Collaborative Monitoring for Sustainable Development of Lake Tana UNESCO Biosphere Reserve

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Abstract. Lake Tana, part of the Lake Tana UNESCO Biosphere Reserve in Ethiopia, is threatened by numerous problems causing severe threats to the livelihoods of both the lake ecosystem and local residents. The occurrence and rapid expansion of the invasive water hyacinth (*Eichhornia crassipes*) along several parts of the lake´s shorelines are one of the observed threats. In order to develop and implement targeted measures to monitor the spread of water hyacinth, an evidence-based information foundation on the situation of this aggressive neophyte is necessary. Technology-based methods play an increasingly important role in environmental monitoring, especially remote sensing and geoinformatics. The current research seeks to establish a methodology for monitoring spatiotemporal dynamics of water hyacinth by incorporating technical methods and the participation of stakeholders like fishermen, local community, or Lake Tana and Other Water Bodies Protection and Development Agency in the research process. Stakeholder participation through collaborative monitoring will enable integration of knowledge and capacities of non-scientific actors into the research process, which otherwise may be lost to the scientists. For the specific project, we therefore emphasise on the involvement of stakeholders in the elaboration of research questions, data collection and analysis, publication activities and communication about the project. Thus, in this project we have designed and implemented approaches for stakeholder integration in the form of data collection tools as well as interviews and focal group discussions. Data collected by the developed tools act as ground truthing for remote sensing findings. Thus, this paper describes the workflows developed for the satellite imagery analysis using Sentinel-2 of the European Copernicus program and the data collection activities using the open source Spatial Monitoring and Reporting Tool (SMART) and its mobile companion CyberTracker, as well as the developed interactive ArcGIS StoryMap to provide project results to stakeholders and interested parties. So far, corresponding results of implementations and findings derived from test-runs with stakeholders confirm our approach.

Keywords: collaborative monitoring, participation, biodiversity, biosphere reserve, invasive species

1 INTRODUCTION

Monitoring biodiversity and related parameters enables the identification and quantification of trends in biodiversity status, the measurement of compliance with international and national standards, and the evaluation of the effectiveness of protected area management. Dalton et al. (2021) provide a comprehensive overview of modern biodiversity monitoring technologies and discuss their applicability compared to previous standard practices. The concept of monitoring seems simple but designing an effective biodiversity monitoring program is often challenging. Berger et al. (2022) propose an online configurator as a decision-making – assistant for planning effective environmental monitoring for the selection of the most appropriate biodiversity monitoring tool(s) for the task and location at hand. Monitoring of biodiversity can be practiced by experts and scientists, governmental rangers and other officials, or by local communities.

In this paper we draw on the establishment of a methodology for monitoring spatiotemporal dynamics of water hyacinth (*Eichhornia crassipes*) by incorporating technology-based methods and the participation of stakeholders in the research process. The technological background for the water hyacinth monitoring process is based on a combination of remote sensing data from the European Copernicus program (Sentinel-2) and the open source Spatial Monitoring and Reporting Tool (SMART) in a geographical information system (GIS) environment. Sentinel-2 can collect data appropriate for monitoring vegetation dynamics with a resolution of 10m every 5 days. SMART in combination with its mobile companion CyberTracker is used for terrestrial surveys and data management based on a developed data model for monitoring the distribution of water hyacinth. Stakeholder participation through collaborative monitoring enables integration of knowledge and capacities of non-scientific actors into the research process. Study area is the Lake Tana UNESCO Biosphere Reserve in Ethiopia, which faces a variety of threats to biodiversity, one of which is the invasive water hyacinth. UNESCO biosphere reserves are by definition “learning places for sustainable development” and serve as areas to test interdisciplinary and innovative methods to better understand and manage changes and interactions between social and ecological systems (UNESCO, 2023). By developing a long-term, technology based and open source methodology to collaboratively monitor biodiversity based on the example of water hyacinth in an aquatic and terrestrial ecosystem the project will make contributions to SDG 14 “Life below water” and 15 “Life on land”.

1.1 THE STUDY AREA

Lake Tana UNESCO Biosphere Reserve, registered in 2015, comprises the largest freshwater lake in Ethiopia and is the main source of the Blue Nile. The biosphere reserve plays a crucial role in providing essential ecosystem services and houses a diverse range of flora and fauna, including 67 different fish species, 70% of which are endemic, and 217 different bird species. It is also a vital source of resources for local communities, including food, building materials, domestic water supply, and animal feed (UNESCO, 2018). The division of the biosphere reserve into the core, buffer and a transitional zone is shown in Figure 1.

Nevertheless, Lake Tana faces a multitude of challenges, as highlighted by various studies (e.g. Lemma et al., 2020; Asmare, 2017). These challenges include the excessive use of the lake shore, excessive siltation, water pollution, wetland degradation, infestation by the invasive water hyacinth and overgrazing, all of which pose significant threats to the livelihoods of local residents.

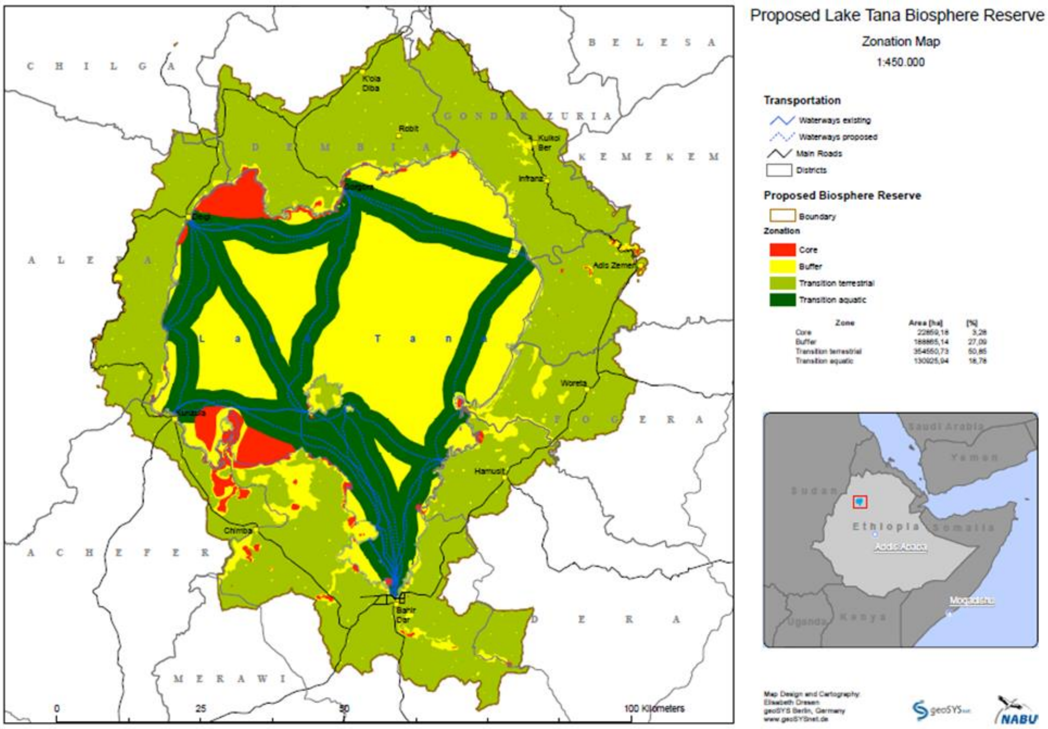

Figure 1: Zonation of the Lake Tana UNESCO Biosphere Reserve (Source: http://www.laketana-biosphere.com/wp-content/uploads/2014/10/LTBR-Day-Manual_English_pilotphase.pdf, accessed 2023-04-10)

This paper focuses on the water hyacinth problem at Lake Tana. The water hyacinth has spread rapidly within only a few years and causes massive problems for biodiversity, the ecosystem services of the lake, and riparian communities (e.g. Damtie et al. 2021, Derrseh et al. 2019, Enyew et al., 2020). Water hyacinth is a free-floating, perennial and fast-growing plant native to tropical and subtropical South America. According to Villamagna et al. (2010), it is one of the ten most ecologically dangerous invasive species. Huge amounts of labour and financial resources have been invested to control water hyacinth (Figure 2) in Lake Tana.

Figure 2: Removal of water hyacinth is time-consuming and cost-intensive. (© Bahir Dar University)

Enyew et al. (2020) reported that over 800,000 human laborers were employed for manual weed removal between 2012 and 2018, and more than one million USD was spent on acquiring harvester machines and conducting bioagent experiments. Despite these investments water hyacinth continues to spread rapidly and invade new areas at an exponential rate. Figure 3 represents the current extent infested by water hyacinth in the northeast shore of Lake Tana. The lack of institutional arrangements, poor stakeholder collaboration, and failure to implement integrated control measures are some of the contributing factors.

Figure 3: The extent of water hyacinth in the northeast shore of Lake Tana (Sentinel-2 image, March 27, 2023)

There is a need for cost-effective techniques to manage the spread of water hyacinth. Among these methods, technical measures, such as remote sensing (e.g. satellite images) and geoinformatics, play an increasingly important role. However, the data obtained from earth observation technologies must be validated through manual verification surveys conducted "on the ground" (known as ground truthing) and interpreted in the appropriate context. The monitoring activities attempted so far were done seasonally and lack collaboration (and elaboration) of different stakeholders.

1.2 MONITORING WATER HYACINTH

Traditionally, monitoring has been conducted through limited field surveys, which created significant accessibility problems due to the density of the plant infestation and caused data gaps in areas where field sampling was impossible (Simpson et al., 2022). The increasing availability of open source satellite data has created new opportunities for cost-effective, large-scale monitoring of aquatic weeds. Multispectral and hyperspectral optical remote sensing data are widely used for aquatic monitoring and provide spatial snapshots with a short time interval of areas known to be infested with water hyacinth. Various satellite-based sensor systems such as optical imagery from Sentinel-2 (e.g., Damtie et al. 2021, Mucheye at al. 2022), Landsat-8 (e.g., Asmare et al. 2020), and PlanetScope (e.g., Worqlul et al. 2020) are used to monitor water hyacinth. However, the dependence of optical satellite imagery on cloud cover can cause problems in the availability of qualitative images. In contrast, SAR (side-looking aperture radar) imagery has the advantage of being less affected by cloud cover and can be monitored in all weather conditions, day and night (e.g., Simpson et al. 2022).

Another method of monitoring water hyacinth is the involvement of volunteers from the general public (citizen scientists) in research, which has been proposed as a means of improving sampling across environmental gradients and spatial and temporal scales (Dickinson et al. 2010). Monitoring by citizen scientists provides valuable information at the lowest possible cost and is also an effective tool for outreach, education and societal awareness (e.g. Groom et al. 2019).

2 METHODS

Stakeholders are defined as "individuals, organizations or communities that have a direct interest in the process and outcomes of a project, research or policy endeavour" (Deverka et al., 2012). Integration of stakeholders in scientific processes opens several advantages. Engagement of stakeholders is crucial for "*understanding perceptions and practices, promoting awareness and social learning, building collaborative research, reaching consensus and agreements, solving conflicts, aiding prioritisation and planning and formulating co-management programs*" (Shackleton et al. 2019, p.89). Stakeholder engagement helps to ensure that the research is relevant to the needs and concerns of stakeholders. Involving stakeholders in the research process can help improve the quality of research, as they can provide valuable insights into e.g. the research question, study design, and data interpretation, which can subsequently improve the validity of the findings. In addition, it can help to promote transparency and increase the impact and relevance of the research, which can ultimately lead to better outcomes and an increased acceptance of results.

In this project we developed a concept for stakeholder engagement in the collaborative monitoring of the invasive water hyacinth that includes the following: identify relevant stakeholders; determine appropriate methods for stakeholder engagement; implement the selected methods and test them in test runs. Various governmental and non-governmental organizations, educational institutions, and the local community were identified as stakeholders (Figure 4) for the collaborative monitoring of the invasive water hyacinth at Lake Tana UNESCO Biosphere Reserve.

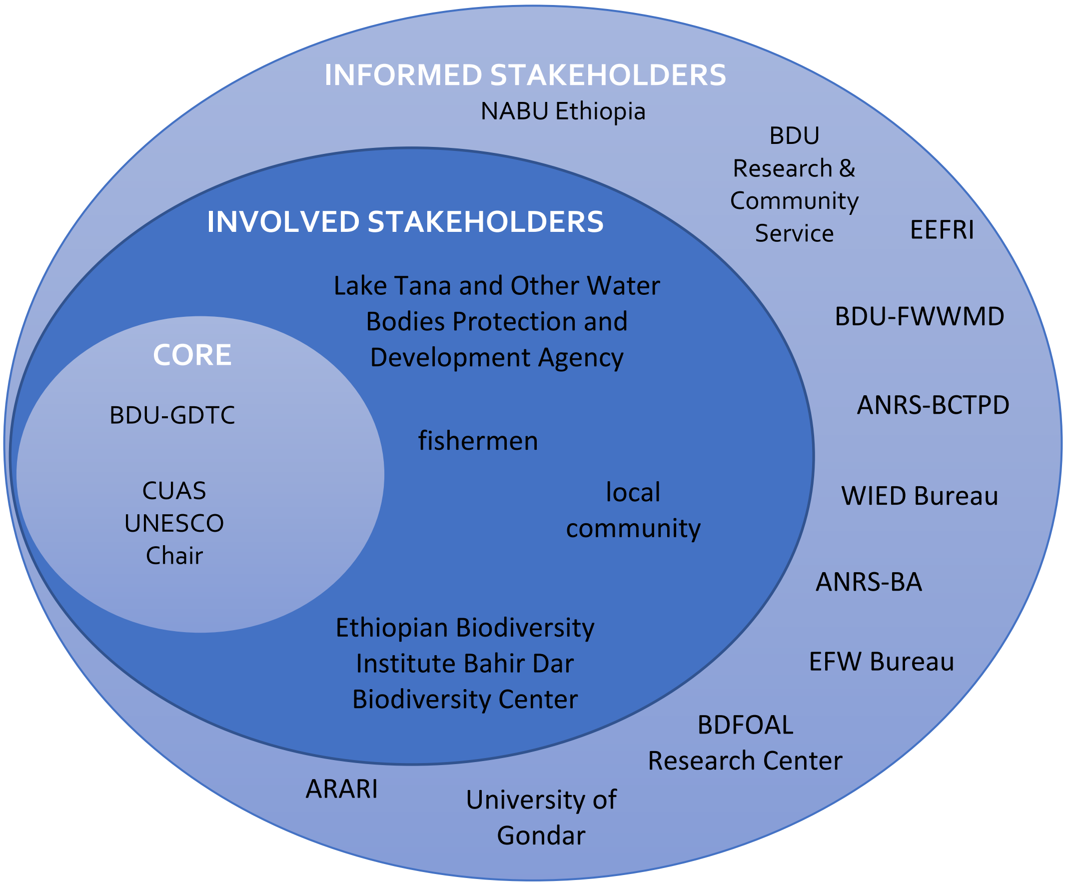

Figure 4: Stakeholder map for a collaborative monitoring including Bahir Dar University – Geospatial Data and Technology Center (BDU-GDTC); Carinthia University of Applied Sciences – UNESCO Chair on Sustainable Management of Conservation Areas (CUAS UNESCO Chair); fishermen; local community; Lake Tana and Other Water Bodies Protection and Development Agency; Ethiopian Biodiversity Institute Bahir Dar Biodiversity Center; Naturschutzbund Germany Ethiopia Head Office (NABU Ethiopia); Bahir Dar University (BDU) - Research and Community Service; Bahir Dar University – Fisheries, Wetland and Wildlife Management Department (BDU-FWWMD); Amhara National Regional State Bureau of Culture, Tourism and Parks Development (ANRS-BCTPD); Ethiopian Environment and Forest Research Institute (EEFRI); University of Gondar; Water, Irrigation and Energy Development Bureau (WIED Bureau); Environment, Forest and Wildlife Bureau (EFW Bureau); Amhara Regional Agricultural Research Institute (ARARI); Bahir Dar Fisheries and Other Aquatic Life Research Centre (BDFOAL Research Center); Amhara National Regional State Bureau of Agriculture (ANRS-BA)

The integration of stakeholders in scientific processes opens new ways of gaining knowledge. We propose the selective involvement of stakeholders in the research process (Figure 5) to ensure transparency in research activities and measures, to guarantee that the research is relevant to stakeholders, and to establish a sense of connection and identification with the research itself:

- Research Questions: This project proposes that researchers and stakeholders finalize and focus research questions in stakeholder workshops, individual interviews or focal group discussions.
- Data Collection: This project proposes that employees of the biosphere reserve as well as members of regional and local administrative units are trained in using the data collection tool and carry out recordings in the field documenting the presence and

absence of water hyacinth.

- Data Analysis: This project proposes to invite stakeholders to the presentation of results to provide feedback and comments, and thus to contribute to the reflection and revision of the findings.
- Publication activities: This project proposes to assess the capacities of the respective stakeholders for potential co-authorships.
- Communication: This project proposes to establish a communication plan that defines which stakeholders should be informed about the project, the project progress and the project results at what time and in what way.

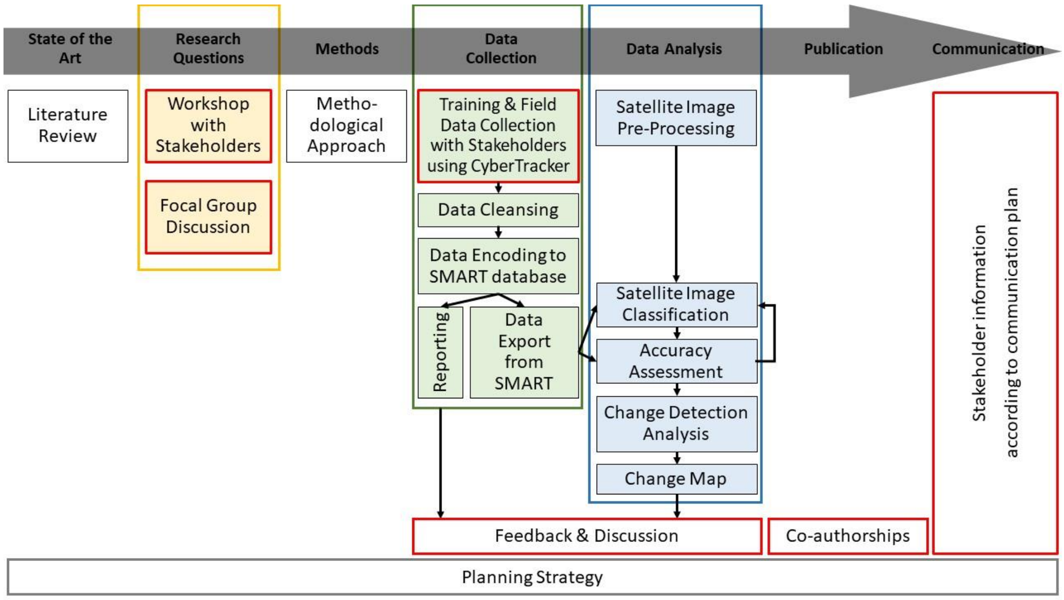

Figure 5: Workflow for a collaborative monitoring of water hyacinth with stakeholder engagement activities highlighted in red.

The present project proposes to use the open source tool SMART (https://smartconservationtools.org/) and its mobile companion CyberTracker (https://cybertracker.org/) for data collection and management. SMART was developed by global conservation organisations in close collaboration with protected area authorities and other key stakeholders, and supports a wide range of conservation management activities, including biodiversity conservation. The SMART platform consists of a suite of software and analytical tools designed to help conservationists manage and protect wildlife and wild areas. SMART can help standardise and streamline data collection, analysis and reporting, making it easier for important information to get from the field to decision-makers. As the collection of data on water hyacinth at Lake Tana will involve different stakeholders, it is important that data collection is based on a unified structure. Therefore, a SMART data model for water hyacinth monitoring has been created to serve as a basis for data collection, storage and management.
SMART can be combined with several mobile technologies for data collection, including CyberTracker, which was specifically developed for non-literate trackers. CyberTracker

combines indigenous knowledge with state-of-the-art computer and satellite technology, enabling scientists and local communities to work together in key areas of biodiversity. Based on the created SMART data model, a CyberTracker project for data collection in the field was designed and implemented. This CyberTracker project is imported into the CyberTracker application on the mobile device and is used for fieldwork. The usage of pictograms simplifies the work with the app. Collected field data can be imported into SMART for quality assessment and storage in the SMART database. Preparation of data templates allows to produce standardized reports in SMART, that can be visualised with a few clicks as a dashboard to visualise monitoring results. The generated data templates as a standard enabling consistent reporting for long-term monitoring of water hyacinth. Quality-checked field data are exported from SMART for training and accuracy assessment of satellite image classification.

The use of optical Sentinel-2 satellite imagery for water hyacinth monitoring has proven useful in numerous studies (Thamaga & Dube 2019, Damtie et al. 2021, Mucheye at al. 2022). Image classification of Sentinel-2 satellite imagery is done by using two thirds of the collected ground truth data in a supervised classification based on a Maximum Likelihood Classification. After that, an accuracy assessment of the classified maps is done using one third of collected ground truth data. Finally, changes can be detected by comparing independently created, classified images of the same area but from different points in time using image algebra. The classified map and the change map provide an essential basis for planning measures against water hyacinth.

3 FINDINGS

3.1 INTEGRATION OF STAKEHOLDERS IN FOCAL GROUP DISCUSSIONS AND INTERVIEWS

Focal group discussions (FGD) were conducted in two sampled districts to check and refine the data collected from interviews. The FGDs were held in groups of 9 to 11 subjects. Subjects were elders, youth and prominent men and women, and fishermen. The FGD subjects were selected in consultation with district focal persons and chief administrators of Kebele Association assuming that they are helpful in identifying individuals who are knowledgeable and thought to have particular insights and opinions about the focus of our investigation. Guiding questions were developed for the FGDs by the project team. Similarly, key informant interviews (KII) were undertaken for around 60 individuals found in the lakeshore area. The magnitude of water hyacinth infestation along the lakeshore and associated wetlands and the effect of the weed on socio-economic activities of the community were the key issues of the KIIs and FGDs and are summarized as follows:

Crop production and productivity: Crop production is the main agricultural activity that serves as a source of food and income for the people in the area. The FGD and KII findings show that water hyacinth infestation of the Lake Tana shore affects crop production by destroying agricultural plants, inhibiting germination, hindering and making weeding and harvesting difficult, and clogging irrigation channels. In addition, water hyacinth compacts farmland due to its long roots, making it difficult to plough the soil.

Fish and Fishing: The invasion of water hyacinth on the shores of Lake Tana and in breeding grounds (river estuaries and wetlands) has increased the decline of fish populations in Lake Tana and forced most fishermen to seek alternative work. During the KIIs and FGDs fishermen described how the infestation of lake shores, river estuaries, and swamps by water hyacinth is depriving fish of food and hindering their migration to spawning habitats. Mats of water hyacinths often block access to fishing grounds, clog and damage fishing nets, and damage the motor of fishing boats. Fishermen reported that water hyacinth reduces the lifespan of their boats and nets and so increases the annual fishing costs. At the same time, the catch rate per fisherman has decreased.

Livestock feed: The plain areas surrounding the basin are known for livestock production. Fogera cattle, one of the 29 cattle breeds of Ethiopia, are primarily raised in the Amhara region, particularly in the Lake Tana belt (Tesfa et al., 2022). According to FGD results, communal grazing pastures were the primary source of livestock feed for all herders. However, the grazing pasture of the lakeshore and associated wetlands have been degraded over time due to farmland expansion and overgrazing. The invasion of water hyacinth has further worsened this loss of grazing pastures. The weed invades pasture areas and competes with native species, causing submerging grasses and other native species to become devastated. As a result, the massive mats of water hyacinth destroy the most important pasture species. Therefore, farmers have resorted to purchasing supplementary feeds for their cattle, as the grass on the grazing lands around the lake has been destroyed by the invasive water hyacinth.

Water supply: The main sources of water for livestock watering, clothes washing, bathing, and household purposes for the surrounding community are Lake Tana, river mouths, and swamps. However, the invasion of water hyacinth in the shores of Lake Tana has negatively affected the water supply for various purposes. FGD participants have reported that the weed blocked the digging of boreholes and the fetching of water for drinking and cooking from the lake and river mouths. The floating thick mat of water hyacinth on the water surface, which eventually dies and decays, deteriorates the quality of water. Livestock watering is difficult for herders due to the blockage of the weed and even poor quality and odour of water. As a result, the community has resorted to using water from dug wells as their main source of drinking and cooking water.

Livestock health: Participants in the FGD and KII outlined that feeding of water hyacinth caused gut bloating and continuous diarrhoea on their livestock. According to Enyew et al. (2020) the consumption of stalk tissues of water hyacinth, which contain intercellular spaces filled with air, is the main cause of gut bloating and continuous diarrhoea in ruminants. To mitigate this issue Ofulla et al. (2010) suggested chopping the water hyacinth to eliminate the intercellular spaces filled with air, thereby making it a healthy feed for livestock. Furthermore, the presence of water hyacinth in lakeshores and associated swamp areas increases the intensity of breeding of leeches and other parasites. This highly contributed in the loss of body weight and death of livestock.

Human health: Water hyacinth acts as a medium for the proliferation of disease-causing organisms such as mosquitoes, snails, and other vectors associated with human illnesses including malaria, schistosomiasis, encephalitis, filariasis, and cholera. Degaga (2019) confirmed that the obstruction caused by water hyacinth results in stagnant water, which creates a microhabitat suitable for breeding many vectors of human diseases as well as hosting poisonous snakes. FGD participants and interviewees also reported that individuals involved in physically removing water hyacinth are susceptible to skin allergies.

3.2 INTEGRATION OF STAKEHOLDERS IN DATA COLLECTION

By using the CyberTracker desktop software, a CyberTracker application for mobile devices was designed in accordance with the SMART data model developed for water hyacinth monitoring. The structure of a CyberTracker application is based on screens (see Figure 6) that can contain text, icons, photos, voice recordings, and real-time GPS maps. The icon user interface was originally developed for trackers who cannot read and write, but scientists also benefit from the simple presentation as it allows much faster data collection than text user interfaces.

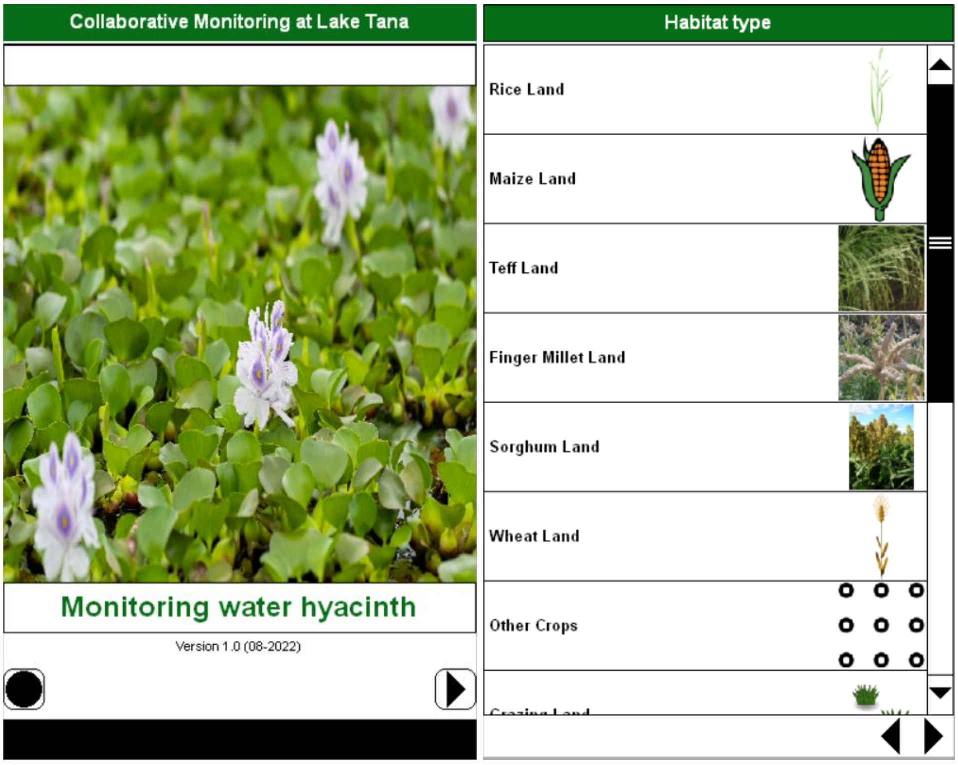

Figure 6: Example screenshots of the CyberTracker application

The project implemented two test runs involving stakeholders from various administrative levels (including regions, districts, and kebeles) and different disciplines from government institutions to local communities. The test runs took place in accordance with the phenology of the water hyacinth during the dry season, with low water hyacinth coverage, and after the rainy season, with peak water hyacinth coverage. Equipment including GPS, smartphones, tablets, and boats, was utilized during the test runs. As a part of the training process, the project team installed the CyberTracker app on the participants' mobile devices and provided an explanation of its functionality before testing the app on land and water for its use in continuous monitoring of water hyacinth (Figure 7).

Figure 7: Pictures taken during the test run with stakeholders collecting data on land (left) and on the shoreline (right) (© Bahir Dar University)

During the test runs, various aspects of the overall data model and the use of the CyberTracker app for data collection were evaluated together with stakeholders, leading to the identification of areas for improvement. For instance, the acceptable level of error during field measurement, data retrieval and editing processes on the app, data redundancy management, and the utilization of the collected data for calculating water hyacinth coverage were among the issues raised by stakeholders.

After the training, stakeholders collected ground control points (GCPs), photos, and text data, which were subsequently imported into the SMART database. An extract of the collected data is provided in Table 1.

Table 1: Sample data collected by project team and stakeholders during the test run using the CyberTracker application

Waypoint ID	X	Y	Time	Sampling Unit	Observation	Comment	Attachment	Last Modified
1	11.57085	-0.72065	10:32:53	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
2	11.4562666666667	-0.504	10:51:37	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
3	11.3483166666667	-0.25145	11:03:06	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
4	11.6090833333333	-0.24291...	12:48:07	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
5	11.6693333333333	-0.24306...	12:50:56	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
6	11.549	-0.66065	13:37:11	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
7	11.53545	-0.62346...	13:37:57	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
8	11.5126833333333	-0.56093...	13:39:10	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
9	11.4355	-0.38535	13:52:28	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
10	11.4218	-0.34468...	13:53:19	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
11	11.3509666666667	-0.24228...	13:56:51	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
12	11.4571	-0.24255	13:59:49	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
13	11.5335333333333	-0.24273...	14:01:13	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
14	11.5704166666667	-0.24281...	14:01:55	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
15	11.6746166666667	-0.30321...	14:05:33	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08
16	11.6657333333333	-0.48878...	14:14:45	(None)	Ground trouth (1)		(None)	26-Oct-2022 14:18:08

3.3 COMMUNICATION WITH STAKEHOLDERS THROUGH A STORY MAP

Selected content of the project has been incorporated into university teaching. In this context, an ArcGIS StoryMap was implemented as part of a student project as an interactive presentation option of the project and selected results for different target groups (Schwarzl et al. 2022). This web-based GIS application (https://storymaps.arcgis.com/) conveys information through narrative text, interactive maps, and various multimedia content (e.g., images, videos, audios). In a requirement analysis students identified the intended functionality, interactivity of the components and necessary geodata for the Story Map. Essential contents of the project were prepared as text and integrated into the Story Map in the form of chapters that can be accessed via a menu (Figure 8). This includes detailed background information on the project and Lake Tana UNESCO Biosphere Reserve, information on the threats to the biosphere reserve - especially the problems concerning the water hyacinth, a presentation of the collaborative monitoring approach of this project, and information on the Sustainable Development Goals addressed by the project. The narrative text is supported by interactive maps and photographs.

This interactive Story Map presentation option provides an easy access to project results for stakeholders and interested parties. Currently, the Story Map covers the collaborative approach to water hyacinth monitoring. Just as the collaborative monitoring at Lake Tana can be extended to cover other aspects of monitoring (e.g. land degradation), the Story Map can also be extended. by, for example, making additions to the menu navigation. In the long term, the Story Map has the potential to serve as a source of information for stakeholders on holistic collaborative monitoring in Lake Tana UNESCO Biosphere Reserve.

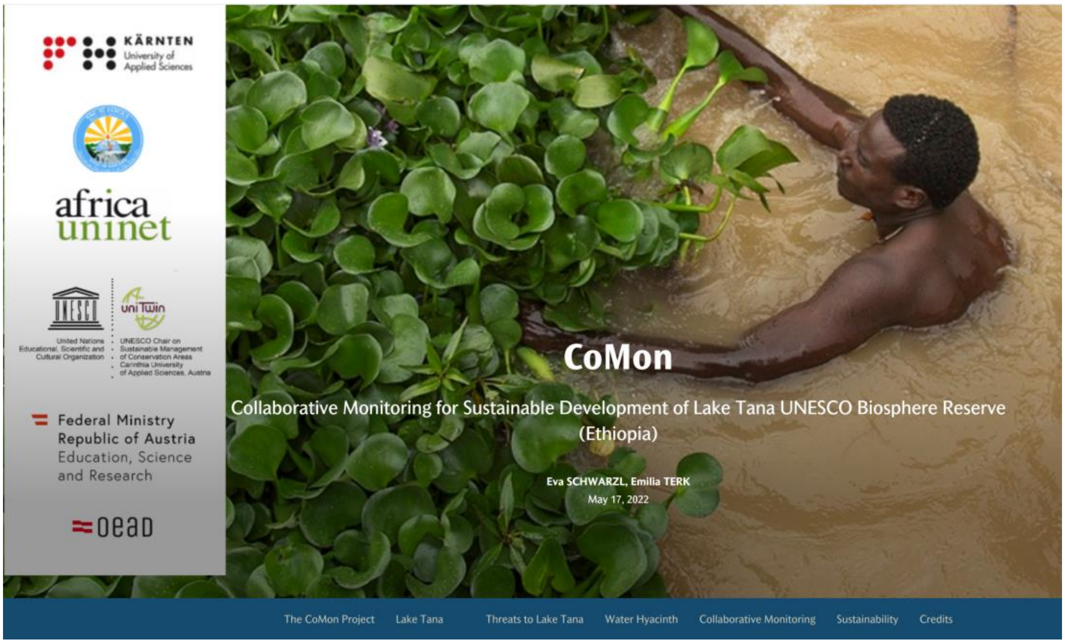

Figure 8: Welcome screen of the CoMon ArcGIS StoryMap (https://arcg.is/1biKmb0)

4 CONCLUSION

The stakeholders recognized and appreciated the added value of the collaborative approach of the project, which they found to be both innovative and participatory. They considered the participatory approach a strength of the project. Additionally, the stakeholders valued their role within the project, which fostered a sense of belonging and contributed to the project's success. The stakeholders also acknowledged the potential significant contribution of the project's success towards finding a sustainable solution in fight against, i.e., monitoring of water hyacinth for Lake Tana UNESCO Biosphere Reserve. As a result, they expressed their willingness to support the project. However, stakeholders also expressed concerns about data redundancy, which often occurred in previous monitoring activities, and expected that the collaborative approach would bring a solution to this problem.

The rise of citizen science (Hecker et al. 2018) is prompting a re-evaluation of the functions and responsibilities of researchers and scientists, and altering the role of various participants in the research process. Instead of solely functioning as experts in research, scientists are required to act as facilitators and collaborators, working alongside citizen scientists. It is the responsibility of scientists to maintain transparency by effectively communicating research objectives, methodologies, and findings to citizen scientists. Scientists must also ensure that citizen scientists receive appropriate training and support to obtain data that meets scientific standards. The implementation of quality control measures to verify and validate collected data is therefore essential. It is crucial that citizen science projects are inclusive and accessible to a diverse range of participants. Therefore, scientists must be mindful of power imbalances and work towards creating an equitable partnership between scientists and citizen scientists.

Biosphere reserves in general are considered to be instruments for implementing the UN Sustainable Development Goals (SDGs). The present project makes concrete and indirect contributions to SDG4, SDG14 and SDG15. Water hyacinth creates a very complex habitat structure by restricting the growth of other submersed macrophytes. This modification and habitat complexity at the surface of the water are likely affecting fishes and another invertebrates' habitat. The proliferation of water hyacinth in lakeshores, river mouths, and swamps has negative effects on fish feeding and migration, hindering their access to spawning habitats. Additionally, the intrusion of water hyacinth into pastures leads to competition with native species such as submerging grasses, causing devastating ecological impacts. The stagnant water caused by water hyacinth obstruction provides a microhabitat for the breeding of many vectors of human diseases and represents an ideal habitat for poisonous snakes. Continuous monitoring and locating of weed hotspots therefore contribute significantly to their eradication and sustainable management of the lake and its submerged aquatic life and therefore to SDG14 "Life below water". The present project also makes contributions to SDG15 "Life on land" by developing a long-term, technology-based and open source methodology to monitor the invasive water hyacinth at Lake Tana and as a result provide evidence-based information for the planning of counter-measures on land and water ecosystems to control or eradicate the invasive plant. By involving non-scientific actors and stakeholders of diverse groups in the research process through training them in the monitoring activities at Lake Tana, and communicating with them about the project, the project also makes indirect contribution to SDG4 "Quality education" by providing learners with knowledge and skills needed to promote sustainable development.

During the development of the technical framework for collaborative monitoring, special attention was paid to the expandability of the system in order to be able to also consider future aspects of monitoring in Lake Tana UNESCO Biosphere Reserve. Through close coordination with the stakeholders, further data models can be developed for other monitoring activities in SMART. On this basis, corresponding CyberTracker projects can then be implemented for use in the CyberTracker app in the field. Satellite image analysis can also be adapted to other use cases, for example by using spectral channels tailored to the use case or by using other satellite image products if necessary. Possible extensions of the collaborative monitoring approach would be for example in the context of land degradation, wetland degradation or overgrazing, all also threats to the biosphere reserve.

Expanding the collaborative monitoring approach beyond water hyacinth monitoring is one potential direction for future development. Moreover, integrating SMART Connect within the technical framework of collaborative monitoring presents another promising avenue. SMART Connect is an online operating environment that supplements SMART with real-time connectivity, which substantially enhances the pace of data transmission from the field, the dissemination of SMART data, maps, and reports at regional and national levels, and the capability to merge with multiple mapping, analysis, and data collection platforms.

5 ACKNOWLEDGEMENT

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