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Original Article

Application Software for Water Quality Data Management (MajiBora-DM) in Tanzania

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Abstract

In Tanzania, water quality laboratories face the difficult task of managing all of the processes involved in handling water samples. These tasks include registering samples, evaluating their quality, documenting critical parameters, analyzing data, making professional recommendations on water treatment solutions to achieve superior results, and creating comprehensive reports for clients. In this paper, the authors explain the development of the Majibora-DM program, a comprehensive tool for managing water quality data. The authors developed MajiBora-DM using the Python Integrated Development Environment (IDE), pyinstaller, and the Inno compiler, then tested it on a Windows operating system computer. It demonstrated the ability to register samples, allow data sharing among computers connected to the internet, record water quality parameters, analyze water quality, interpret data, and generate reports with water treatment approach recommendations. The software plays a crucial role by calculating the impact of chemical dosages on water quality parameters in water treatment plants, thereby recommending the most effective dosage to achieve the desired quality. Also, it can simplify water quality data analysis, allow real-time data sharing, generate water quality reports, and suggest the appropriate water treatment method using artificial intelligence to achieve clean and safe water for the intended use.

Keywords: Clean and safe water, Water quality data management, Water quality laboratories, Water quality report generation, and Water treatment solutions

1 Introduction

Water quality data includes all parameters that define the safety and status of the water in place (Kumpel et al., 2020). Water quality data determine its suitability for various uses as it encompasses the chemical, physical, and biological parameters that show the presence of contaminants and pollutants in the water (Bhateria and Jain, 2016). Chemical parameters are the properties influenced by mineral ions such as fluoride, chloride, calcium, magnesium, sodium, and arsenic concentrations (Behailu et al., 2018). Physical parameters measure the properties that alter the water's physical properties, such as color, taste, electric conductivity, turbidity, and temperature (Patil et al., 2012). Then, biological parameters involve measuring the extent to which microorganisms like bacteria exist in the water sample (Cabral, 2010). Therefore, water quality monitoring is crucial for human health, ecosystem sustainability, and the community's overall well-being (Alcamo, 2019; Forget and Sanchez-Bain, 1999). Whether used for drinking, irrigation, or recreational purposes, water quality is significant for health in developing

and developed countries (Islam et al., 2021). Measuring and assessing water quality involves analyzing multiple parameters regarding water quality and mainly focusing on specific critical pollutants (Gholizadeh et al., 2016). The measured water quality parameters data are stored, analyzed, and interpreted to understand the water quality clearly, and this is known as water quality data management, which also helps scientists and water environmental agencies to understand the health of water ecosystems, identify sources of contamination, and develop appropriate water quality management strategies (Krenkel, 2012).

In Tanzania, water quality data are produced mainly by regional water quality laboratories from samples obtained in Water Supply and Sanitation Authorities (WSSA) schemes, Rural Water Supply and Sanitation Agencies (RUWASA) schemes, natural water resources, and water samples from any other customer (Mangione et al., 2020). These water quality data are recorded and stored in Microsoft Excel sheets and manually analyzed and interpreted by the user to identify the water quality status of the area where water sample data has been gathered (Hila, 2009). The Microsoft Excel-based system has played a pivotal role in facilitating water sample data entry, making calculations, and developing calibration graphs in the laboratory (du Plessis et al., 2023; Stainbrook et al., 2022). However, it is still challenging as the Microsoft Excel-based system currently used to record, interpret, and report data is technically tough and time-consuming (Gardener, 2015; Kiangi, 2014). The Excel-based system has no aiding tool to suggest water treatment methods to achieve quality water, which is crucial in water quality reports (Makropoulos et al., 2008; Nambundunga, 2021). Also, Excel-based data input does not allow real-time data sharing within the laboratory; hence, one needs to share a file from one person to another after finishing his/her corresponding task (Khan and Turowski, 2016). This makes it a massive task for the scientists and technicians in the water quality laboratories to analyze and interpret water quality data and prepare a comprehensive valuable report to water quality stakeholders and the Tanzania water quality headquarters.

Water quality headquarters in Tanzania is the Department of Water Quality Services (DWQ), which works under the Ministry of Water (Guerra and Ledesma, 2015; Wilson, 2015). DWQ receives Microsoft Excel files with water quality data from 17 regional water quality laboratories in Tanzania monthly via email (Ministry of Water, 2018). The received files are collected and read manually, and a person must write a report explaining the water quality status in a whole country. Downloading email attachments with water quality data documents, reading them, and writing a report including all received documents is technically tough and time-consuming.

Despite the aforementioned challenges, the Tanzania Ministry of Water has undertaken initiatives to implement Laboratory Information Management Systems (LIMS), however, its adoption in most of the water quality laboratories remained limited, probably because of its technical complexities (Berger, 2014). LIMS can automate various laboratory activities, such as sample registration, analytical data recording, sample data sharing, and water quality report generation (Bartholomay et al., 2021). However, they do not fulfill the critical role of suggesting optimal chemical dosing and water treatment method recommendations, which are essential tasks for laboratory scientists when identifying unqualified water samples (Adams et al., 2022).

Therefore, there is a need for a technically affordable solution that can automate data entry, data sharing, data interpretation, and report generation to streamline the workload in DWQ and water quality laboratories. Henceforth, this paper presents an application software tool called MajiBora-DM that the authors developed. It can be installed in the Windows operating system computers and used to register water samples, record analytical data, make interpretations, and suggest appropriate treatment methods or chemical dosing to attain clean and safe water which is pivotal to Tanzania water quality stakeholders, especially DWQ and all water quality laboratories.

2 Materials and Methods

2.1 Software Tools Used to Develop MajiBora-DM

The authors developed MajiBora-DM utilizing Python Integrated Development Environment (IDE) and Inno Compiler software development tools. The software development tools were obtained from their official websites (www.python.org and www.jrsoftware.org) and installed on the computer to construct the MajiBora-DM software. The download of the software packages and installation procedures were adopted from the works performed by van Rossum (2016).

2.2 Software Development Procedure

The MajiBora-DM program was initially developed by writing scripts in the Python IDE. The scripts were developed to create a user interface for inputting water quality data, organizing data, visualizing and analyzing it, and generating water quality reports. Additionally, the scripts address strategies for water treatment to achieve the desired quality. The technical process of building the Python scripts to create this software involved vital components such as the graphical user interface, email-based data sharing, and artificial intelligence for report generation. The technical way to develop the Python scripts was adopted from Fehily (2002), McKinney (2013), Goerzen and Goerzen (2004), and Moore (2021).

After that, the Python IDE scripts were created to use pyinstaller to produce the MajiBora-DM Windows program. Windows-based programs were designed to be compatible with any Windows Operating System computer, provided that Python is not installed. The methodology for creating a window-based application using Python scripts was derived from various sources, as demonstrated by Cortesi (2022), Koutsokostas and Patsakis (2021), and Sarvade and Pore (2019).

Finally, the MajiBora-DM window-based application was transformed into a Windows installation setup using the Inno compiler software. The technical processes used to create the application setup were adopted from Hetland (2005).

2.3 Testing MajiBora-DM Software

The MajiBora-DM program was installed on three distinct computers running 64-bit Windows operating systems. To ensure that data sharing over the Local Area Network (LAN) was avoided, each computer was connected to separate internet networks. This allowed for a comprehensive evaluation of its performance in remote data-sharing scenarios, particularly in Wide Area Network (WAN) environments (Radcliffe et al., 2019). After launching the MajiBora-DM program on each machine separately, thorough testing was carried out to confirm the functionality of all its features.

3 Results and Discussion

The authors have successfully developed the MajiBora-DM application and conducted tests on computers running the Windows operating system. MajiBora-DM was successfully installed and executed on a 64-bit Windows operating system. During the testing of MajiBora-DM, it was observed that the features and functionality worked properly on three different machines. The software had the capability to record water samples, facilitate data input for water quality, generate reports, and automatically interpret the water quality with recommendations for improvement. Additionally, it enabled the sharing of sample data across computers linked to different internet networks. The capability of computers connected to multiple network sources to communicate with MajiBora-DM demonstrates the software's capacity for remote data management, extending beyond the laboratory to the water quality headquarters (Boss, 2008).

The performance of MajiBora-DM is critical in managing water quality data, as it entails accurate collection, secure storage, thorough analysis, and efficient transfer of information to ensure accuracy and relevance in environmental monitoring and decision-making (Behmel et al., 2016). This section explains the features present in MajiBora-DM and how they can be useful in Tanzanian water quality laboratories and the Department of Water Quality Services to assist in managing water quality data. Figure 1 illustrates the initial interface of the MajiBora-DM, which integrates essential

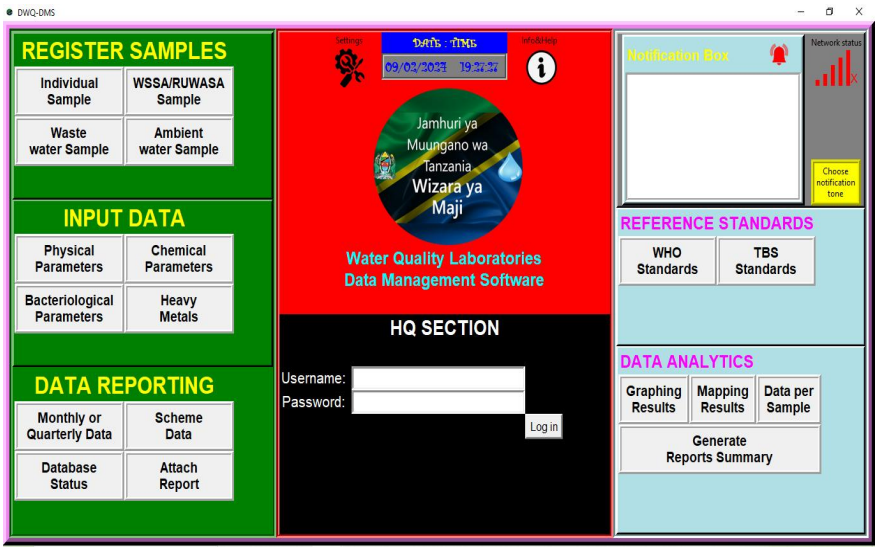


Figure 1: First interface of MajiBora-DM (Authors' construct)

functionalities for managing water quality data. These features will significantly enhance the efficiency of recording sample data throughout the entire process, from its reception at the laboratory to the creation of the final sample report.

3.1 Sample Registration Features

The sample registration feature segment, depicted in Figure 1, is one of the features produced by the authors for MajiBora-DM. It consisted of four buttons labeled "Individual Sample, WSSA/RUWASA Sample, Wastewater Sample, and Ambient water sample." These distinct buttons are utilized to indicate the specific category of a water sample that has undergone analysis in the laboratory. According to the

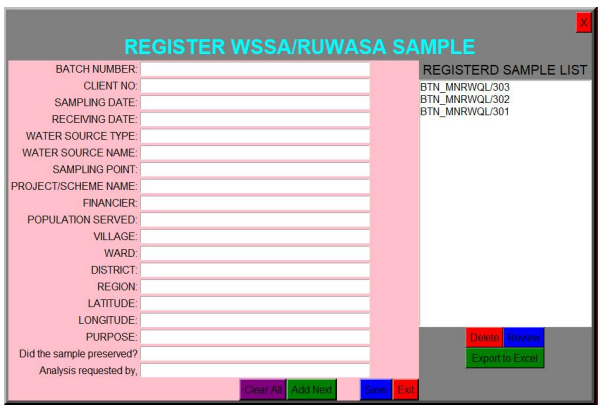


Figure 2: Sample registration interface of MajiBora-DM (Authors' construct)

regulations for monitoring water quality in Tanzania, an individual water sample is a sample submitted to a laboratory for analysis by a private company or person for their own specific purpose (Ngasala et al., 2019). WSSA/RUWASA samples are taken from either the scheme itself or the water sources that WSSA/RUWASA utilizes to provide water to the community (Mangione et al., 2020). Wastewater refers to water samples collected from sewage, marshes, or industrial effluent (Okereke et al., 2016). Ambient water refers to the water present in natural water bodies (Warner et al., 2022). The sample registration function enables personnel to designate the sample precisely during registration.

The water sample can be collected from various sources, including the individual client, the WSSA/RUWASA system, wastewater, or natural (ambient) water resources. By selecting one of the buttons in the sample registration area, the sample details entry widget will appear (Figure 2). The entry requirements for that widget closely reflect the data input for sample registration that has been lately conducted in Tanzania water quality laboratories using Microsoft Excel sheets. Another benefit of using MajiBora-DM instead of Microsoft Excel for sample registration is that the program instantly synchronizes the entered data with the cloud when the computer is connected to the internet. Once the sample details are uploaded to the cloud, they can be easily accessed by any authorized computer with the

MajiBora-DM program. This allows one person to register a sample while another simultaneously enters analytical data. This capability is not available in Microsoft Excel.

3.2 Data Input Feature

Among the features of MajiBora-DM that the authors created is the data input feature shown in part of Figure 1. This feature lets the person add analysis data collected for the registered sample. The analytical data on water quality in Tanzania is categorized into four types: physical, chemical, bacteriological, and heavy metal, as per current water quality monitoring practices (Ngowi, 2022). MajiBora-DM had buttons in the data input section corresponding to all the water quality analytical data types stated earlier. By clicking on one of the buttons associated with these data kinds, the user is provided with a widget to choose a specific parameter. Additionally, entry boxes are available for the user to provide the corresponding value for the analyzed sample. Figure 3 displays an instance of a widget that appeared when the "Chemical Parameters" button was clicked. Recently, Microsoft Excel has been commonly used for this purpose. However, MajiBora-DM offers an additional advantage. When data is entered into the entry box, it is automatically saved. The added data is uploaded to the cloud if the computer is connected to the internet. This allows authorized individuals to access the data immediately when using the MajiBora-DM software for further actions.

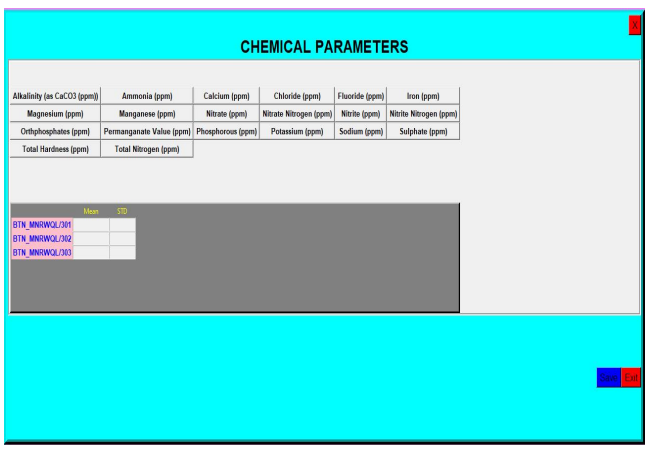


Figure 3: Data input interface for MajiBora-DM (Authors' construct)

3.3 Data Reporting Feature

The data reporting capability, which is depicted in Figure 1 of the MajiBora-DM software, was created by the authors to let Tanzanian water quality laboratories transmit data about water quality to the Department of Water Quality Services (DWQ), the head office for water quality. In accordance with the water quality monitoring strategy implemented by the Tanzanian government, a total of seventeen water quality laboratories situated in various locations throughout the nation provide the Department of Water Quality (DWQ) with data regarding the overall water sources or schemes they have monitored (Ministry of Water, 2023). These statistics must be submitted monthly and quarterly throughout the year. Additionally, the laboratories provide a Microsoft Excel-based database each month, a separate Excel sheet containing water scheme sample data, and laboratory-written water quality reports to DWQ. The data reporting section has buttons that can execute the tasks indicated above. By selecting the "Reporting Monthly or Quarterly data" button in this section, the widget displayed in Figure 4 will appear. The widget allows the user to choose a registered sample within a specified time range, starting from the date the sample is registered and ending on the last date for submission.

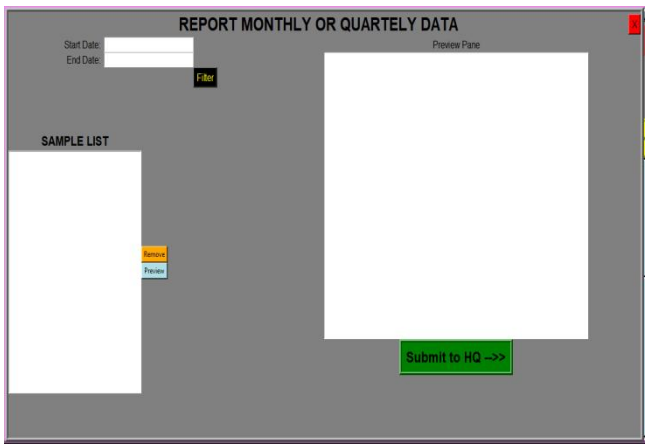


Figure 4: Data reporting interface of MajiBora-DM (Authors' construct)

3.4 Headquarters Section

The developers of the MajiBora-DM program have designed a Headquarters section, as depicted in Figure

1. The Department of Water Quality (DWQ) in Tanzania, which operates under the Ministry of Water, is the headquarters overseeing water quality (Ministry of Water, 2023). It receives water quality data and reports from various laboratories nationwide through email. The headquarters section in MajiBora-DM software has been enhanced to automatically collect water quality data from all laboratories. This component includes a login feature that requires a username and password. It serves as a pathway for authorized individuals at DWQ to log in and access the ability to monitor all water quality data and reports from various water quality laboratories, as depicted in Figure 5. This post-login interface allows users to build a comprehensive report consolidating data from many laboratories. This report provides an overview of the state of water quality in the entire country, eliminating the need to read and compile individual reports as was done previously manually. In addition, individuals at DWQ have access to comprehensive water quality information regarding the water systems utilized in Tanzania, including data on water quality status during specific periods and reports on water quality provided by laboratories. Additionally, it can rapidly detect regions that face water quality issues along with their respective metrics. The interface features a pie chart in the upper-right corner of Figure 5 that shows the percentage of safe water quality coverage in the country and the percentage of unsafe water coverage. These percentages are based on the samples registered and examined in the laboratories.

Figure 5: Headquarters Interface of MajiBora-DM (Authors' construct)

3.5 Reference Standard Section

In Figure 1, the authors have incorporated the reference standard section into the first widget of the MajiBora-DM software. The authorities or agencies in charge of public water delivery utilize the Tanzanian water quality standards for water quality control in their procedures (Pantaleo, 2019; Tumbo et al., 2007). Following laboratory investigation, authorities utilize pre-established criteria, particularly Tanzanian water quality standards, to ascertain the suitability of the water for any purpose. The reference standard section in the MajiBora-DM program allows users to input water quality metrics based on the World Health Organization (WHO) or the Tanzania Bureau of Standards (TBS) criteria. After a user from the laboratory adds these standards, they do not need to do so again. However, they can amend them if water quality standards are revised. The application inputs default values to construct a report and determine whether the samples meet the specified standards. When a button in that section is clicked, a pop-up widget displaying the arrangement depicted in Figure 6 will emerge. The widget empowers the user to modify the parameters obtained from the water sample, allowing the software to ascertain its suitability for the intended purpose.

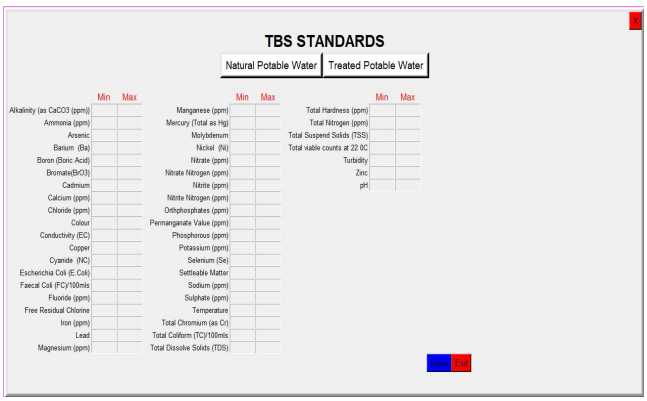


Figure 6: Interface for WHO or Tanzanian standards input in MajiBora-DM (Authors' construct)

3.6 Data Analytics Features

The authors created the data analytics functionality in MajiBora-DM software to optimize data analysis processes in water quality laboratories. Data analysis is a significant responsibility in the water quality laboratory (Hounslow, 2018). It entails measuring

essential characteristics of water samples to obtain information about water quality, contamination, and suitability for different purposes. Laboratory scientists and technicians often face difficulties in interpreting sample data and extracting valuable insights using Microsoft Excel (Ham and MaHam, 2024). Hence, the data analytics functionality of MajiBora-DM eliminates the need for manual analysis by autonomously generating essential insights from the examined water sample using artificial intelligence. Figure 1 has a section displaying the data analytics capability, including four buttons: “Graphing Results, Mapping Results, Data per Sample, and Generating Report Summary.” Upon clicking the “Graphing Results” button, the software presents graphs illustrating each parameter of the chosen water quality. The widget shown in Figure 7 is the graph representing the electric conductivity of different samples in which the red bars indicate samples that failed to meet the water quality standards, the green bars represent samples that met the assigned standards, and the orange bars represent samples that fell precisely within the boundaries of the assigned standards.

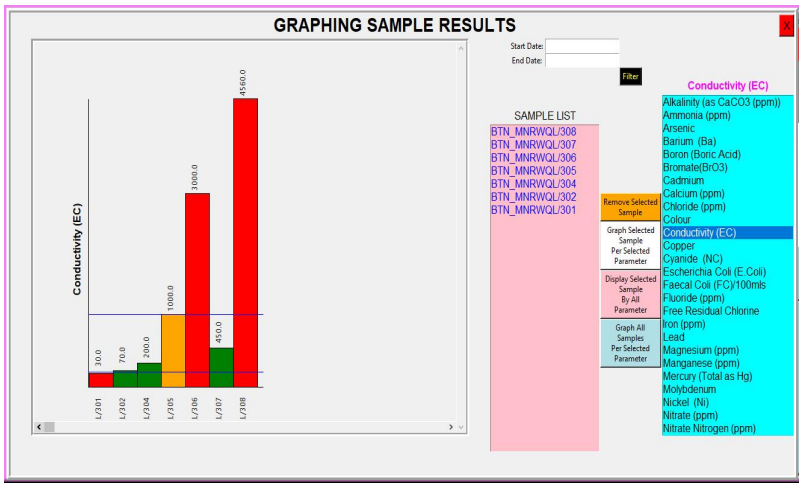
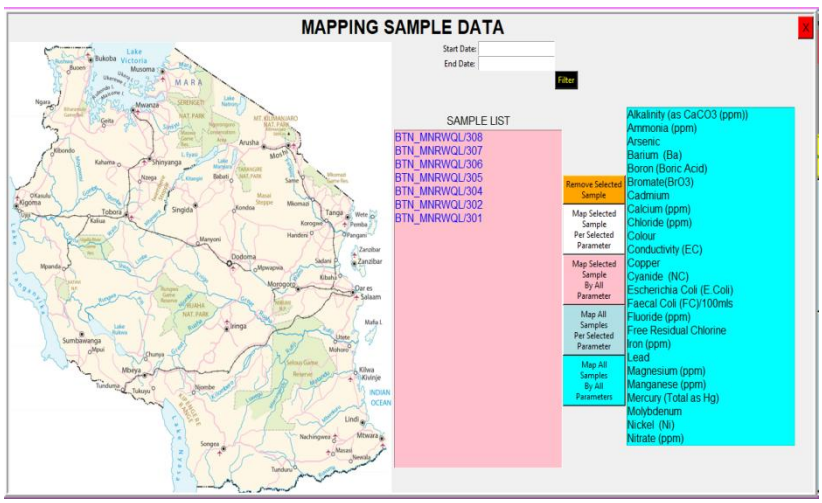


Figure 7: Data analytics interface to show sample parameters in the graph (Authors’ construct)



Therefore, an individual can rapidly understand a specific parameter by analyzing multiple samples. By clicking on “Mapping Results,” the map will show all chosen samples along with their corresponding water quality data, enabling someone to discern the pattern of the specific parameter based on the geographical position of each sample. For example, the interface depicted in Figure 8 showcased the water sample's position on the map. This provides a rapid comprehension of the water quality and possible

pollution from human activities or geological characteristics. When clicking "Data per Sample," a graph showing all the parameters examined for that particular sample will appear. The graph will also include a mark indicating the standard range, which helps quickly identify whether the sample is within or beyond the expected range for each parameter. Selecting the "Generate Report Summary" option will generate a Portable Document File (PDF) with comprehensive details regarding the registered sample and its corresponding water quality status. In addition, the report summary provides a statistical analysis of the population with access to safe water and identifies regions where the water does not meet the required standards. Moreover, if a specific parameter surpasses the established range, artificial intelligence recommends modifying the water quality by considering variations in other factors.

4 Conclusion and Recommendation

This paper explains the features of the MajiBora-DM program that the authors developed. These features facilitate water quality data management and enhance awareness of the present water quality state. The latest capabilities of the MajiBora-DM software are sufficiently substantial to be integrated into water quality laboratories and successfully assist in managing water quality data. Moreover, this program streamlines data analysis and reporting, reducing the time required for water quality report creation. The utilization of the MajiBora-DM software system is crucial due to its automatic data uploading feature to the cloud upon input, guaranteeing backup availability in case of machine loss or damage. This software produces a report that includes geographical mapping and specifies the water quality and the population it serves, which differs from the current reports often generated by water quality laboratories and DWQ. Additionally, it employs artificial intelligence to propose treatment approaches that ensure the safety of water for its intended purpose while also anticipating the alterations in water quality parameters that will occur as a result of the treatment. Hence, using MajiBora-DM software can potentially enhance efficiency in data reporting and water quality management in laboratories and water quality offices.

Lastly, the authors recommend conducting longitudinal studies on the MajiBora-DM software in water quality laboratories to assess the accuracy, efficiency, and effectiveness of data handling. Comparative studies should demonstrate improvements in efficiency, the ability to be scaled up, and the capacity to adapt in Tanzania. These studies should provide evidence to support decision-making based on facts and adopting global water quality management practices. Also, MajiBora-DM currently supports only the Windows operating system and is not compatible with other operating systems. The performance of MajiBora-DM has been evaluated solely on three computers to date, highlighting a limitation of the current study. Future research efforts might concentrate on expanding the scope of MajiBora-DM to improve its reliability. This can be achieved by doing thorough testing in various computer settings.

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Declarations

Conflict of Interest

The authors assert that they have no conflicts of interest related to the creation and execution of the Majibora-DM program, which is discussed in this work.

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