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Utilization of Hydrological Software for Effective Water Governance and Capacity Building in the Nigerian Water Sector

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ABSTRACT. Good water governance, strong political will, capacity building, enabling environment, financial viability, accountability framework, reliable service and acceptable standards are essential for efficient and sustainable water supplies in developed and developing countries. The methodology includes literature reviews, case studies and information collated from experts in the water sector. To address these complex issues, hydrological software has emerged as an indispensable tool for enhancing water governance and capacity building in the water sector. Geospatial Data Abstraction Library (GDAL), Sea Surface Temperature (SST), Soil Water Assessment Tool (SWAT), Land Surface Analysis Satellite Applications Facility (LSA-SAF), data assimilation (DA), GIS, HEC-HMS, EPANET and much other software can assist in obtaining hydrological data. Hydrological software offers powerful capabilities for collecting, analyzing, and visualizing hydrological data, enabling water managers, policymakers, and stakeholders to make informed decisions based on scientific evidence. This software leverages advanced algorithms and models to simulate water flow, quantify water availability, predict floods and droughts, and assess the impact of various interventions on water systems. It is necessary to use software and create new training programs with local stakeholders to increase water security to satisfy the expanding need for capacity in the water industry. Software for data analysis for hydrological components can be utilized for adequate forecasting and planning of water projects. It was concluded that with a comprehensive understanding of the hydrological cycle and its interdependencies, these tools and software offer crucial benefits for the sustainable management of water resources.

Keywords: water governance, capacity building, soil water assessment tool, hydrological software, geospatial data abstraction library

1. Introduction

Water is an invaluable resource that sustains life and plays a critical role in economic development, ecological balance, and social well-being. However, effective management of water resources poses significant challenges such as urbanization, population growth and climate change. The decision-making procedures are what governance is all about. Although governance has long been discussed concerning development, it has only lately come to have substantial significance in the water industry. The hydrological cycle is continuously simulated through the hydrological simulation model (rain-fall-runoff model) HYSIM using data on rainfall and potential evaporation. According to estimates from the Wang et al. (2024), "extremely high levels" of baseline water stress are experienced by close to one-fourth of the world's population. That proportion may increase to more than 50% by 2050. A significant factor in the increase of extreme weather events that endanger water infrastructure, and the unpredictability of rainfall patterns is climate change. Other factors such as growing populations and developing economies may cause a 40% increase in demand for water by 2030. One of the primary benefits of hydrological software lies in its ability to support effective water governance. By integrating data from diverse sources, including meteorological stations, river gauges, and satellite observations, these software solutions enable real-time monitoring and analysis of hydrological conditions. This timely information empowers decision makers to respond swiftly to changing circumstances, implement adaptive water management strategies, and mitigate the risks associated with water-related disasters.

The objective of this study is to check the utilization of hydrological software for effective water governance and capacity building in the Nigerian water sector. Government and the act of directing society, particularly concerning authoritative direction and control, were historically defined as nearly synonymous terms. This definition of governance emphasized the efficiency with which political decisions were carried out by the executive and legislative arms of government. Currently, the term governance is seen and understood to encompass a wide spectrum of social actors. By providing a comprehensive understanding of the hydrological cycle and its interdependencies, these tools offer crucial insights into the sustainable use and management of water resources. Moreover, hydrological software plays a vital role in capacity building within the water sector. By providing user-friendly interfaces and interactive features, these tools facilitate knowledge transfer and enhance the technical skills of water professionals. Through simulations, scenario modelling, and data-driven visualizations, hydrological

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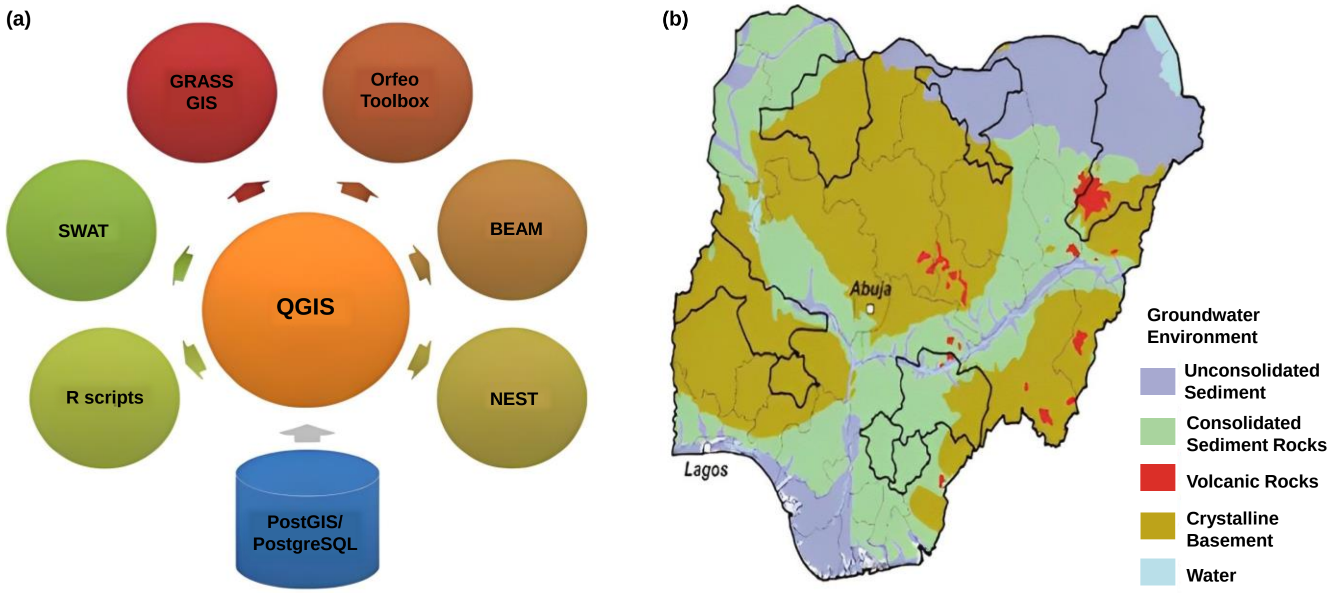

Figure 1. (a) Open-source software packages integrated as part of the Water Observation and Information System (WOIS); (b) map of hydrological locations in various geopolitical zones in Nigeria.

software enables users to explore different water management scenarios, evaluate the impact of policy interventions, and develop robust strategies for sustainable water governance.

An open-source software program called the Water Observation and Information System (WOIS) allows for the monitoring, evaluation, and inventorying of water resources utilizing Earth Observation (EO) data. The Height Above Nearest Drainage (HAND) index (Rennó et al., 2008) is used to mask out areas that are not prone to flooding and to remove pixels incorrectly classified as water due to topogray-induced radar shadows. It measures the height of a cell in a digital elevation model (DEM) about the closest DEM. For automating specific activities and integrating the various tools, Python scripts were employed. The multifunctional system known as WOIS integrates full versions of the component software into a storage container for the geodata as well as the extraction and processing of the EO data using specialized processing tools, integrated models, and tools for decision assistance, such as hydrological modelling and tools for visuization and analysis included into geographic infor-mation systems (GIS).

To examine the explanatory variables of urban floods and the spatially explicit interactions between explanatory factors and a dependent variable, Wang et al. (2016) used the greyter recycle model. To estimate PM2.5 concentration in China, You et al. (2016) used geographically weighted regression based on aerosol optical depths (AOD) measured by the Multi-angle Imaging Spectro Radiometer (MISR) and Moderate Resolution Imaging Spectroradiometer (MODIS). Researchers are working on the creation and use of GWR concurrently. A partially physical, spatially weighted regression was developed by Zhang et al. (2016). To create a high-resolution satellite map of fine particulates over the Jing-Jin-Ji region in China, Zou et al. (2016) used spatially weighted regression. This map is a model for real-time estimation of satellite derived PM2.5. Management of water resources (WRM) is a major issue on a global scale. Water is necessary for life because it is used for drinking and sanitation and because it is crucial for the production of food, energy, and health (Sheffield et al., 2018).

Stakeholders have been trying to provide a supportive atmosphere and bring about universal access there (Fuest et al., 2007). To demonstrate community involvement with local government in implementing rural programs, WaterAid has organized the Local MDG Initiative (LMDGI), which includes Ghana, Mali, Burkina Faso, and Nigeria (Nashuri, 2006; Tropp, 2007; GWP, 2008). Software can be used to do this. Fresh-water scarcity and overuse are serious and growing obstacles to environmental preservation and sustainable development. The management of water resources can be considerably improved with Geospatial technology (GST) and similar techniques at a significantly lower cost, with greater precision, and with a much wider spatial coverage.

The use of RS-based Land Use Land Cover (LULC) maps, soil mapping, and DEMs for estimating runoff potential and soil erosion of an area (Garg et al., 2012), groundwater potential mapping, soil erosion, sediment yield, and reservoir sedimentation assessment (Lilhare et al., 2014; Rawat et al., 2017; Foteh et al., 2018), are examples of efforts made in previous flood and drought mapping, monitoring, and damage assessment; snow cover and glacier mapping, and monitoring (Thakur et al., 2012; Aggarwal et al., 2014; Nikam et al., 2018), economic and hydrologic evaluation of watershed management plans (Refsgaard and Abbott, 1996; Rao et al., 2003; Sharma and Thakur, 2007), and mapping and monitoring of irrigated land and irrigation infrastructure, irrigation water and supply needs (Durga Rao et al., 2009), and analyses of the effects of land use, land cover, and climate change on water availability (Aggarwal et al.,

Figure 2. Simulation and modelling of dam through software.

2012; Nikam et al., 2018). Since the deployment of the ERS-1, ERS-2, and Radarsat series of satellites in the mid-1990s and early 2000s, active microwave (MW) remote sensing has been added to most of these applications (Thakur et al., 2018). A sophisticated method for accurately determining water quality is remote sensing technology. The physical, chemical, and biological features of the water can be used to determine its quality (Sagan et al., 2020). Sentinel data can be used to evaluate the spatiotemporal variability in estuary water, which is very dynamic (Hommersom et al., 2009; Nechad et al., 2015). The accuracy of the water quality monitoring from space can be addressed by the radiometric matching between satellite products and in-situ data (Salama et al., 2022; Xin, 2022; Li et al., 2023). One of the high-resolution sensors that can be used to evaluate the aquatic environment is the LISS IV (Satapathy et al., 2010; Dey and Vijay, 2021). GST is the combination of remote sensing, GIS, and global positioning systems (GNSS). With this technology, data is collected by sensors, stored, and processed by systems, and used by people. Through mapping, monitoring, and retrieval of different hydrological components at synoptic and recurring sizes, geospatial technology has demonstrated enormous promise for enhancing water resources management. Since no single software package could provide all the required features, the main design strategy was to develop a system that uses specialized software for specific tasks and links the various software components into a single graphical user interface (GUI). The open-source (free) software that serves as the basis for every WOIS software component includes the following samples (Figure 1a).

The literature review highlights the significant role of hydrological software in enhancing water governance and capacity building in the water sector. The integration of hydrological modelling, real-time monitoring, and decision support systems has improved water resource management practices. Furthermore, the use of hydrological software has facilitated capacity building, knowledge transfer, and stakeholder engagement, promoting inclusive and participatory decision-making processes. However, challenges remain, emphasizing the need for further research and technological advancements to overcome these barriers and harness the full potential of hydrological software in achieving effective water governance and capacity building.

A watershed's flood-prone zones can be modelled hydrologically using two different wetness indices: the topographical wetness index and the system for automated geo-scientific analyses (SAGA) wetness index. The digital elevation model of the research region can also be created using GIS, hydraulic model, HECRAS, and Quantum GIS (QGIS) software (Aksoy et al., 2016).

One of the main challenges to IWRM implementation in many locations/areas around the world is the lack of disseminating, organizing, and sharing water information and data (Doro et al., 2020; Ben-Daoud et al., 2021; Ngene et al., 2021). The connections between the sustainable development goal 6 (SDG 6) (Clean water and sanitation) and the other SDGs, when viewed in the context of the SDGs, highlight the importance of water as a resource (Le Blanc D., 2015; Ait-Kadi M., 2016; GWP, 2000; Huang et al., 2020; Yang et al., 2022; Guerrero et al., 2022). However, to ensure that the UN SDGs are achieved by the goal year of 2030, it is imperative that the issue of ecologically friendly water system recharge, sustainable abstraction, and use be given priority. According to GWP's definition of IWRM, sustainable water resource development integrates water management into a country's economic and development strategies, as well as its social, technological, and environmental advancements (Thomas and Durham, 2003; Cardwell et al., 2006; Agyenim and Gupta, 2012).

2.Methodology

The methodology includes literature reviews, case studies and information collated from experts in the water sector. A thorough review of relevant academic papers, research articles, re-

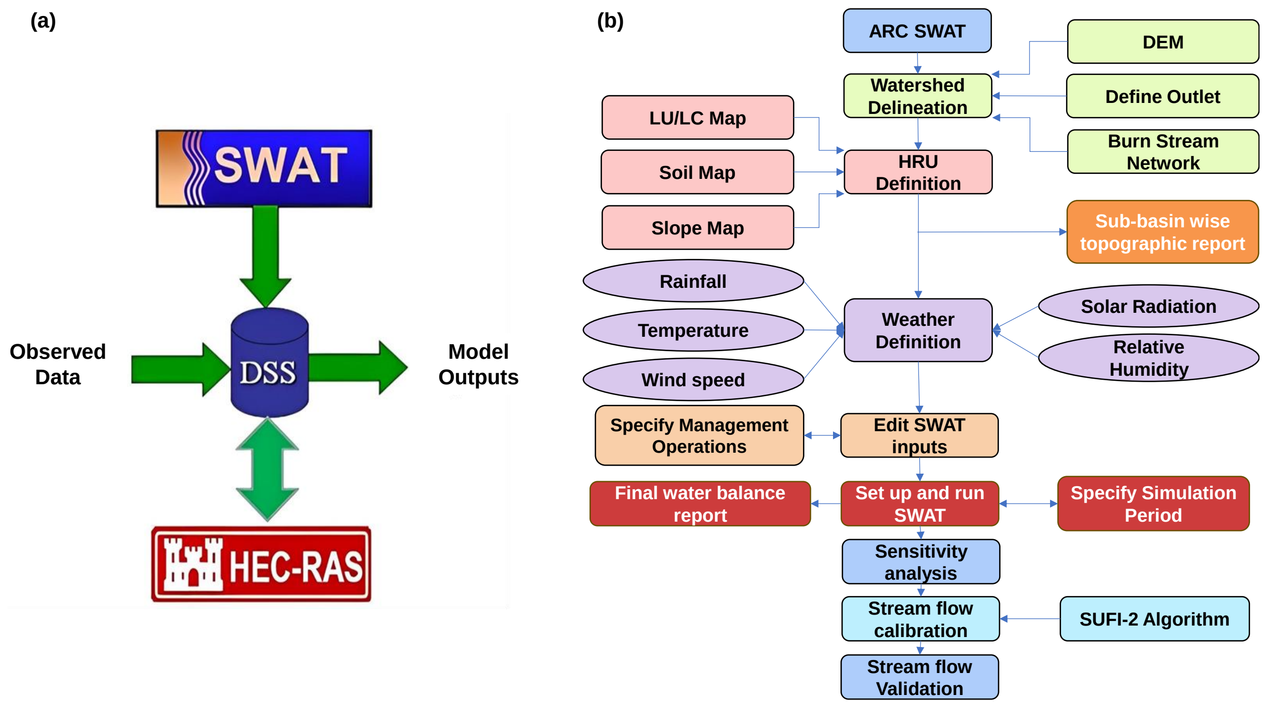

Figure 3. (a) Combination of observed data and model output from SWAT and DSS; (b) combination of SWAT and ArcView Analytical Model.

ports, and publications will be conducted to gather insights into the use of hydrological software in water governance and capacity building. The literature review will encompass studies related to hydrological modelling, decision support systems, capacity-building approaches, and participatory processes in the water sector. This review will provide a theoretical foundation and identify gaps and research trends in the field. Case studies include a selection of real-world case studies that will be analyzed to examine the practical application of hydrological software in water governance and capacity building. These case studies will represent diverse geographical regions and water management contexts to ensure a comprehensive understanding of the software's effectiveness. The case studies will focus on projects that have successfully integrated hydrological software into water governance frameworks, showcasing the impacts on decision-making process, stakeholder engagement, and capacity-building initiatives.

The study area is Nigeria, Figure 1b presents the map of hydrological locations in various geopolitical zones in Nigeria. To assess the contributions from water management stakeholders in the research area, a process of indicator selection was used as the approach. Stakeholders who participated in the consultation phase are recognized indicators for a framework for understanding integrated water resource management. This study investigates recent changes in the Nigerian water industry using interviews and an examination of policy and regulatory documents to pinpoint issues with good governance in the management of water resources.

Expert Interviews were done to gain insights from practitioners and experts in the water sector, structured interviews will be conducted. Water managers, policymakers, researchers, and software developers with expertise in hydrological software and its applications will be invited to share their experiences, challenges, and perspectives. These interviews will provide valuable firsthand information about the practical aspects, benefits, limitations, and prospects of hydrological software in water governance and capacity building. Utilizing qualitative analytical methodologies, information gathered from the literature research, case studies, and expert interviews was examined. Themes, patterns, and commonalities will be identified to form a comprehensive understanding of the role of hydrological software in water governance and capacity building. The analysis will highlight key findings, best practices, success factors, and challenges associated with the use of hydrological software. Figure 2 indicates a typical dam that can be modelled by appropriate software for effectiveness and efficiency.

3. Results and Discussions

3.1. Results Analysis

Water governance and capacity building in the water sector are crucial aspects of sustainable water resource management. Over the years, hydrological software has gained recognition as a valuable tool for achieving effective water governance and facilitating capacity-building efforts. This literature review aims to explore and synthesize existing research, studies, and practices related to the use of hydrological software in enhancing water governance and capacity building in the water sector.

Hydrological modelling for water resource management:

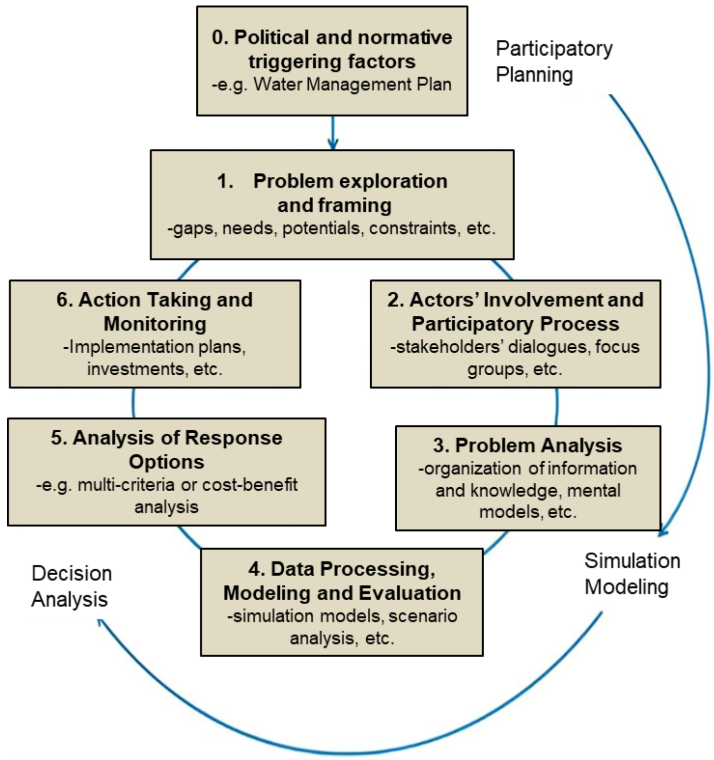

Figure 4. Water distribution system monitoring and decision support.

Hydrological modelling plays a vital role in understanding the complex dynamics of water systems and predicting their behaviour. Several studies have demonstrated the efficacy of hydrological software in simulating and forecasting water availability, flood events, and drought conditions. For example, the application of sophisticated modelling methods, such as the SWAT or the River Analysis System of the Hydrologic Engineering Center (HEC-RAS), has enabled water managers to optimize water allocation, design effective flood control measures, and develop strategies for water conservation.

Figure 3a presents the fact that SWAT, DSS and HECRAS can be combined for river and other hydrological analysis. Figure 3b resented the combination of SWAT and ArcView analytical Models while Figure 4 presented the water distribution system monitoring and decision support.

Decision-making and strengthens the capacity of individuals and organizations involved in water resource management. Furthermore, the use of hydrological software promotes transparency and inclusivity in water governance processes. By making hydrological data and models accessible to a wide range of stakeholders, including local communities, academia, and non-governmental organizations, these tools encourage active participation and collaboration. This participatory approach fosters a shared understanding of water challenges, encourages dialogue, and facilitates the cocreation of solutions that align with the diverse needs and aspirations of different stakeholders.

The integration of hydrological software with real-time data acquisition systems has revolutionized water governance practices. By collecting data from multiple sources, including weather stations, river gauges, and satellite imagery, hydrological software facilitates continuous monitoring of hydrological conditions. This enables decision-makers to respond promptly to changing circumstances, make informed decisions, and implement adaptive management strategies. Studies have shown the effectiveness of decision support systems, such as the River-Ware software, in improving water allocation, reservoir operations, and drought management. Participatory approaches and stakeholder engagement: Effective water governance requires the active involvement of diverse stakeholders. In developing and developing countries, environmental degradation and concerns with flooding must be avoided (Oyebode and Otoko, 2022; Oyebode and Paul, 2023). Over the past 10 years, novel stormwater management approaches that differ from conventional "end of pipe" tactics (focused on transporting water offsite to centralized detention facilities) have drawn more and more attention (Sage, 2015). The SWAT makes it possible to simulate a variety of physical watershed processes (Neitsch et al. 2011, Oyebode and Paul, 2023). Hydrological software has facilitated stakeholder engagement and decision-making processes by providing accessible tools for data visualization and scenario modelling. Studies have emphasized the role of hydrological software in fostering collaboration, enhancing transparency, and enabling stakeholders to actively contribute to water management initiatives. Participatory approaches, supported by hydrological software, have facilitated the integration of local knowledge, community aspirations, and indigenous practices into water governance frameworks. The hydrological area has 910.61 mm of yearly rainfall at its lowest point and 1,452.49 mm at its highest point. The data appears to be negatively skewed and not regularly distributed,

Figure 5. Challenges of security, privacy, artificial intelligence, big data, legislation, policy and deployment cost.

as shown by the coefficients of kurtosis and skewness, which were –0.45 and –0.04, respectively. The temporal variability of the annual rainfall in the basin was 9.87%, according to the coefficient of variation. The Mann-Kendall (MK) test indicates a significant ($P < 0.05$) yearly trend of decline. The non-parametric MK trend test is frequently used to identify trends in rainfall time series. Adequate design and modelling of water retaining structures, urban stormwater management, and treatment infrastructure area, essential for sustainable environment (Oyebode and Umar, 2024, Oyebode, 2022a). Traditional approaches of wastewater treatment have been stretched to their limits because of the exponential expansion in wastewater production that has been caused by urbanization (Ramalakshmi et al., 2024). Waste management requires adequate attention by all and sundry for the achievement of cleaner environment, circular economy and effective waste management (Oyebode, 2022b). Policy measures, practices and challenges of waste-to-energy must be adequately tackled in developing countries (Khanal et al., 2024).

3.2. Challenges and Future Directions

While hydrological software has demonstrated immense potential in water governance and capacity building, certain challenges persist. These challenges include data quality and availability, model calibration and validation, and the needs for interoperability among different software platforms. These issues should be addressed in a future study, along with the exploration of cutting-edge techniques like machine learning and artificial intelligence for better hydrological modelling and decision support systems. Figure 5 presented various challenges of security, privacy, artificial intelligence, big data, legislation, policy and deployment cost.

This section presents the analysis of the results obtained from the methodology employed in the study on hydrological software for effective water governance and capacity building in the water sector. The analysis encompasses findings from the literature review, case studies, and expert interviews, providing insights into the role and impact of hydrological software in water resource management. They are as follows:

(i) Role of hydrological software in water governance: The analysis revealed that hydrological software plays a crucial role in supporting effective water governance. By integrating real-time data acquisition systems with advanced modelling techniques, hydrological software enables continuous monitoring and analysis of hydrological conditions. This empowers decision-makers with accurate information for making informed decisions, optimizing water allocation, and implementing adaptive management strategies. The software facilitates data-driven decision-making processes, improving the efficiency and effectiveness of water governance practices.

(ii) Capacity building through hydrological software: The findings indicate that hydrological software contributes significantly to capacity building in the water sector. The userfriendly interfaces, interactive tools, and training modules offered by these software solutions enhance the technical skills and knowdledge of water professionals. The software enables users to analyze and interpret hydrological data effectively, fostering a culture of evidence-based decision-making. The incorporation of hydrological software in educational curricula and training programs has shown positive results in empowering water professionals to address complex water management challenges.

(iii) Stakeholder engagement and participatory processes: The analysis highlights the role of hydrological software in facilitating stakeholder engagement and participatory decision-making processes. The software provides accessible tools for data visualization, scenario modelling, and sharing of information among diverse stakeholders. This promotes transparency, inclusivity, and collaboration in water governance initiatives. Participatory approaches, supported by hydrological software, enable the integration of local knowledge, community aspirations, and indigenous practices into water management frameworks. The findings emphasize the importance of involving stakeholders in decision-making processes for sustainable water resource management.

(iv) Challenges and future directions: There are many challenges and issues linked to water governance and capacity building in the water sector. The analysis identified several challenges associated with the use of hydrological software. These challenges include data quality and availability, model calibration and validation, interop erability issues, and capacity constraints in utilizing software effectively. Addressing these challenges requires further research and technological advancements. The analysis also indicates the potential of emerging technologies, such as machine learning and artificial intelligence, for improving hydrological modelling and decision support systems. Future research should focus on overcoming these challenges and exploring innovative approaches to enhance the efficacy of hydrological software in water governance and capacity building. The use of these tools has improved recently with the development of GIS and remote sensing techniques that improve the use of physically and spatially based models to simulate and predict some of the main functions of watershed systems. Functioning Software that has been identified can be used to evaluate a potential component of an early flood warning system. Performance analysis reveals that by replicating the local rainfall features, the soft ware agrees more with observations across all climatic zones.

The full potential of the governance revolution to enhance the management of water resources and services has not yet been fully realized. At the moment, water managers and decision-makers are not fully aware of the development potentials of new forms of governance. Water governance refers to the assortment of political, social, economic, and administrative systems put in place to develop and manage water resources and to provide water services at different levels of society. The effectiveness of institutions, the caliber of leadership, and the transparency with which sector institutions and key stakeholders manage resources are the fundamental determinants of good governance.

4. Conclusions and Recommendations

The management of water resources has been revolutionized by hydrological software. Its power to offer precise data, analytical tools, and visualization skills facilitates decision-making, supports effective water governance, and strengthens capacity building. We can solve the complicated problems affecting our water supplies and clear the way for a resilient and sustainable future by utilizing the power of technology. It has been investigated how hydrological software might improve water governance and capacity building in the water sector. The findings highlight the significant contribution of hydrological software in supporting effective water resource management. By integrating real-time data acquisition systems, advanced modelling techniques, and user-friendly interfaces, hydrological software enables continuous monitoring, data analysis, and informed decision-making processes. Moreover, the software facilitates capacity building efforts by enhancing the technical skills of water professionals and promoting a culture of evidence-based decision-making. Participatory approaches, supported by hydrological software will foster stakeholder engagement and inclusivity in water governance initiatives. Despite certain challenges, such as data quality, model calibration, and capacity constraints, hydrological software holds immense potential in addressing complex water management challenges.

The analysis of the results highlights the significant role of hydrological software in enhancing water governance and capacity building in the water sector. The software facilitates data-driven decision-making, improves technical skills, fosters stakeholder engagement, and promotes participatory processes. However, challenges related to data quality, model calibration, and capacity constraints need to be addressed. The findings provide valuable insights for policymakers, water managers, and researchers in harnessing the potential of hydrological software for effective water governance and capacity building, paving the way for sustainable water resource management. A well-functioning water sector monitoring and evaluation system mechanism should be adopted. Several recommendations for decision-makers are listed as follows:

(1) Efforts should be made to provide training and capacity building programs to water professionals, policymakers, and stakeholders on the effective use of hydrological software. Training modules should focus on enhancing technical skills, data analysis, and interpretation of hydrological data.

(2) Policymakers and organizations involved in water resource management should prioritize investment in hydrological software. This includes funding for the development, maintenance, and regular updates of software platforms that cater to the specific needs of water governance and capacity building.

(3) To maximize the effectiveness of hydrological software, efforts should be directed towards ensuring data quality and availability. This includes investing in robust data collecon systems, standardizing data formats, and implementing quality control measures to improve the reliability and accucy of the data used by the software.

(4) Developers of hydrological software should work towards enhancing interoperability among different software platforms. Seamless integration of data and models across various software systems will enable comprehensive analyses and decision-making processes.

(5) Promoting collaboration and stakeholder engagement is essential for effective water governance. The employment of hydrological software as a tool to support democratic decision-making procedures is recommended, this will ensure the inclusion of diverse stakeholders and their perspectives in water management initiatives.

(6) Further research and innovation are necessary to address the existing challenges associated with hydrological software. This includes exploring advanced modelling techniques, incorporating emerging technologies like machine learning and artificial intelligence, and developing userfriendly interfaces that cater to the needs of different stakeholders.

(7) Capacity building is essential for enhancing the skills and knowledge of water professionals involved in water resource management. Hydrological software offers a platform for capacity building by providing user-friendly interfaces, interactive tools, and training modules. Researchers have highlighted the positive impact of hydrological software in enhancing technical skills, fostering a data-driven approach, and promoting

evidence-based decision-making. The incorpotion of hydrological software in educational curricula and training programs has empowered water professionals to analyze and interpret hydrological data effectively.

(8) By implementing these recommendations, stakeholders can harness the full potential of hydrological software in achieving effective water governance, strengthening capacity building efforts, and promoting sustainable water resource management practices.

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