Digital innovation with miniSASS, a citizen science biomonitoring tool

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ABSTRACT

The mini stream assessment scoring system (miniSASS) was developed as a citizen science biomonitoring tool for assessing the water quality and health of stream and river systems. A miniSASS survey involves sampling the aquatic macroinvertebrate community in a stream or river reach and using the known sensitivities and tolerances of the taxa present to infer information about the water quality and health of the stream or river. The quality of the outcomes of a miniSASS survey is dependent on good sampling technique and accurate identification of aquatic macroinvertebrates by low-skilled citizen scientists. As such, there is potential for errors in sampling and identification which may impact the accuracy of results. In response, we aimed to 1) develop a smartphone application (miniSASS mobile app with built-in machine learning (ML) algorithm for the automatic, real-time identification of aquatic macroinvertebrates) to assist in miniSASS surveys, 2) modernize and upgrade the miniSASS website to handle new data submissions (including photographs) and improve the user interface (UI), and 3) develop an online miniSASS training course. This report presents the methodology and preliminary results pertaining to these objectives.

1. Introduction

1.1. Background

MiniSASS is a simple and accessible citizen science biomonitoring tool for assessing the water quality and health of streams and rivers (Graham et al. 2004). The miniSASS concept was developed in South Africa, based specifically on the South African Scoring System (SASS) versions 4 and 5 (Dickens and Graham 2002; Graham et al. 2004). Like SASS5, a miniSASS stream or river health assessment relies on inferring ecological condition based on the established relationships aquatic macroinvertebrates share with the condition of their environment (e.g., Dickens and Graham 2002; Morse et al. 2007; Paisley et al. 2014; Odountan et al. 2019; Ndatimana et al. 2023). Essentially, different aquatic macroinvertebrates have different sensitivities to, or tolerance levels for, disturbance (e.g., via pollution or invasion by alien species) in their habitat. As a result, the macroinvertebrate community composition within a stream or river is an excellent indicator of the water quality and health of a stream or river (Alhejoj et al. 2014; Ndatimana et al. 2023). Healthy streams and rivers with good water quality will be typified by sensitive species which would be removed by disturbance, while poor quality, unhealthy streams and rivers will be characterized by an absence of sensitive species and a dominance of species tolerant of disturbance (Dickens and Graham 2002; Palmer and Taylor 2004).

1.2. The need for digital innovation with miniSASS

MiniSASS samples the macroinvertebrate community (identified to *Order* level groupings allowing for easy identification by citizen

scientists) in a river reach (Graham et al. 2004). The taxon-specific pollution and disturbance tolerances are then used to generate a stream or river health index (Graham et al. 2004). In a 2018 assessment of the suite of citizen science water resource monitoring tools used in South Africa, miniSASS was identified as the most promising for broader use in water quality monitoring (Graham and Taylor 2018). This recognition was based on it being a relatively easy technique to use, especially low-cost, and that there is no requirement for laboratory analyses – the results are developed in-field, real-time (Taylor et al. 2022). The potential of miniSASS was also recently recognised by the United Nations committee responsible for Sustainable Development Goal (SDG) 6 on Water, which is exploring the use of miniSASS for reporting on progress towards SDG 6.3.2 and SDG 6b. MiniSASS is featured in the current progress report for SDG Indicator 6.3.2, "*Progress on Ambient Water Quality Global Indicator 6.3.2: Updates and Acceleration Needs 2021*[1]."

However, despite its potential, miniSASS still has some drawbacks that limits its global utility and full integration into the range of tools available to gather data for SDG6 reporting. As miniSASS currently stands, the information from a miniSASS survey relies heavily on adequate sampling technique and the accurate identification of aquatic macroinvertebrates to *Order* (or Order-level groupings) level by low skilled (minimally trained) citizen scientists. This leaves potential for errors in both sampling and identification, which may impact the accuracy, validity, and reliability of the river health assessment. As with most citizen science, questions over data validity and reliability pose a huge challenge to having the data used for management or policy (Balázs et al. 2021). Citizen science is still broadly viewed with skepticism in terms of the utility and trustworthiness of the data it generates (Cohn 2008; Bonney et al. 2009; Kolok et al. 2011; Cook et al. 2021). The reality is that the data generated by citizen science must be considered high quality, trustworthy and legitimate if they are going to be used in natural resource management and policy (Buytaert et al. 2014; Hulbert et al. 2019; Arndt et al. 2022).

To attempt to address any reservations about miniSASS data validity, GroundTruth engaged with CGIAR, IWMI, Amazon Web Services (AWS), the United Nations Children's Fund (UNICEF), and North-West University (NWU), in research and development of 1) a miniSASS smartphone application (app) with built in machine-learning (ML) for identification of macroinvertebrates, 2) an upgrade to the miniSASS website (https://minisass.org) to streamline user interaction and enable capture of more complex and comprehensive data from miniSASS assessments, and 3) an online, interactive course for miniSASS to educate and train miniSASS practitioners. Combined, these aims work towards the broad objective of digitally innovating and upgrading the entire miniSASS process, including training, surveying, identification, and data handling and visualization, so that verified miniSASS data can be collected and used with greater reliability. Ultimately, these developments aim to

give miniSASS the credibility and reliability required to enable its use for water resource monitoring throughout Southern Africa, and even globally.

2. MiniSASS Mobile App

2.1. Macroinvertebrate photographic database creation

The process of app development required collection of images of aquatic macroinvertebrate specimens from all 13 miniSASS macroinvertebrate groups: 1) flat worms, 2) worms, 3) leeches, 4) crabs and shrimps, 5) stoneflies, 6) minnow mayflies, 7) other mayflies, 8) damselflies, 9) dragonflies, 10) bugs or beetles, 11) caddisflies (cased and uncased), 12) true flies, and 13) snails. Thirteen sites, 6 sites in the North-West (NW) and 7 sites in Kwa-Zulu Natal (KZN) Provinces, South Africa, were sampled exhaustively to obtain images for all 13 MiniSASS groups (Table 1). Sites were sampled using standard miniSASS techniques, modified by sampling for a greater period to thoroughly sample the study area (for details, see Graham et al. 2004 and Pattinson et al. 2022). The images were used to create a database that could train an artificial intelligence (AI) machine-learning (ML) identification algorithm.

2.2. Machine Learning algorithm training and development

After pre-processing (i.e., cropping, sharpening, brightening, and increasing contrast; Figure 1), the database of aquatic macroinvertebrate images was refined to ~1000 images in each miniSASS group. Of these, 900 per group were used for training the ML identification algorithm over the course of 19 epochs or iterations. The ML identification algorithm uses neural networks to automatically identify and assign unique features of an image, and over repeated iterations learns the common unique traits typical of each group (Pattinson et al. 2022). After training, the model was tested on ~100 unseen images from each miniSASS group.

2.3. Mobile app development

App development began with defining the requirements of the app. The primary requirements of the app were defined as:

- Navigation to main screens correlating to primary functions of the app

- Map screen linked to Google Maps and miniSASS sites (the same as on the miniSASS website).

- Sites screen containing a list of the sites the user has created. This will be stored as part of the user profile, which will be accessible via the website as well.

- About screen including a short blurb on miniSASS, a link to the

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[1] https://www.unwater.org/publications/progress-on-ambient-water-quality-632-2021-update

Table 1. Table of the sites sampled for macroinvertebrates within the mini stream scoring assessment system (miniSASS) groupings. Site name, global positioning system (GPS) coordinates, a site description (including a subjective water quality measure), miniSASS groups sampled at the site, and the biotopes available for sampling (vegetation = VEG; gravel, sand, & mud = GSM; stone out of current = SOC; stones in current = SIC) are shown (Source: Table from Pattinson et al. 2022, reproduced with author permission).

Site name	Location (Lat, Lon)	Site description	Macroinvertebrate groups sampled	Biotopes sampled
S1 Mooi River	-26.68053, 27.0986	Medium depth, wide channel present with abundant riparian vegetation. Water quality moderate.	All groups - No stoneflies; No clams	VEG, SOC, GSM
S2 Mooi River	-26.68119, 27.09838	Deep, wide channel with soft sediment. Many reeds present. Water quality moderate.	All groups - No stoneflies; No clams	VEG, GSM
S3 Mooi River	-26.68431, 27.09954	Small, deep channel, slow flowing. Abundant riparian vegetation. Water quality moderate with some	All groups - Few dragonflies; No stoneflies	VEG, SOC, GSM
S4 Mooi River	-26.68558, 27.10148	Small, shallow stream with many boulders. High stream flow. Little to no riparian vegetation.	Mayflies; Bugs & Beetles; Some Dragonflies	SIC
S5 Mooi River	-26.68676, 27.10341	Heavily shaded stream, small channel width and depth. Little riparian vegetation. Some pollution	Most Groups - No Stoneflies; Many clams.	GSM
S6 Mooi River	-26.6935, 27.10305	Site within NWU sport grounds. Many freshwater red algae. Strong current with many boulders. Some	All groups - No stoneflies; No clams	VEG, SIC, GSM
Karkloof Tributary	-29.30106, 30.22779	Pristine mountain stream, shading abundant. Shallow stream with scattered shallow pools. Some riparian	All groups (mostly stoneflies)	VEG, SIC, GSM
Karkloof River at Spitskop	-29.3336, 30.2353	Slightly impacted site, located under bridge. Abundant riparian vegetation. Small stream with sloped	All groups	VEG, SIC, GSM
uMgeni River downstream of Midmar	-29.49484, 30.22218	Large, wide channel. Mostly large boulders present. Little GSM. Some Riparian vegetation.	All groups - few stoneflies	VEG, SIC, SOC
Rietspruit	-29.50413, 30.26829	Small to medium stream, small waterfall present. High biotope diversity. Slightly impacted site. Rocky	All groups - no stoneflies	VEG, SIC, SOC, GSM
uMgeni River at uMgeni Valley Nature Reserve	-29.49844, 30.24635	Large wide channel, deep with strong flow. Many large boulders with abundant of algae. GSM abun-	All groups - no stoneflies	VEG, SIC, SOC, GSM
Town Bush Stream	-29.5717, 30.35493	Many large boulders with abundant of algae. Little vegetation, abundant GSM.	All groups - Many crabs; No stoneflies	VEG, SIC, GSM
Mlazi River	-29.81584, 30.44901	Site near agriculture practice, small to medium stream. Biotopes abundant, little boulders. Good, fair	All groups - Many stoneflies & Shrimp	VEG, SIC, SOC, GSM

miniSASS website, and other relevant information (e.g., training videos, miniSASS how- to guides, the miniSASS dichotomous key, and scientific papers or online articles pertaining to miniSASS).

- MiniSASS survey site creation includes options to input site user and site data, including the site name and location, the stream / river name, type, and description, the date, the collector's name, email address, and organization, and any other notes. Options to input anecdotal data into other fields, including pH, water temperature, water clarity (as measured by

a clarity tube), dissolved oxygen, along with the GPS location service to capture site location.

- MiniSASS survey:

  - Capture photographs of aquatic macroinvertebrates.
  - Provide access to interactive dichotomous key (with photo examples) for assisting the user with identification.
  - Allow the user to identify and label photographs.
  - In the background, use the ML identification algorithm to identify and label the photos.
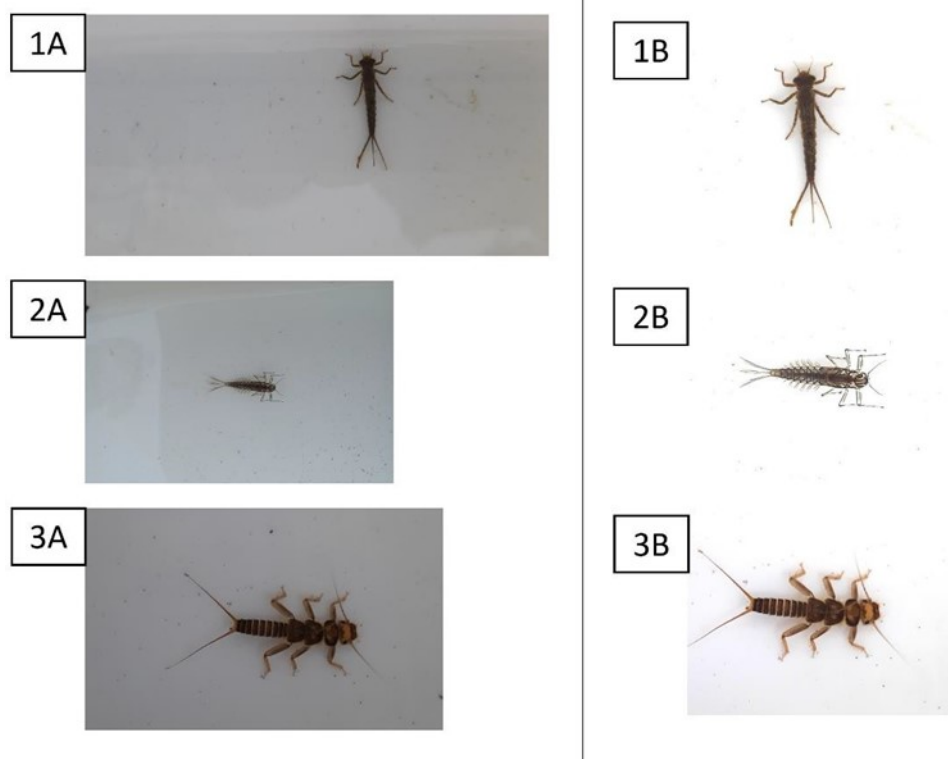
Figure 1 Examples of images of aquatic macroinvertebrates going through pre-processing before being used to train the machine-learning (ML) identification algorithm. Images of 1) a damselfly, 2) a minnow mayfly, and 3) a stonefly, prior to pre-processing (A, left column) and after pre-processing (B, right column).

- Automatic calculation of the user miniSASS score and ML miniSASS score. The user score can be based on all the groups the user lists as present, even without photographs uploaded in support of an identification. The ML score will be based on ML identification of photographs uploaded.
- Upload photos, site metadata, assessment data, and miniSASS scores from the user and ML identification model, along with user metadata (acquired based on the user profile). The data can be collected offline and submitted once a WIFI connection is established.

2.4. User research and design (beta testers)

A beta version of software contains most of the major features of the software. However, the beta version of an app can potentially contain errors and bugs. Therefore, beta versions of software are often released only to a specific group of people to conduct testing and provide feedback. The app developers can then fix any issues raised by the beta-tester feedback. After all issues are identified and fixed, the final version of the mobile application can be released. The users selected as beta-testers were people experienced with conducting miniSASS surveys. Expert miniSASS practitioners were chosen given that:

1) A beta-tester has to be able to provide high-level feedback on specific errors that may arise, maximizing the efficiency of discovering and dealing with bugs/errors.

2) Expert miniSASS identification and sampling by the user are essential; the data received during beta-testing need to be accurate and trusted since they will be used for further research and decision making. The data collected during beta testing are used to assess the feasibility of automatic data validation through the comparison of the accurate (i.e., expert) user calculated score and the ML algorithm score.

3) Expert miniSASS practitioners are likely to have the best insights regarding feedback on optimum app functionality for the end-users of the finalized app, which will initially be predominantly inexperienced, novice users. Final stage beta-testing will likely incorporate novice users, to test out functionality and ease-of-use for all users going forward.

2.5. Prototyping and wireframing

Prototyping and wireframing covers creating a visual representation of the mobile application's functionality and interface. The use-cases for the mobile application largely serve as the visual representation of

the functionality of the application as for the intended user. The beta-version of the mobile app was developed for Android devices; iOS devices are not supported. This minimized development and support costs, while maximizing the reach and usability of the app.

2.6. Development

Android Studio (https://developer.android.com) was used to develop the mobile app. Predetermined use cases (based on expert knowledge of miniSASS assessments, data collection and handling) were used to create the main activities, layouts, models, and functionality. All functionality was continuously tested using the Android Studio debugging tools as the development went through its iterative stages.

2.7. Data security and privacy

All data captured by the app are safely stored in a local database on the user's device. The final version of the app will push data to the miniSASS website. These data will be encrypted and sent to the miniSASS website Application Programming Interface (API) which will receive and handle the data.

3. Upgrade of the miniSASS website

GroundTruth are working with Kartoza (https://kartoza.com), with support from CGIAR and UNICEF, to upgrade, modernize, and streamline the miniSASS website, which has become outdated and lost some functionality since its launch over a decade ago. The miniSASS website was built over a decade ago by Kartoza and is currently hosted by The South African Institute for Aquatic Biodiversity (SAIAB; https://www.saiab.ac.za).

3.1. Defining requirements for website upgrade and modernization

Beginning the website upgrade began with defining the primary objectives:

- Modernization and streamlining, given that the old site had become outdated and suffers from a multitude of logic redundancies.
- The landing page needed easy login and user profile settings which interface with the miniSASS app, with access to an editable user profile containing the user's name, organization, and details on all miniSASS submission records.
- Redesign of an easy, accessible platform for data entry.
- Improved data visualization, summarization and reporting capacities.
- The new website needed to host all the new forms of data that will be submitted, including the site photographs, the images of

aquatic macroinvertebrates, and the ML identification algorithm's predicted miniSASS score.

- The map visualization needed to be improved by opening on the user's location when they navigate to the map and simplifying the map interface to be more globally applicable. This meant that some functionality of the map interface, such as the map layer containing South Africa's schools or rivers, needed to be removed.
- Media associated with miniSASS (i.e., publications, blogs, newsletters, photos, and training and education media) needed to be easy and intuitive to access.
- Links to other relevant pages. These include the Pluto Learning Management System[2], which currently hosts the miniSASS training course, the miniSASS YouTube page[3], the miniSASS Facebook page[4], and the resource on SDGs and miniSASS[5].

Beyond these primary goals, some additional goals were also outlined:

- Development of a dashboard summary on miniSASS similar to that for the Freshwater Biodiversity Information System (FBIS; https://freshwaterbiodiversity.org), as well as links to the relevant SDGs. This could include having the landing page carrying improved summary data, covering, for example, the number of countries with assessments, the number of miniSASS assessments submitted, statistics on miniSASS scores, and number of records within each miniSASS group, all globally and per country.
- People in control of the website being able to add miniSASS-related photos, blogs, or any other related media, as needs be.
- The website will ideally have language translation capabilities.
- Data linkages to global databases, e.g., the Global Biodiversity Information Facility (https://gbif.org) or FBIS, so that the miniSASS data are openly accessible across multiple global platforms for further use in research, policy, and management.
- Method detailing how to use the data for publication.

4. Research and development of the miniSASS training course

In parallel with the development of the miniSASS app and upgrading the miniSASS website, new miniSASS education and training media could be created and integrated into a newly designed and developed online miniSASS training course.

4.1. Defining the media content required

GroundTruth synthesized an outline of the miniSASS education and

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[2] https://groundtruth.plutolmsapp.com/enrol/index.php?id=374
[3] https://www.youtube.com/@groundtruthcitizenscience
[4] https://www.facebook.com/p/Minisass-Mini-Stream-Assessment-Scoring-System-100075822699486
[5] https://www.unwater.org/sites/default/files/app/uploads/2021/09/SDG6_Indicator_Report_632_Progress-_on-Ambient-Water-Quality_2021_EN.pdf

Table 1 The 22 features used in the new mini stream assessment scoring system (miniSASS) dichotomous key filter system. For each of the 13 miniSASS groups, an 'x' is shown if they possess the feature. Each miniSASS group is defined by a unique combination of features.

Group / Feature	Bugs and beetles	Caddis-flies	Crabs and shrimps	Damsel-flies	Dragon-flies	Flat-worms	Leeches	Minnow mayflies	Other mayflies	Snails, clams, and mussels	Stoneflies	Trueflies	Worms
Shell										x			
Shelter		x											
Clearly defined legs	x	x	x	x	x			x	x		x		
Segmented body							x					x	x
Long, thin body	x	x		x								x	x
Appendages	x	x										x	
Three pairs of legs	x	x		x	x			x	x		x		
Four or more pairs of legs			x										
Elongated tail								x	x		x		
Tufted tail		x											
Short tail	x	x											
Plate-like gills								x					
Feather-like gills	x	x							x		x		
Leaf-like gills				x									
Bulging eyes					x								
Stocky body	x				x								
Antennae	x		x	x	x			x	x		x		
Suckers at both ends							x						
Wing buds				x	x			x					
Flattened body						x							
Short, stubby legs												x	
Rounded body	x												

training media required by drawing on internal experience based on having developed and run miniSASS since 2004, as well as through coordinating several meetings and workshops with personnel from the Water Research Commission (WRC), UNICEF, Yoma (https://yoma.africa), and Duzi-uMngeni Conservation Trust (DUCT). These are all users of, and stakeholders in, miniSASS in South Africa. Therefore, they had valuable inputs towards the research and development of miniSASS media. The following content was identified as the best approach to splitting up the information and training needed:

- A short summary blurb in blog, digital pamphlet, and short video format, of what miniSASS is, what it achieves, and how and why to get involved in miniSASS and citizen science water resource monitoring.

- Short instructional 'talking heads' video explanations of:

  - The important safety aspects of carrying out a miniSASS survey,

  - How to select a miniSASS survey site within a river or stream reach,

  - How to carry out miniSASS sampling within the different biotopes or micro- habitats within the stream, and

  - How to identify the macroinvertebrates sampled using the dichotomous key and generate a miniSASS score from the sample.

- A video explaining the outcomes of a miniSASS assessment covering (updated once the website is upgraded and functional to align with the process of data submission and viewing):

  - What the miniSASS results mean in terms of the ecological health of the stream, and what to do with that information (i.e., reporting to a local water authority, or uploading the data to the website manually or via the app),

  - How the images captured can be used to create a global database for demographic research,

  - How the results can be used to identify and report local water quality issues, and

  - How the results contribute to a global database for SDG reporting and scientific publication.

- A training video on how to use the app (to be developed once the app is finalized).

- A video explaining how to use the basic functions of the website, including how to upload observations and view the map (to be developed once the upgraded website is launched).

These media are initially made available in English. A stretch goal is that they may become available in other languages.

4.2. Content creation

The miniSASS blog summary and information brochure were created using GroundTruth and open source imagery. Filming of original footage for the miniSASS education and training videos was primarily conducted by a local film duo, Luyanda Msane and Chikatizhyo Zulu from Chika Art, as well as GroundTruth. Publicly available imagery and audio files under Creative Commons licenses (CC 3.0 and CC0) were also used in media creation. Video editing and media creation were done primarily by GroundTruth.

4.3. Beta testing the course

The goal of the miniSASS training and education course is to develop proficiency conducting a miniSASS survey and understanding its outputs. This will be achieved in a adaptive-response manner via beta testing the media. Through the joint project efforts with UNICEF and Yoma, several hundred youth will undertake the miniSASS course online. They will be able to provide feedback on the course training and education media, highlighting any shortcomings or requirements for further media creation. A stretch goal is to incorporate training with the finalised app and website to ensure people undertaking the miniSASS course develop basic proficiency with use of the app and website.

Ultimately, selected resources developed for education and training in miniSASS will be integrated with the miniSASS app and website for public access and use.

5. Results and Discussion

5.1. MiniSASS app

- **Macroinvertebrate database:** Through extensive sampling at 13 sites, 20,711 raw images of specimens from all 13 miniSASS groups were collected for creation of the ML training database. After pre- processing, the database was refined to ~1,000 good quality images in each miniSASS group (Pattinson et al. 2022).

- **ML identification algorithm:** The model reached 78.31% identification accuracy to miniSASS group level, with 0.13% information loss, when identifying the unseen images. This was satisfactory performance to incorporate the model in the beta-version of the miniSASS app. Training of the ML algorithm will be ongoing as aquatic macroinvertebrate image submissions come in during the beta-testing phase, as well as over time after the app is launched. In this way, the identification continuously improves to ever-increase accuracy based on a global database of images.

- **App development:** The following set of images (Figure 2) illustrate the current miniSASS mobile app screens as they appear in the preliminary beta-version of the app.

5.2. MiniSASS website

As the miniSASS website upgrade stands:

- The primary aims and functions of the miniSASS website and app, as well as the requirements for them to interface

once they are both functional, have been defined.

- The design of the app and website, with regards to appearance (e.g., color scheme, fonts, screen resolution, photos and videos; Figure 3), functionality (i.e., core functions for information presentation, mapping, data upload and visualization), and logic (e.g., page navigation, hyperlinks to other resources, how each button or link operates and how data should be entered) have all been discussed and finalized, subject to refinement during beta-testing.

- The app development team have begun integrating

feedback on the beta version of the app, as well as incorporating the same appearance as the website.

- The web development team have begun building the website, including prototyping the user interface integrating the modernized and streamlined look and operation.

- The role of AWS for aiding in funding and development in terms of developing and hosting the app and website has been defined, with their required contributions made clear.

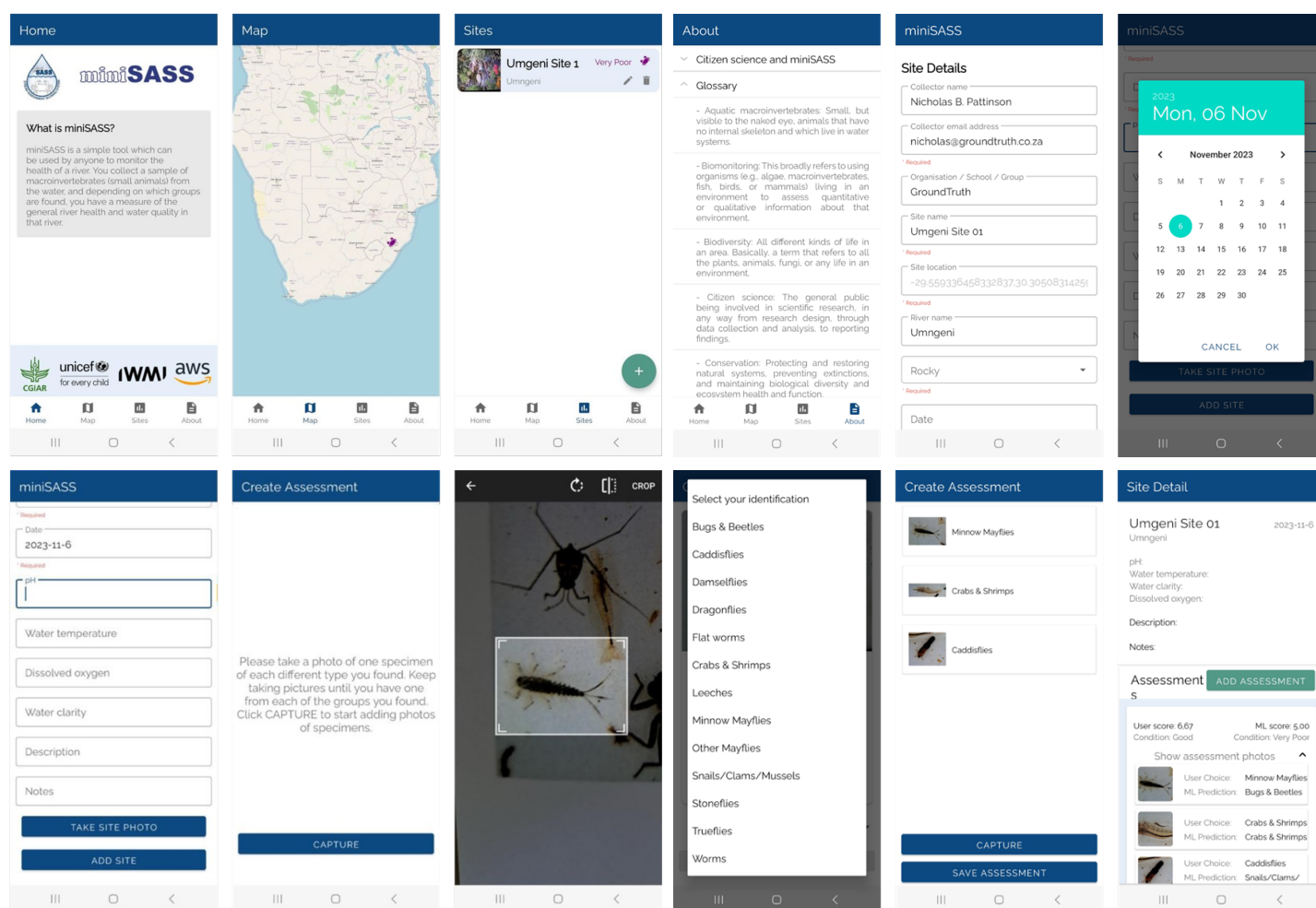- AWS has been solidified as the host of the app and

Figure 2 Screen shots showing the basic functions of the beta-version of the miniSASS mobile application (app), including a 'Home' login screen, 'Map' screen giving a view of the user location and miniSASS sites previously submitted, a 'Sites' screen showing the sites previously generated by the user along with the submissions at that site, an 'About' page showing pertinent information for miniSASS, a screen to capture information for creating a new site, with the associated information input features, the screens for capturing images of macroinvertebrates sampled during a survey, identifying them, and viewing the list of images captured, and finally the outcome of a survey, showing the user and machine learning (ML) generated scores. The ML score is generated based on the ML identification algorithm running on the images submitted by the user as a background process. Note: All metadata, miniSASS scores, and photos in the images are only used for testing purposes and do not reflect real-world data.
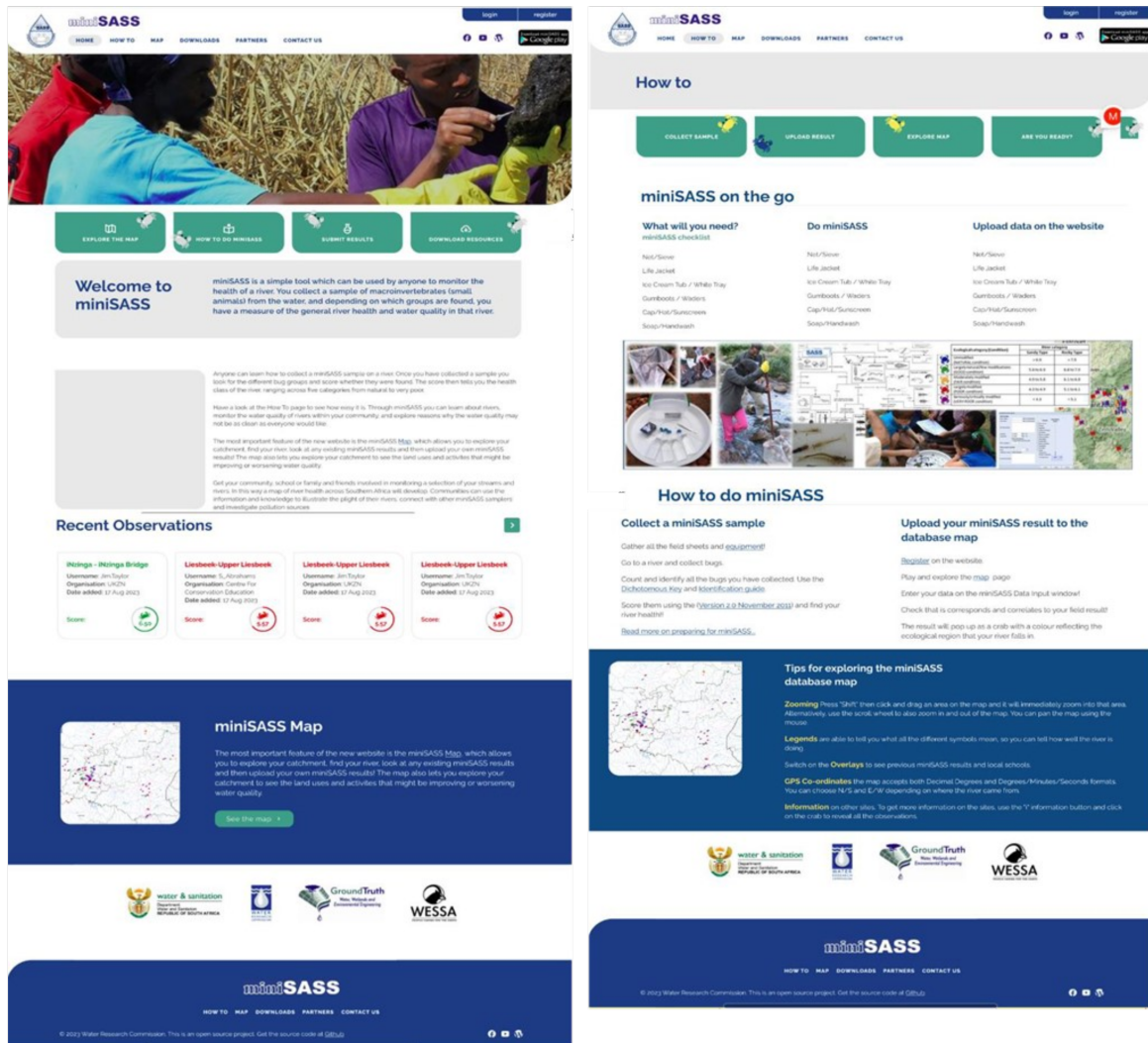
Figure 3 Prototype miniSASS website with upgraded appearance style. Content is based on the previous website and is subject to change with ongoing developments.

website back-end and data going forward, as supported by the relationship between CGIAR and AWS Non-profit team. AWS and Kartoza have developed an ongoing hosting and maintenance cost for CGIAR to support hosting the miniSASS app and website.

5.3. MiniSASS training and education courses

All the training and education media for miniSASS are available on the PlutoLMS as part of the miniSASS training course developed and run by GroundTruth. The course covers background information on miniSASS, including short videos on a number of topics:

1) "Getting to know the course coordinators."

2) "A quick introduction to miniSASS" broadly explaining the concept.

3) "Citizen science in Mpophomeni - a real life example", a story of how the Enviro- Champs from Mpophomeni have been using miniSASS and other citizen science tools to monitor the quality of the water in their community.

4) "What is in a "miniSASS kit"?" covering the equipment needed.

5) "Safety concerns for miniSASS" and "Before you go into

the water" covering the safety considerations while doing miniSASS sampling.

6) "How to choose a site" covering how to select a good site to conduct a miniSASS survey.

7) "How to take a miniSASS sample", covering how to sample each of the main target habitats in a stream for a miniSASS survey.

8) "How to clean your miniSASS sample", covering how to process the sample you have taken before proceeding to identification.

9) "How to use the key to identify what you have caught", covering how to use the dichotomous key to identify the aquatic macroinvertebrates, generate the miniSASS score, and then get the ecological category.

10) "How to calculate the miniSASS score", an explanation of how to calculate the miniSASS score based on your sample.

11) "Uploading your miniSASS score", a tutorial on how to upload your miniSASS score to the miniSASS website.

12) "Using miniSASS for monitoring", a brief explanation of setting up routine monitoring.

13) "miniSASS in summary", a brief video summarizing the entire miniSASS process.

The PlutoLMS miniSASS course also includes simple quizzes to unlock each step of the course. At the end of the course, a certificate is granted for proficiency in the miniSASS theory for use on the Yoma platform.

Acknowledgements

References

Alhejoj, I.; Bandel, K.; Salameh, E. (Eds.) 2014. Macrofaunal and floral species in Jordan and their use as environmental bio-indicators. The University of Jordan, Amman. Amman, Jordan: SMART Project. 259p.

Arndt, J.; Kirchner, J.S.; Jewell, K.S.; Schluesener, M.P.; Wick, A.; Ternes, T.A.; Duester, L. 2022. Making waves: Time for chemical surface water quality monitoring to catch up with its technical potential. Water Research 213: 118168. https://doi.org/10.1016/j.watres.2022.118168

Balázs, B.; Mooney, P.; Nováková, E.; Bastin, L.; Arsanjani, J.J. 2021. Data quality in citizen science. In: Vohland, K., Land-Zandstra, A., Ceccaroni, L., Lemmens, R., Perelló, J., Ponti, M., Samson, R., and Wagenknecht, K. (eds.) The science of citizen science. Cham, Switzerland: Springer. pp.139–157. https://doi.org/10.1007/978-3-030-58278-4_8

Bonney, R.; Cooper, C.B.; Dickinson, J.; Kelling, S.; Phillips, T.; Rosenberg, K. V; Shirk, J. 2009. Citizen science: A developing tool for expanding science knowledge and scientific lieracy BioScience 59(11): 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Buytaert, W.; Dewulf, A.; Bièvre, B. De; Clark, J.; Hannah, D.M. 2016. Citizen science for water resources management: Toward polycentric monitoring and governance? Journal of Water Resources Planning and Management 142(4): 1816002. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000641

Cohn, J.P. 2008. Citizen science: Can volunteers do real research? BioScience 58(3): 192–197. https://doi.org/10.1641/B580303

Dickens, C.W.S.; Graham, P.M. 2002. The South African Scoring System (SASS) version 5 rapid bioassessment method for rivers. African Journal of Aquatic Science 27(1): 1–10. https://doi.org/10.2989/16085914.2002.9626569

Graham, P.M.; Dickens, C.W.S.; Taylor, J. 2004. MiniSASS—A novel technique for community participation in river health monitoring and management. African Journal of Aquatic Science 29(1): 25–35. https://doi.org/10.2989/16085910409503789

Graham, P.M.; Taylor, J. (Eds.) 2018. Development of Citizen Science Water Resource Monitoring Tools and Communities of Practice for South Africa, Africa and the World. Pretoria, South Africa: Water Research Commission (WRC) Report No. TT 763/18. 167p. Available at https://www.wrc.org.za/wp- content/uploads/mdocs/TT%20763%20web.pdf (accessed on November 06, 2023).

Hulbert, J.M.; Turner, S.C.; Scott, S.L. 2019. Challenges and solutions to establishing and sustaining citizen science projects in South Africa. South African Journal of Science 115(7–8): 1–4. https://doi.org/10.17159/sajs.2019/5844

Kolok, A.S.; Schoenfuss, H.L.; Propper, C.R.; Vail, T.L. 2011. Empowering citizen scientists: The strength of many in monitoring biologically active environmental contaminants. BioScience 61(8): 626–630. https://doi.org/10.1525/bio.2011.61.8.9

Morse, J.C.; Bae, Y.J.; Munkhjargal, G.; Sangpradub, N.; Tanida, K.; Vshivkova, T.S.; Wang, B.; Yang, L.; Yule, C.M. 2007. Freshwater biomonitoring with macroinvertebrates in East Asia. Frontiers in Ecology and the Environment 5(1): 33–42. https://doi.org/10.1890/1540-9295(2007)5[33:FBWMIE]2.0.CO;2

Ndatimana, G.; Nantege, D.; Arimoro, F.O. 2023. A review of the application of the macroinvertebrate-based multimetric indices (MMIs) for water quality monitoring in lakes. Environmental Science and Pollution Research 30: 73098–115. https://doi.org/10.1007/s11356-023-27559-0

Odountan, O.H.; Bisthoven, L. de; Abou, Y.; Eggermont, H. 2019. Biomonitoring of lakes using macroinvertebrates: Recommended indices and metrics for use in West Africa and developing countries. Hydrobiologia 826: 1–23. https://doi.org/10.1007/s10750- 018-3745-2

Paisley, M.F.; Trigg, D.J.; Walley, W.J. 2014. Revision of the biological monitoring working party (BMWP) score system: Derivation of present-only and abundance-related scores from field data. River Research and Applications 30(7): 887–904. https://doi.org/10.1002/rra.2686

Palmer, R.W.; Taylor, E.D. 2004. The Namibian Scoring System (NASS) version 2 rapid bio- assessment method for rivers. African Journal of Aquatic Science 29(2): 229–34. https://doi.org/10.2989/16085910409503814

Pattinson, N.B.; Koen, R.; Koen, R. 2022. Artificial intelligence-based biomonitoring of water quality. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Initiative on Digital Innovation. 32p. Available at https://www.iwmi.cgiar.org/Publications/Other/PDF/artificial_intelligence-based_biomonitoring_of_water_quality.pdf (Accessed 06 November 2023).

Taylor, J.; Graham, P.M.; Louw, A.J.; Lepheana, A.T.; Madikizela, B.; Dickens, C.W.S.; Chapman, D. V; Warner, S. 2022. Social change innovations, citizen science, miniSASS and the SDGs. Water Policy 24(5): 708–17. https://doi.org/10.2166/wp.2021.264