons given above for the five less turbid wetlands plus the fact that they are almost all fully cultivated. The wetland in Sindi-Kihanga has been unstable, with unexplained oscillations reaching readings above 90 for three months and above 80 for one month. It is likely that this wetland can still recover its filtering function if it is kept unsolicited, as its status is partly cultivated. Given that there are very few taps for water in this community, with most people being sourced from wetlands for water use, it is important to plan a wetland restoration project and find a mechanism for stopping the solicitation of this wetland, such as providing water tanks to harvest rainwater that can be used by the wider public. The time of turbidity may coincide with the period of intense solicitation by the population for the five reasons explained above. Again, as explained previously, August showed a significant decrease in the readings value at all nine sites, and the same trend was observed for March, May, and November.

The second explanation for this level of turbidity is the deforestation on the hills surrounding the wetlands that has been observed, which easily leads to the drainage of sediments and soil to the wetlands during heavy and torrential rains. Most hills in the district have been deforested, leading to soil erosion and facilitating the movement of landslides to wetlands. This accumulation of landslides covers the water stream and can lead to water source loss with the risk of water scarcity. Studies have shown that drinking turbid water is associated with the occurrence of outbreaks and gastroenteric endemic diseases [3, 4]. It is important to check the frequency of these health conditions in this area and support community members in implementing preventive measures.

The project staff are engaged in community awareness and mobilisation, and they work together with the community members to avoid this risk in two ways. First, community members can be encouraged to constantly monitor the presence of these landslides and remove them on time to maintain the water stream. Second, the Napier grass planting materials were provided, and community members were trained on how to plant them to avoid soil erosion in their gardens on hills. This helps to stop washing the soil from the hills to the wetlands. By doing so, the wetlands remain free of sediments from the hills, and the fertile soil needed for food production is kept in the gardens. Again, this finding shows how important this project is for direct environmental protection and indirect protection of two main health sectors, namely, preventing malnutrition by increasing access to food and preventing water-borne diseases by protecting wetlands to maintain filtering functions. Multiple studies have shown the efficacy of Napier grasses in preventing soil erosion, stabilizing the soil, preventing floods and landslides, and increasing fertility [27–33]. The conservation project has helped local community members and a large audience understand that the protection of wetlands benefits not only the cranes that live and grow there but also the preservation of population health.

The government of Uganda has recognised the value of wetlands in removing pollutants such as toxic products, sediments, and organic particles from water to preserve population health [26]. This means that the conservation project in the Rukiga district is supporting the government mission for the wellbeing of both people and animals. This programme should receive much attention from donors to help them achieve more progress, as more needs are expressed by community members to address water stress.

It is a serious matter that the number of wetlands that are very turbid is greater than the number that are less turbid, and only one wetland out of fifteen provides clear water. Is there any hope to reverse this situation from very turbid to less turbid and then to non-turbid? Previous studies have shown that by using novel and improved technologies, wetlands can be restored [19]. A study conducted in Australia showed that using wetland plants can restore wetland filtering ability [19]. It is important that the stakeholders and leaders in the Rukiga conservation project contact the Society of Wetland Scientists to seek advice and obtain a solution to restore these wetlands. It is also important to organise a community dialogue with community members to involve them in solution seeking and inspire them to stop further destruction by self-commitment and being involved in local monitoring to stop others from doing further destruction.

The majority of wetlands in the conservation project area have been destroyed by agricultural activities with the purpose of increasing food productivity. However, these practices are likely to have serious negative impacts on district population health due to an increase in water turbidity. This study showed that the more wetlands are cultivated, the more turbidity increases. These findings are in line with what was found by Gleason and Euliss in 1998, who showed that cultivated wetlands are subject to premature filling by sediments, leading to increased turbidity, loss of filtration function and protection of invertebrate species [3]. Another study conducted in Spain showed that water in wetlands has been more turbid during intensive agricultural activities, especially during rice production, which has brought more nutrients and pollutants to wetlands [37]. There has been a lack of leadership to sensitise and orient populations toward human actions in the past. Most people who have solicited land slots in wetlands do not know that doing so may have a negative impact on their own health. The work being done by the consortium of organisations is an open eye to making community members aware of this negative impact and bringing them to the frontline in the protection of wetlands through environmental conservation practices.

As most people have no access to other water sources, they feel obliged to use what nature offers to them. Those with springs as water sources do not have them always reliable because they become contaminated during the rainy season with frequent floods. However, it is important to let people know that agricultural activities are worsening water quality and explain what solutions may be possible to maintain the quality of water at an acceptable level. It is important to note, in addition, that people who mix tap/spring water and wetlands feel forced to do so for two major reasons. First, for some parishes that have public tap water, it is not offered for free. People have to pay to fetch water, and most of them are not in a position to afford the cost. Second, most people travel long distances to reach the point of tap/spring water. This makes people discouraged, and they prefer to use easier ways to obtain water.

The integration process has positively impacted the response and mobilisation of community members in preventing soil erosion and therefore protecting water in wetlands. This is explained by the fact that members of the integrated sites were supported with seeds to plant on top of the Napier grass for soil protection, while those in parallel sites could benefit only the Napier grass to plant. This has given the integrated sites additional motivation for planting Napier grass to protect their crops and to demonstrate high production to donors. A study conducted in Kenya has shown the effectiveness of Napier grass in protecting the soil and increasing its fertility [30]. However, the same study demonstrated that adding other protective plants, such as leguminous schrubs or Calliandra, on top of Napier grass helps to produce more than using Napier alone [30]. Hence, it is important that project staff think about adding these other species to support community members in responding to the climate change crises they are facing. This approach can accelerate the response and allow community members to obtain sustainable results. In addition, it is important to add more integrated sites or integrate all of them to increase the impact of project activities on environmental protection and sustainability.

This study revealed that integration has not had an impact on water turbidity in wetlands. This is explained by three main reasons. First, the message regarding wetland conservation seems not to have been leveraged at parallel sites; most efforts are concentrated on integrated sites. Second, the wetlands were already cultivated at the time of the project implementation. Third, there is a lack of improved water sources in the areas leaving communities without any choice to use wetland water for daily and routine activities.

This situation seems to contradict scientific findings showing the efficacy of Napier in preventing landslide movement from hills to wetlands [30]. However, in this study, four major reasons can explain this situation according to the observations of the author. First, many farmers have not yet planted Napier grass in their gardens. Second, there are many other practices in these regions that make water turbid, such as people washing their feet in the stream after agricultural activities, people bringing their animals to the stream to drink water, people washing their motorcycles and bicycles from the stream. The third factor is hunting activities in the wetland. Fourth, the project is still at a younger age, and the change requires long-term activities and a reduction in wetland solicitation.

5 Conclusion

Together with human activities, climate change negatively impacted the water sources provided by wetlands in the conservation project catchment zone in the Rukiga district. It is likely that the filtering ability of the vast majority of wetlands has decreased throughout the 18-month period of data collected from October 2021 to March 2023; only one wetland still exhibited good results for this purpose, and its filtering function was maintained during this 18-month period. There has been high pressure on wetlands, leading to their use in agriculture for food production, which has led to an increase in water turbidity while being used by local populations for their daily life, exposing them to the risk of disease. The integration process (a multidisciplinary approach for environment conservation and health) has had a positive impact on mobilising community members to plant Napier grass to prevent soil erosion, while this was not the case for water turbidity given that the project is still at a younger stage. The vast majority of people living in this project zone use non-recommended water (by the WHO) for domestic use due to a lack of (or insufficient) improved sources of water. There is a need for wetland restoration projects. It is important to start water quality and safety checks to protect people's and animals' health and this opens window to further research. The conservation project is contributing to helping community members become front-line responders and creating local ownership for wetlands and environmental protection. Community members, donors, and the government still need additional support to restore wetlands and reinforce community actions against soil erosion.

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Declarations

Competing interests The authors declare no competing interests.

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