Cooperation in
International
Waters in Africa

Water Data Revolution

OVERVIEW REPORT, 2024:

Closing the Data Gap for Transboundary Water in Africa

HOSTED BY
WORLD BANK GROUP
Water

CIWA

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ABOUT CIWA

The Cooperation in International Waters in Africa (CIWA) was established in 2011 and represents a partnership between the World Bank, its African partners, the European Commission, and the governments of Denmark, Norway, Sweden, the Netherlands, and the United Kingdom. CIWA supports riparian governments in SubSaharan Africa to unlock the potential for sustainable and inclusive growth, climate resilience, and poverty reduction by addressing constraints to cooperative management and development of international waters. Please visit us at www.ciwaprogram.org and www.ciwaprogram.org/fr or follow us on Twitter @CIWAProgram

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1. Introduction

Africa's rapidly increasing population, expanding economies, and changing climate are driving increased demand for water, while outdated data systems hinder effective management of this resource. Rising water needs for agriculture, industry, and households often strain existing resources, creating tensions among competing sectors.

The scarcity of water resources is further exacerbated by climate change, which increases the frequency and intensity of droughts, floods, and other extreme weather events.[1] These climatic stresses not only strain water availability but also undermine agricultural productivity, affecting livelihoods, infrastructure, and food security, and pushing vulnerable populations further into poverty.[2] This further complicates the political, institutional, economic, and financial challenges countries face as they manage and develop their transboundary rivers, lakes, and aquifers. These impediments affecting the water sector constitute a bottleneck to growth and prosperity in Africa. Capacity for sustainable water management is increasingly vital to stabilize ecosystems, protect infrastructure, and support equitable development.

As the saying goes, "*you can't manage what you can't measure*". Information and data on quantity and quality of water is vital to ensure equitable and efficient use of transboundary water – which is imperative for addressing other major development challenges in the region, such as agricultural production and food security, and reducing conflict and displacements. With 90 percent of water in Africa falling within 63 international river basin catchments crossed by multiple borders, water management in the region is inherently an international and cooperative endeavor.[3]

Improved management of water resources and increased resilience to hydrological extremes requires understanding water resource dynamics at the basin level. This can only be achieved based on data and observations, and it is the foundation for efficient and environmentally sound management of water with proper consideration for upstream and downstream users.[4] Basin organization are formed to collectively collaborate on these shared issues but often lack the complete picture of the situation to do so. To face these challenges adequately, governments and regional organizations need data-driven decisions to inform cooperative transboundary water

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[1] Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Available at: https://www.ipcc.ch/report/ar6/wg2/.

[2] African Development Bank. *Africa Water Vision 2025: Equitable and Sustainable Use of Water for Socioeconomic Development*, 2010. Available at: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/african%20water%20vision%202025%20to%20be%20sent%20to%20wwf5.pdf

[3] World Bank. "Cooperation in International Waters in Africa (CIWA) Program." *World Bank*, 2023. Available at: https://www.worldbank.org/en/programs/cooperation-in-international-waters-in-africa

[4] García, L.E, Rodríguez, D. J. , Wijnen, M., & Pakulski, I. (Eds.). (2016). *Earth observation for water resources management: Current use and future opportunities for the water sector*. Washington, DC: World Bank Group.

management. That is, sustainable transboundary water management requires timely, pragmatic decisions based on adequate information on the status of resources, historical trends, and future availability. This information, such as measurements on rainfall, stocks and flows, and groundwater, are key to making decisions to improve water quality, water use, long-term environmental impacts, and local and regional economies.

Many of the most water vulnerable places are also the most hydrologically data poor. In Africa, hydrometeorological and agricultural monitoring networks are often sparse and have large latency, making them impractical for real-time decision-making. To make up for a shortage of water data, a consequence of limited in-situ monitoring networks, many water managers need better access to remotely sensed data acquired from satellites. Where the need for information is arguably greatest, the data collection infrastructure and human capacity to monitor and forecast hazards is generally low because of a decline in hydro-meteorological monitoring networks over the past 30 years[5] and an ongoing lack of investment in infrastructure and training. A key limitation at the national, sub regional and continental levels is the paucity of data on water resources. This limitation is linked to inadequate human capacity for the collection, assessment, and dissemination of data on water resources. There is, therefore, an urgent need for improved data collection, better tools for water resources monitoring, and enhanced cooperation between countries sharing transboundary water resources.

Figure 1 summarizes some of the key challenges such as insufficient data coverage, incomplete historical records, high data collection costs, and barriers to cross-border cooperation, across Africa.

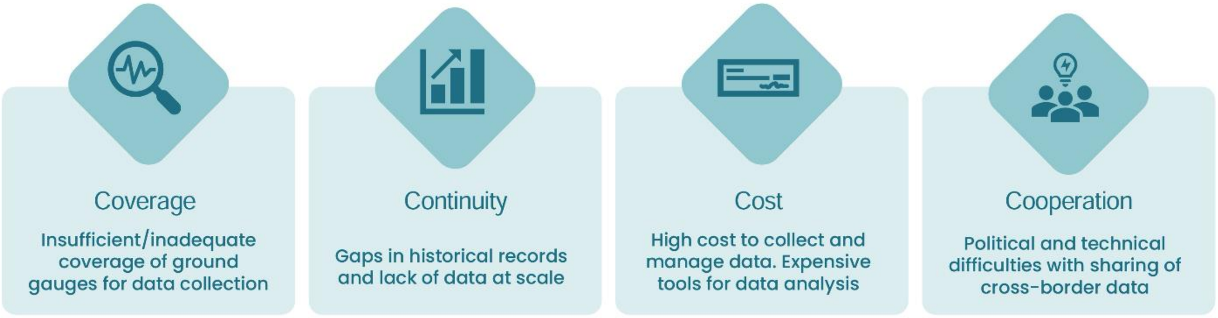

Figure 1: *Key challenges in transboundary water data management in Africa include limited data coverage, gaps in historical records, high costs of data collection, and difficulties in cross-border cooperation.*

Historically, water data collection relied heavily on ground-based methods, including the installation of hydrometeorological meters and rain gauges at specific locations. Remote

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[5] Lorenz, C., & Kunstmann, H. (2012). The hydrological cycle in three state-of-the-art reanalyses: Intercomparison and performance analysis. *Journal of Hydrometeorology*, *13* (5), 1397-1420.

sensing (RS) technology presents a valuable solution for addressing some of the key challenges associated with the limitations of in-situ data[6]. RS can mitigate issues related to gaps in ground-based observations by providing broad spatial coverage across regions, including areas where in-situ data is limited or entirely absent. With continuous historical records, RS data offers consistent time series, making it particularly useful for analyzing long-term trends in climate, hydrology, and land use. Additionally, remote sensing data is often available at high spatial resolutions, which is essential for detailed environmental monitoring and precise applications, such as water allocation and disaster forecasting. Unlike in-situ data, RS datasets are also typically free or low-cost and are not restricted by national boundaries, which allows for cohesive analysis at a basin, continental or global scale.

RS enables the collection and estimation of essential data for effective transboundary water resource management. The main data derived from RS relevant for water applications includes precipitation, evapotranspiration, soil moisture, vegetation and land cover, groundwater, surface water, snow and ice, and water quality. In the context of Africa, data from all these variables, except for snow and ice, are crucial for managing water resources. In addition to supporting applications such as flood and drought hazard mapping, RS data can assist tracking changes in land use and land cover, analyzing vegetation indices, and assessing agricultural water productivity5. Furthermore, RS plays a vital role in basin-scale water accounting, offering consistent and reliable data for evaluating water availability, usage, and sustainability, while also contributing to broader climate and environmental assessments[7].

Furthermore, RS data brings strategic value in the political context by enabling open data-sharing practices and fostering trust and collaboration among countries. RS data allows riparian countries to address transboundary water problems, such as drought and flood forecasting on transnational rivers, and facilitates broader discussion on sharing of water resources. Recent advances in cloud storage and computing power have also made RS data more accessible, allowing it to be stored and analyzed in real-time on a global scale, often at low cost. Publicly available RS data and data products enhances transparency and equity in transboundary water governance by providing unrestricted access to consistent hydrological information across national borders. This accessibility improves collaboration among riparian countries, reduces data ownership disputes, and supports evidence-based decision-making for sustainable management[8].

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[6] García, L.E., Rodríguez, D.J., Wijnen, M., & Pakulski, I. (Eds.). (2016). Earth observation for water resources management: Current use and future opportunities for the water sector. Washington, DC: World Bank Group.

[7] Bastiaanssen, W.G.M., Molden, D.J., & Makin, I.W. (2000). Remote sensing for irrigated agriculture: Examples from research and possible applications. *Agricultural Water Management, 46*(2), 137–155.

[8] Christina Leb, "Data Innovations for Transboundary Freshwater Resources Management: Are Obligations Related to Information Exchange Still Needed?" in Data Innovations for Transboundary Freshwater Resources Management (2020): 3–78, https://doi.org/10.1163/9789004429000_002.

RS does not replace ground measurement – they are more effective when combined – but it does shift the possible cost-benefit of different approaches to water data collection and expands the ability of countries to collect data on basins that extend past country borders. It can fill the spatial and temporal gaps, enabling improved decision making for management of water resources. Remotely-sensed data and information, combined with in-situ data, can provide continuous and reliable coverage to be used for basin and water planning and for cross-border applications, such as monitoring of surface water quality, tracking of water diversions and allocations, and quantification of water storage in reservoirs.

To address these challenges while capitalizing on available opportunities, the *Water Data Revolution (WDR): Closing the Data Gap for Transboundary Water in Africa, supported by Cooperation in international Waters in Africa (CIWA) program* was launched in 2021. This initiative, also aligned with the Resilience pillar of the World Bank's Africa Regional Integration (RI) strategy[9], aims to connect decision-makers across Africa with demand-driven, accessible data tools to strengthen cooperative water management across borders. The WDR worked closely with African River Basin Organizations (RBOs)[10] and Regional Organizations (ROs)[11] to identify and prioritize their specific data needs and build capacity around digital tools and applications at transboundary level.

Similarly, CIWA's overarching objective is to assist riparian governments in Africa in unlocking the potential for sustainable, climate-resilient growth by addressing key constraints to cooperative WRM. Collaborative management of transboundary water resources is vital for Africa to meet the SDG targets and to address cross-cutting issues influencing water decisions, such as climate change, fragility, conflict, violence, gender equality, social inclusion, human capital, and economic development. Transboundary cooperation is strengthened by improving access to information and through identifying, preparing, or mobilizing sustainable investments. Through initiatives like WDR, CIWA is building the capacity of its partners to make evidence-based decisions and utilize cutting-edge technologies, while creating a collaborative atmosphere to promote equitable decision-making addressing challenges associated with transboundary WRM.

The WDR recognizes that technological advancements in data collection and analysis often progress rapidly, yet they are frequently developed without fully considering the practical needs of end-users. To address this gap, the program connected users to the data through a multi-

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[9] The pillar emphasizes supporting regional cooperation to enhance resilience against risks such as food insecurity, natural disasters, and economic instability, which are increasingly prevalent across the African continent. World Bank, Africa Regional Integration Strategy: Resilience Pillar (Washington, D.C.: World Bank, 2024)

[10] River basin organizations oversee activities that have basin-wide impacts, including at the transnational, national, or local scales.

[11] Regional organizations refers to organizations that service multiple rivers and basins, such a multi-governmental organizations focused on regional or continental operations.

faceted approach that ensures both utility and transparency. This includes: (i) a “top-down” approach to connect innovation and technologies accessible to the users and to identify “fit-for-purpose” at scale, (ii) a “bottom-up” user-driven approach to understand and address end-users’ specific data requirements and to identify and support commonalities among them, and (iii) a “middleware” approach that bridges providers and users through scalable platforms. By aligning technological solutions with user needs, this holistic approach not only improves data accessibility but also fosters transparency, trust, and cooperation among African countries sharing transboundary water resources.

2. Water Data Revolution Program

2.1 Objectives and goals

The development objective of the WDR program is to build regional institutional capacity and demonstrate applications of remote-sensing data platforms to improve management of transboundary water in Africa.

The WDR is a transformative initiative focused on enhancing the sustainable management of transboundary water resources across Africa by strengthening institutional capacities to collect, store, and analyze data for informed decision-making. The project's primary objective is to bridge critical data gaps by leveraging cutting-edge technologies such as remote sensing (RS), which provides scalable and cost-effective solutions for monitoring water resources across vast and often inaccessible areas.

Through its focus on reducing the cost and complexity of water data collection and analysis, the WDR aims to make water data and information accessible to decision-makers. By connecting them with demand-driven analytical tools and state-of-the-art RS products, the initiative empowers water organizations (e.g. RBOs) to adopt data-driven approaches, promoting sustainable water management practices across Africa's river basins. Additionally, the program integrates capacity-building efforts to ensure that institutional stakeholders can effectively translate this data into actionable strategies for addressing water resource challenges.

Figure 2 illustrates the WDR's systematic approach, illustrating the progression from raw RS data to processed data products, through advanced analytical tools, and ultimately to decision-ready information that supports strategic water management.

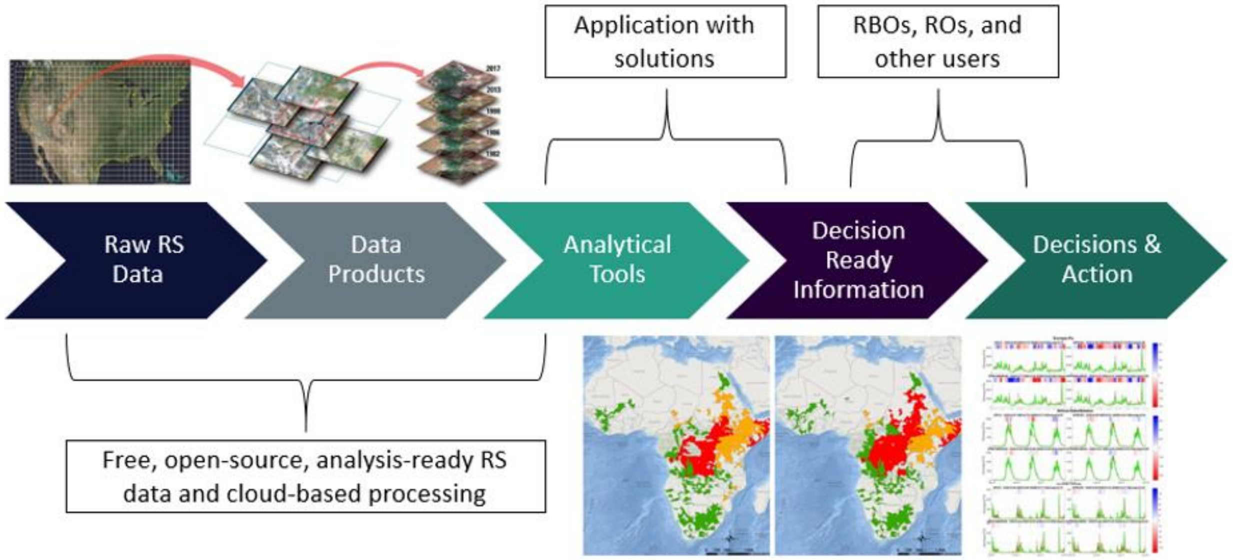

Figure 2: *This figure demonstrates how RS data progresses from raw satellite imagery to processed data products, which are then input into analytical tools for applications such as flood forecasting and drought monitoring. Decision-ready information derived from these tools enables organizations to make informed, strategic choices for sustainable water management.*

2.2 Structure

The WDR project was organized around three strategic interconnected pillars, each addressing essential aspects of data needs, capacity building, and practical applications for regional water organizations in an ordered step-by-step approach:

Pillar A: Assessment of Current Status of End-users and Identification of the Needs

Pillar A assessed the data needs and capacities of African RBOs, identifying gaps that informed tailored capacity-building interventions under subsequent pillars. This assessment focused on identifying critical gaps in data collection, technical capacity, and data-sharing practices that hinder the effective management of transboundary water. By pinpointing these specific needs and challenges, Pillar A established a foundation for targeted support and informed the design of capacity-building and technology initiatives in the subsequent pillars. This groundwork enabled the development of customized data tools, products, and training programs that would equip organizations to make evidence-based, sustainable water management decisions aligned with the unique requirements of each RBO in Africa.

Pillar B: Inception Workshops and Capacity Building

Based on the findings of Pillar A, Pillar B aimed to improve the accessibility and usability of RS data. This pillar focused on strengthening organizational capacity through online targeted training and workshops, providing water organizations with the expertise required to collect, manage, and analyze RS data. By aligning training programs with the specific needs identified in the assessment, Pillar B ensured that organizations gain the knowledge and tools necessary for sustainable, data-driven water management. This capacity building supports RBOs and ROs in applying RS data to address critical issues like water allocation, monitoring, and resource planning.

Pillar C: Adapting Innovative Tools for WRM

Pillar C served as a pilot initiative that partnered with selected RBOs to address specific water management challenges through customized, low-cost RS data solutions. Building on the practical needs identified in Pillar A, this pillar developed tailored Water Accounting (WA) dashboards for real-time monitoring for selected basins. To ensure effective integration, Pillar C provided in-person trainings, enhancing RBOs technical capacity to incorporate data-driven strategies into daily operations. By piloting these solutions, Pillar C demonstrated scalable, sustainable approaches to cooperative water management across Africa, empowering water organizations to make informed decisions.

The following sections provide a summary of the progress and achievements of each pillar within the project. For a more detailed overview of the specific activities, methodologies, and outcomes associated with each pillar, please refer to Annexes 1 through 3.

3. Pillar A – Assessment of Current Status of End-users and Identification of the Needs

Pillar A involved conducting an initial assessment of the needs and capacities of RBOs in Africa by evaluating the status, availability, and use of data, data products, and analytical tools. This assessment identified key data gaps within the RBOs and led to the development of an initial strategic plan to address these gaps. The strategy focuses on enhancing data management capabilities through the adoption of RS data, open data products, and WRM analytical tools that leverage RS data.

The assessment was carried out through written surveys distributed to 15 RBOs[12] and 3 ROs to better understand their current data needs and usage. The surveys gathered information on the status of data usage, data products, and analytical tools; practices for collecting, storing, managing, and analyzing RS data; and the challenges RBOs and ROs face when utilizing RS data and related tools. On average, each RBO consists of 4 to 5 member states, representing a total of 37 countries across the region (Figure 3). These surveys were followed by a series of interviews with the organization's staff to enhance and complement the comprehensive assessment.

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Figure 3: *Countries represented in the Assessment carried out in Pillar A*

The assessment findings revealed varying levels of familiarity and usage of RS data among organizations, with limitations primarily due to technical capacity and financial constraints (Figure 4). Key priorities for addressing these gaps include providing training on acquiring, managing, and utilizing RS data, data products, and analytical tools, with a focus on affordability and effectiveness.

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[12] The Nile Basin Initiative (NBI) (including the NBI Secretariate (Nile-SEC), Nile Equatorial Lakes Subsidiary Action Program (NELSAP), and Eastern Nile Technical Regional Office (ENTRO))

Additionally, the assessment highlighted a strong demand for training in the application of RS data and tools across three main topics: water accounting, drought monitoring, and flood management (Figure 5). While drought and flood management are critical topics, it is acknowledged that various initiatives are already supporting RBOs across Africa in these areas (e.g. NBI). Moreover, generating effective analytics for these topics—especially for flood management—faces several challenges. The spatial and temporal resolutions of public domain RS data may not adequately meet the specific needs of local flood management, particularly for addressing small-scale or flash floods. While some RS platforms provide near-real-time data, delays in data acquisition, processing, and interpretation can hinder timely and effective flood response.

RBOs expressed an urgent need for RS and analytical tools that support decision-making related to transboundary water resources management (Figure 6). In this context, water accounting analytics is highly relevant and critical due to its potential to support RBOs fulfill their mandates and its broad applicability across various water management organizations. Furthermore, recent advancements in open-access remote sensing data and analytics have made it possible to develop water accounting tools at a lower cost—an important factor for ensuring the sustainability of these tools.

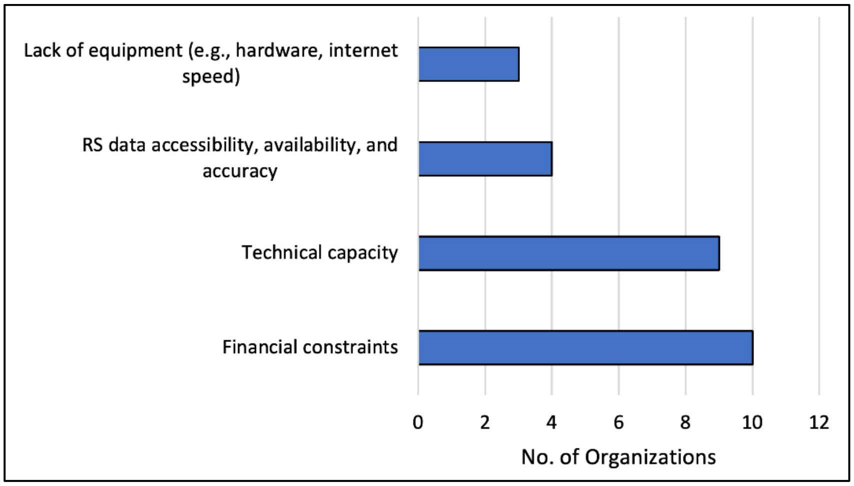

Figure 4: *Constraints identified by respondents that inhibit working with tools using RS data for WRM.*

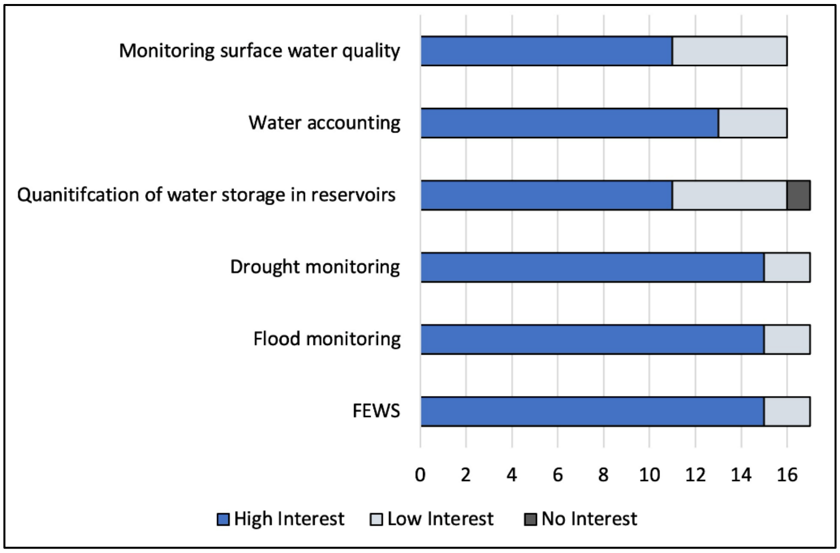

Figure 5: *Level of interest by organizations to receive trainings on analytical tools using RS to perform monitoring of surface water quality, water accounting, quantification of water storage, drought monitoring, flood monitoring, and FEWS.*

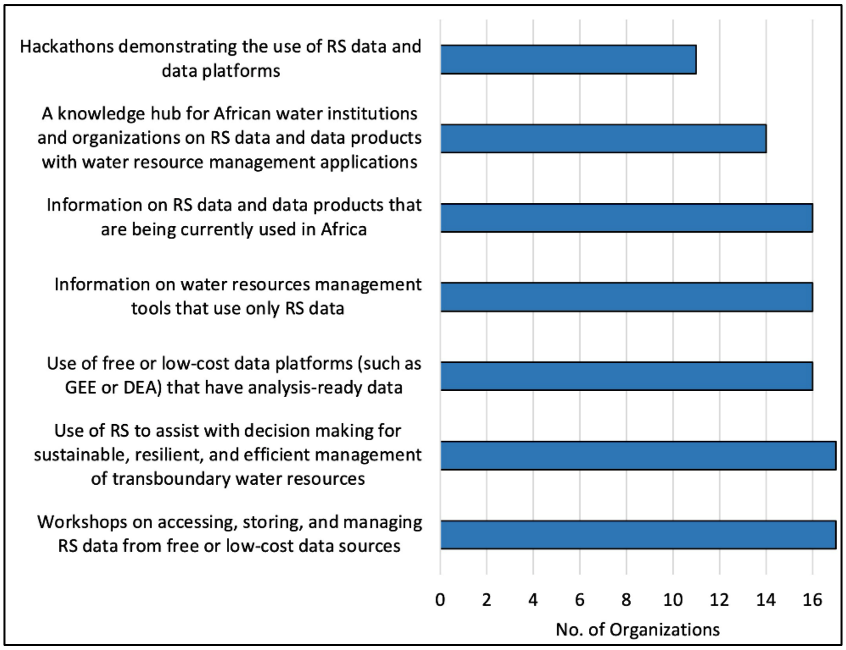

Figure 6: *Number of organizations interested in receiving trainings on various topics.*

These findings have provided foundational input for the development of capacity-building activities on the priority topics identified by RBOs, as detailed in Pillar A's report (Annex 1, Chapter 7). Additionally, Annex 1, Chapter 10.1 presents a summary of key free RS data products and their usability for water resource management.

For a comprehensive overview of RS data tools and products that support improved water resource management, including a detailed summary of the assessment conducted, refer to the full report in Annex 1.

4. Pillar B – Inception Workshops and Capacity Building

Pillar B focused on enhancing RS data utilization and building capacity for sustainable transboundary water management in Africa. Built on the findings of limitations and constraints identified in Pillar A'a assessment, Pillar B addressed identified gaps in data access, analytical capabilities, and technical knowledge. This pillar was specifically designed to support African water management bodies with the tools, technical skills, and methodologies necessary for data-driven decision-making in managing shared water resources across international boundaries.

A series of capacity-building workshops were implemented to provide technical training on RS data collection, management, and analysis. Conducted online to maximize accessibility and participation across the continent, the workshops attracted technical professionals from numerous RBOs across Africa. The online format also promoted greater inclusivity, enabling higher number of female participations who might face barriers to attending in-person sessions. The sessions covered a wide range of topics, including data collection techniques, data analytics, and cloud-based platforms for real-time water resource monitoring.

Tools and technologies were carefully selected based on their relevance to RBO operations, ability to address cross-border WRM challenges, cost-free accessibility, and alignment with the latest advancements in data analytics, as summarized below:

Workshop title	Dates	Overview
Water Data Revolution: Modernizing Transboundary Water Data and Analytics	June 13th - 14th, 2023 (2 days)	Introduction to a spectrum of technologies for data/analytics and knowledge generation related to transboundary waters. In-depth focus on modern cloud analytics, interactive dashboards, AI applications, and new open services for historical data insights.

Water Data Revolution: Data and analytics for Water Resources Management	November 29th, 2023 (1 day)	Demonstration of selected tools with applications for empowering water planners in decision-making for WRM, with a focus on allocation planning and irrigation productivity.
Complementary trainings led by Water GP.		The Water GP, through its global unit, has conducted several training sessions focused on modern data and analytical tools for water resources management. These sessions were designed for a broad audience of water specialists and included participation from the RBOs as part of the support provided by the WDR program.

Key tools included Google Earth Engine, the World Bank's geospatial platform, and Hydrosheds, which offer robust capabilities for satellite data visualization, real-time analysis, and access to global hydrological data layers. Participants explored data collection methodologies, including in-situ and Earth observation techniques, complemented by cloud-based tools like Sentinel imagery and Climate Engine for data processing, and interactive dashboards for real-time insights. Topics included AI-driven data analysis and innovative visualization technologies to support informed decision-making. Additionally, frameworks like WA+ and the WaPOR platform were introduced to support water accounting and water productivity tracking for irrigation, both critical for sustainable WRM.

These activities generated critical outcomes, enhancing access to essential tools that lead to strengthening sustainable water management. Participants acquired practical skills in RS data collection and analysis, gaining hands-on experience with platforms like Google Earth Engine and the World Bank's geospatial tools, which enable organizations to monitor water availability, predict hazards, and make data-informed decisions. The workshops prioritized accessible, cost-free RS tools, removing financial barriers for organizations and ensuring that limited resources to not impede capacity-building efforts. To ensure capacity remains within each organization, training materials were shared with participants, supporting ongoing skill reinforcement and knowledge retention.

Further, the "training of trainers" approach was encouraged, equipping key participants to pass on their expertise within their respective organization. Finally, continuous engagement with RBOs and their technical staff is recommended to keep participants updated on evolving technologies and to tailor future sessions to their specific needs and constraints.

Tools related to water accounting emerged as an important focus in the capacity building program under Pillar B, given their important role in quantifying water availability, usage, and allocation. This process is essential for the cooperative management of transboundary water resources, enabling organizations to make informed and equitable decisions on water distribution. The knowledge gained in these sessions laid the groundwork for the next phase, Pillar C, where analytical tools in the form of dashboards were developed to demonstrate the practical application of RS data and tools. These dashboards, in alignment with the RBOs needs outlined in Pillar A, were designed particularly to support water accounting and promote equitable water resource management practices in selected pilot river basins.

For a detailed description and outcome of Pillar B, please refer to Annex 2, where the methods, structure, and key results are comprehensively outlined.

5. Pillar C – Adapting Innovative Tools for WRM

Pillar C focused on adoption of RS data and data platforms for decision making by: (i) supporting end to end sustainable demand-driven services in selected RBOs; and (ii) testing and adopting efficient and free/low-cost hydro-informatics data, tools, and services. Responding to the interests and requests from RBOs, this pillar provided access to a tailored analytical tool that supports decision-making related to transboundary water resources management. In this context, water accounting has emerged as a crucial tool for promoting sustainable water resource management in transboundary basins. In the context of this initiative, the goal of this tool was to serve as a starting point for broader, long-term discussions and engagements and to enhance water resource management (WRM) assessments by leveraging remote sensing (RS) data to bridge the gap between data and decision-making. While the tool was not initially designed as a comprehensive application with definitive decision-making outcomes, it holds the potential to evolve into one over time.

5.1. Understanding Water Accounting (WA): Benefits and Methodology

Given the expected increase in water demand, ensuring sustainable and efficient water availability will require a shift toward investment strategies that enhance the productive use of water. This necessitates a clear understanding of the multifaceted challenges to be addressed, such as inefficient water usage in agriculture, land use practices that lead to excessive water consumption, and a lack of awareness regarding environmental water needs. Overcoming these challenges requires a comprehensive understanding of the unique water context in each region, enabling the development of tailored strategies that account for varying biophysical, societal, and developmental conditions.

Water Accounting provides such critical information, facilitating the identification of investment strategies to improve overall water productivity within a river basin, in such a way that contributes to the accomplishment of targeted development goals in the basin context, which is usually associated to different aspects such as improved and extended water supply, enhancement of food security, environmental preservation which in turn is usually key for sustaining income generating activities across Africa[13].

Water accounting in transboundary river basins provides several key advantages by offering a consistent framework for managing water resources across different scales. This is especially important as it helps in managing shared water systems across countries with varying policies, priorities, and water use patterns. It tracks all sources of water (e.g., rainfall, groundwater, wastewater, desalination) and how it is used (e.g., evaporation, irrigation, industrial use), along with changes in storage (e.g., soil moisture, groundwater reserves). WA promotes transparent decision-making and enables equitable water distribution, which is critical in mitigating disputes among riparian countries. It also facilitates the identification of opportunities for joint investment projects and supports the long-term sustainability of water resources. By creating a common understanding of water availability and demand, it contributes to more informed and cooperative resource management across different scales, helping to prevent over-exploitation and ensuring that water is used efficiently for economic and environmental benefits.

. From a basin perspective, it supports the identification of measures that ensure water resources are managed effectively and equitably, maximizing societal value while accounting for synergies and trade-offs in land and water management. As water scarcity and interdependencies grow, water accounting becomes essential for understanding the consequences of changes in water use and for adjusting water allocations, management strategies, and investment decisions accordingly.

Water accounting in transboundary river basins offers significant advantages by providing a standardized framework for managing water resources. This is especially important as it helps in managing shared water systems across countries with varying policies, priorities, and water use

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[13] FAO (Food and Agriculture Organization). Water Accounting Plus (WA+) Framework: A tool for improving water productivity in agriculture. FAO, 2018

patterns.[14],[15] It promotes transparent decision-making and enables equitable water distribution, which is critical in mitigating disputes among riparian countries. Water accounting also facilitates the identification of opportunities for joint investment projects and supports the long-term sustainability of water resources. By creating a common understanding of water availability and demand, it contributes to more informed and cooperative resource management across different scales, helping to prevent over-exploitation and ensuring that water is used efficiently for economic and environmental benefits

A water accounting system is implemented using a standardized methodology and nomenclature. In recent years, Water Accounting Plus (WA+), developed by the International Water Management Institute (IWMI), has become one of the most widely used approaches. WA+ addresses the limitations of traditional methods by relying on remote sensing technology, open-source hydrological models, and global datasets, rather than relying solely on national-level hydro-meteorological data. This approach offers a significant advantage by enabling consistent and accurate water accounts at different scales, even in regions with limited ground-based data, thanks to the use of satellite-derived information. This is especially beneficial in the context of transboundary river basins, where data access can be challenging due to the participation of multiple countries. In such cases, remote sensing eliminates the need for extensive data collection, which can be resource-intensive and often hinders cross-border collaboration by creating logistical barriers.

WA+ uses satellite-derived data for key meteorological variables (e.g., evapotranspiration and precipitation) to calculate water balances without requiring direct measurements of water withdrawals or return flows. By leveraging advancements in earth observation technology, WA+ provides reliable, continuous, and gridded data on water resources from field to basin scales, ensuring consistency across regions and transboundary basins. This approach offers a comprehensive understanding of water availability, use, and sustainability and is increasingly used to support water resource management and policy decisions, especially in areas where local data is scarce.

Another key advantage of using the WA+ is that it provides a replicable framework. This means that Water Accounting dashboards can be implemented across different basins, creating a common foundation for analytics among RBOs. This approach offers significant benefits, particularly by enabling the future scalability of the CIWA initiative to support additional RBOs,

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[14] GWP (Global Water Partnership). (2014). Water Accounting in Transboundary Basins: A Tool for Ensuring Equitable and Sustainable Water Management. Global Water Partnership.

[15] FAO. (2018). Water Accounting: Framework for Improving Water Productivity and Sustainability in Agriculture. Food and Agriculture Organization of the United Nations.

while also extending capacity-building activities that will benefit not only the RBOs currently involved but also those that may participate in the future. Moreover, the use of a common platform fosters greater collaboration among RBOs. It can facilitate knowledge sharing and best practices, allowing RBOs to learn from one another and adopt successful strategies used in other regions. Given the characteristics of the WA+ methodology and its alignment with the objectives of Pillar C, it was selected as the methodology for developing the Water Accounting tools under this pillar.

5.2. Selection of participating RBOs

To implement Pillar C, the initial step involved identifying key RBOs from those that participated in Pillar A, to determine where pilot projects for Water Accounting Dashboards could be implemented. This pre-identification process was initiated based on an assessment of each RBO, considering multiple key criteria such as capacity, current mandates/activities, potential for taking on the initiative, current and past engagements with the World Bank, and the existence of similar initiatives to avoid duplication and foster synergies. A significant portion of this process was informed by the findings and analyses from Pillar A. Priority was given to RBOs where this initiative could either initiate or strengthen engagement, acting as a catalyst for further dialogue and collaboration.

The pre-identification exercise resulted in the selection of three RBOs: Volta Basin Authority (VBA), Incomati and Maputo Watercourse Commission (INMACOM), and Zambezi Watercourse Commission (ZAMCOM). Following this, conversations were initiated with these RBOs to introduce them to the purpose of the initiative, outline the potential benefits, and clarify the commitment required from them to carry it out. An important aspect of these engagements was the mutual learning between the task team and the RBOs, particularly in understanding the unique characteristics and specific data needs of each RBO to support their day-to-day operations and engagements, which was a building block for strategizing the further development of the dashboards and activities associated.

VBA, INMACOM, and ZAMCOM expressed strong interest in participating in this initiative, emphasizing the value of having a sophisticated analytical tool that could deliver critical information for planning measures to enhance efficient water resource management, particularly in the absence of reliable ground-based data. This is particularly important given the limited availability of such data. Consequently, these three RBOs formalized their interest in participating in the initiative by submitting a request note to the World Bank. The spatial distribution and location of the selected RBOs can be seen in Figure 7.

5.3. Characteristics of selected RBOs

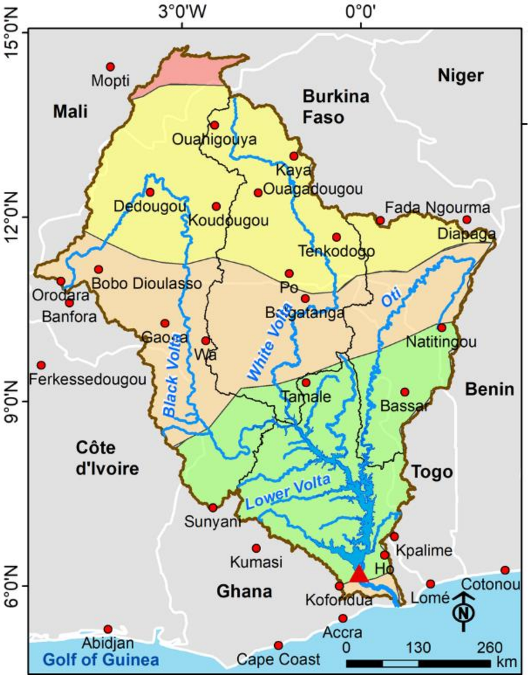

Figure 7: Volta River Basin in West Africa. Figure obtained from Dembélé et al. (2023)[16]

<u>Volta Basin Authority</u>: The Volta River Basin, spanning approximately 400,000 km² across six West African countries—Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, and Togo—supports nearly 23 million people whose livelihoods and economic development are closely tied to its natural resources. Water is critical for agriculture, hydropower generation, livestock, fisheries, and tourism, with agriculture alone accounting for 40% of the basin's economic output. To ensure sustainable management of these shared resources, the riparian countries established the VBA in 2007. The VBA promotes Integrated Water Resources Management and seeks to ensure equitable water use, the development of key infrastructure, and the alleviation of poverty, while fostering socio-economic integration in the region.

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[16] Dembélé, Moctar & Salvadore, Elga & Zwart, Sander & Ceperley, Natalie & Mariethoz, Gregoire & Schaefli, B.. (2023). Water Accounting under Climate Change in the Transboundary Volta River Basin with a Spatially Calibrated Hydrological Model. Journal of Hydrology. 626. 130092. 10.1016/j.jhydrol.2023.130092.

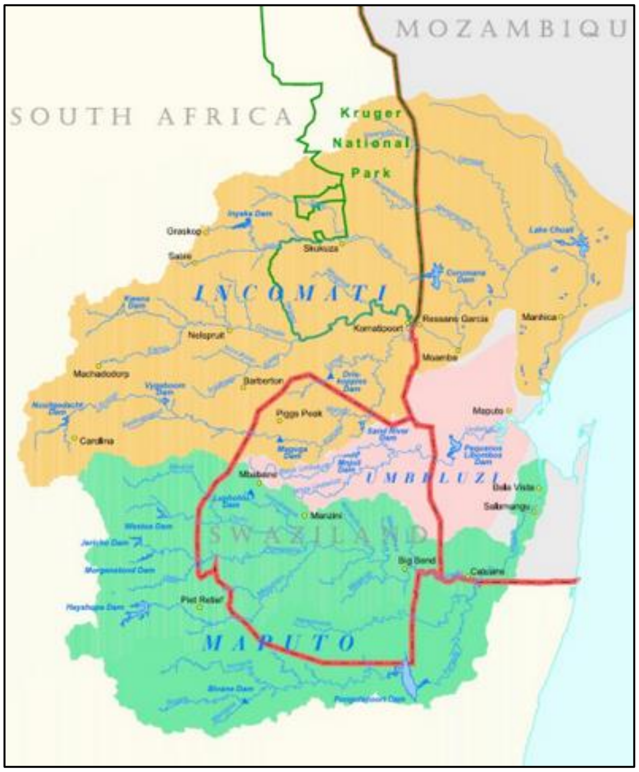

Figure 8: Incomati and Maputo River basins. Figure obtained from Tanner et al (2008)[17].

<u>Incomati Maputo Watercourse commission:</u> The Incomati and Maputo River Basins, shared by Eswatini, Mozambique, and South Africa, are vital to the socio-economic development of the region, with water resources supporting agriculture, hydropower, industry, and conservation. The Incomati Basin, covering 49,000 km² and home to 2.3 million people, is crucial for irrigation, especially for cash crops like sugarcane, which fuels the regional economy, while hydropower dams meet growing energy needs. The Maputo Basin, spanning 30,000 km², relies on irrigation and afforestation, with expanding commercial agriculture and forestry. To ensure sustainable and equitable water sharing, the governments of the three countries established the Incomati and Maputo Water Commission (INMACOM) in 2021, building on the Tripartite Permanent Technical Committee (TPTC) formed in 1983. INMACOM promotes Integrated Water Resources Management (IWRM), supports environmental and socio-economic benefits, and strengthens water resource management through innovative approaches like Water Accounting and the use of remote sensing data to overcome data gaps.

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[17] Tanner, A. & Mndzebele, D. & Ilomäki, J.. (2008). A case study: the approach to the integrated and cooperative management of the water resources of the Maputo River Basin by Moçambique, Swaziland and South Africa. 53-62. 10.2495/EEIA080061.

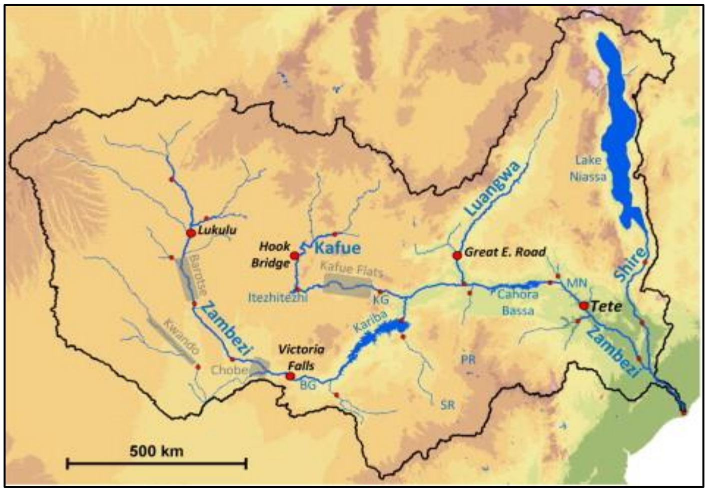

Figure 1: Zambezi River basin. Figure obtained from King et al (2014)[18]

Zambezi Watercourse Commission: The Zambezi River Basin, spanning 1.397 million km² across eight Southern African countries—Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe—supports nearly 30 million people whose livelihoods depend on its water resources. Agriculture, particularly irrigation for both small-scale and commercial farming, is the primary economic activity, while hydropower production from major reservoirs like Lake Kariba and Lake Cahora Bassa plays a crucial role in the region's energy supply, contributing 24% of the Southern African Power Pool's electricity. To promote equitable and sustainable water use, the Zambezi Watercourse Commission (ZAMCOM) was established in 2014 to oversee the management and development of the Zambezi River Basin. ZAMCOM's mandate includes data collection, harmonizing resource management, advising member states on sustainable development and conflict resolution, and raising public awareness. The initiative also supports ZAMCOM's work by advocating for advanced Water Accounting techniques and the use of remote sensing data to enhance water resource management, especially in areas with limited ground data.

5.4. Developing a Water Accounting Dashboard: The Process

The development process of the WA dashboard initiated with an online inception workshop led by WB and IWMI. The workshop targeted technical specialists from the RBOs with the main objective of introducing the initiative, explaining the role of the RBO, and gathering insights into the specific information and data needs of the RBO to support its work in water resources management within its jurisdiction. These insights provided critical inputs to shape the dashboard's development to align with the RBO's requirements and needs.

Building on the insights gained from the inception workshop, the development process of the dashboard began. Once the first prototype was completed, a workshop was organized to present the prototype to the RBO, provide hands-on training on its use and functionalities, and gather

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[18] Kling, Harald & Stanzel, P. & Preishuber, Martin. (2014). Impact modelling of water resources development and climate scenarios on Zambezi River discharge. Journal of Hydrology: Regional Studies. 1. 17–43. 10.1016/j.ejrh.2014.05.002.

feedback to identify necessary improvements for the final version. The workshop also included a capacity-building component focused on more advanced topics in remote-sensing data and its applications in water resources management within a transboundary context, both in relation to the WA dashboard and beyond. The workshops saw active participation from a significant number of RBO members, which facilitated valuable discussions and resulted in strong feedback on the further improvements needed for the dashboard's final development. Moreover, participants expressed high satisfaction with the capacity-building sessions, which allowed them to deepen their technical knowledge and/or acquire new skills. A key outcome of the workshops was their role in fostering a sense of ownership among the RBOs for the dashboard, strengthening their commitment to continue this collaboration.

Building on the feedback obtained during the workshop the WA Dashboard was finalized. A final workshop was carried out to launch the final WA Dashboard and share the outcomes with the RBO. In parallel, complementary capacity building sessions were provided to enhance technical skills in the RBOs for effective dashboard management.

Post-capacity building evaluations revealed a highly positive impact of the training sessions, demonstrating significant enhancement of participants' knowledge across various water accounting topics. These improvements reflect both the effectiveness of the training and the participants' increased engagement with complex concepts. A key highlight was the transformation in participants' understanding of water accounting. Before the training, many had limited knowledge of the subject. By the end, all participants were able to answer fundamental questions, showcasing a remarkable improvement in their grasp of key concepts. The training also met participants' expectations, with 93% expressing that their knowledge had been greatly enhanced. The structure and clarity of the sessions were widely praised, with participants finding the content well-organized and easy to follow. Furthermore, the practical relevance of the WA+ tool was emphasized, with 67% of participants rating it as highly valuable for both current and future projects. This underscores the lasting impact of the training on participants' professional development.

5.5. Technical aspects of the WA Dashboard

The WA Dashboards were developed as web-based tools designed to provide detailed, multi-year water accounts for the basins water resources. They offer insights into water balance components, water usage patterns, water availability and climate change impact, to support informed decision-making for enhanced management of transboundary water resources. A key characteristic of the dashboard is that it facilitates the visualization of complex water data, making it accessible to a range of stakeholders, including policymakers, scientists, and the general public.

Tableau Desktop Public Edition was chosen as the backend architecture for the development of the WA Dashboard given its advanced data visualization capabilities, which allow for the creation of highly interactive and visually engaging dashboards. Its flexibility in handling large and complex datasets, as well as its robust integration with diverse data sources, makes it ideal for the purposes of the WA Dashboard, where data needs to be analyzed and displayed in a clear, insightful manner. Tableau also offers powerful customization options, enabling users to drill down into specific data points, and provides scalability. Figure 8 provides a schematic view of the Tableau architecture of the WA Dashboard.

Satellite imagery and remote sensing data served as the primary sources of input for the WA Dashboards. The spatial resolution of the remote sensing data was resampled to 1 km, and the data were aggregated to monthly time intervals for the water account analysis. Some of the key input parameters derived from RS include dynamic parameters such as precipitation, evapotranspiration and saturated soil moisture, and static parameters such as landcover and reservoir data. More details on the input data and sources can be found in Annex 3.

The WA Dashboard is structured in five tabs, each one providing different sets of information. A description of each tab is provided in the paragraphs below.

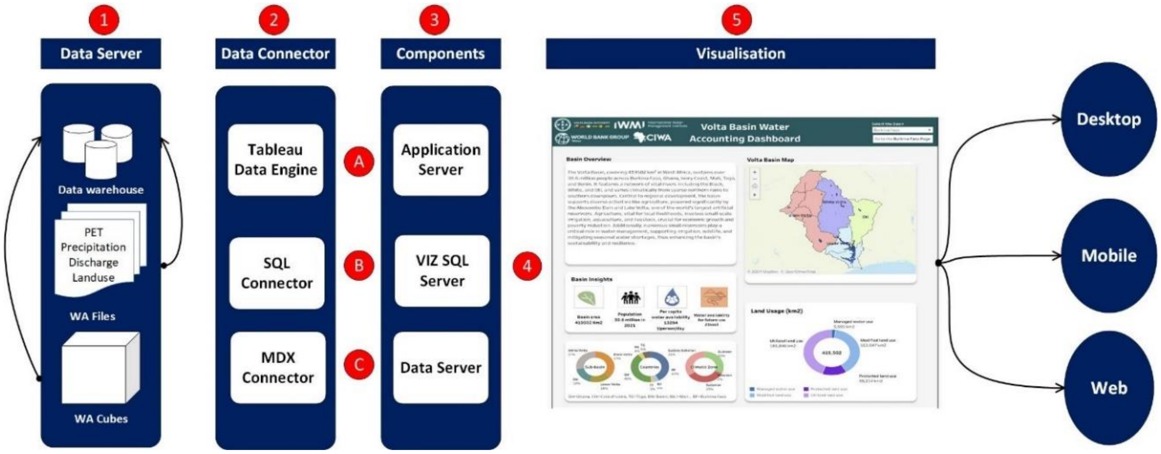
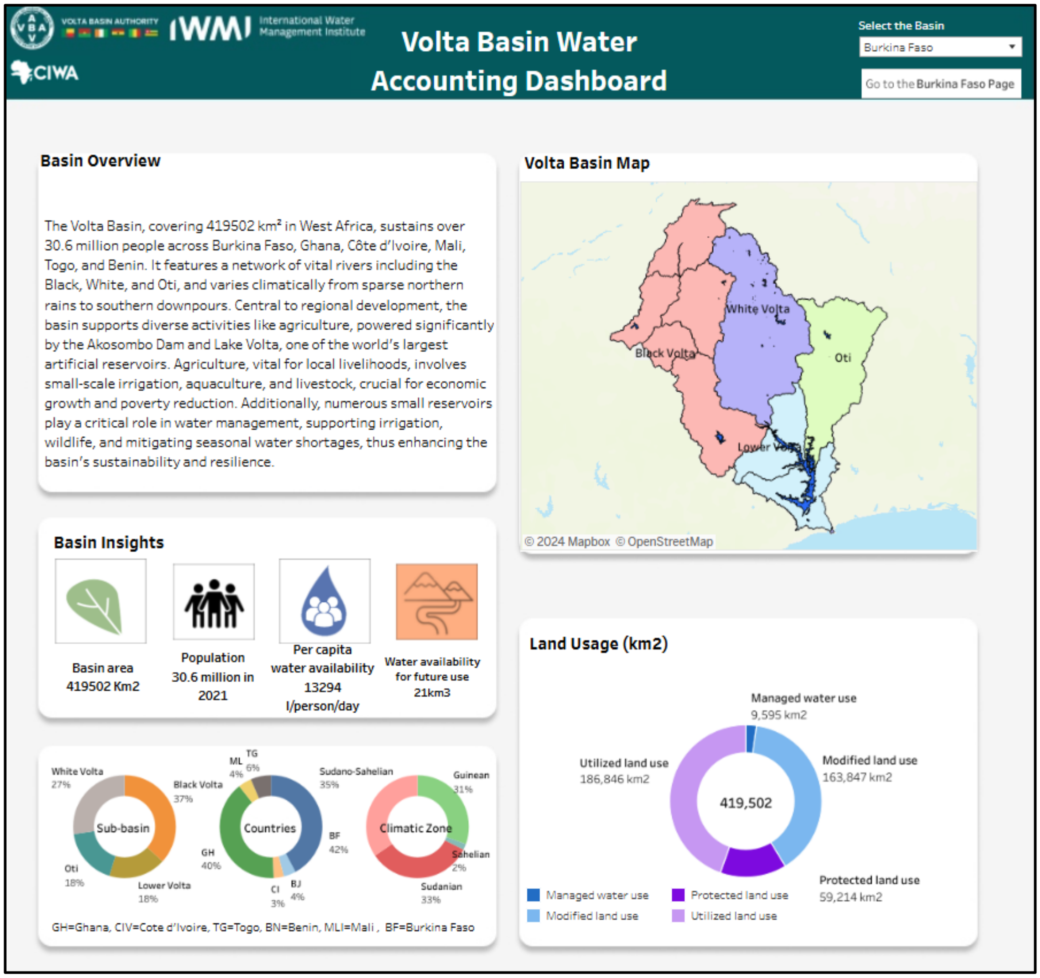


Figure 8: Tableau architecture of the WA Dashboard

Basin Overview Tab: The Basin Overview section of the dashboard provides essential baseline statistics on the river basin, offering a detailed look at the basin's hydrology and key challenges (Figure 9). It includes a brief description of the basin, along with insights like area, population, per-capita water availability, environmental stress, and future water availability. An interactive map allows users to explore the basin's geography, while a double pie chart visualizes land use distribution across categories such as utilized land, managed water, modified land, and protected land. Users can also toggle between years to compare changes in water balance and yield over time.



Volta Basin Water Accounting Dashboard

Select the Basin: Burkina Faso

Basin Overview

The Volta Basin, covering 419502 km² in West Africa, sustains over 30.6 million people across Burkina Faso, Ghana, Côte d'Ivoire, Mali, Togo, and Benin. It features a network of vital rivers including the Black, White, and Oti, and varies climatically from sparse northern rains to southern downpours. Central to regional development, the basin supports diverse activities like agriculture, powered significantly by the Akosombo Dam and Lake Volta, one of the world's largest artificial reservoirs. Agriculture, vital for local livelihoods, involves small-scale irrigation, aquaculture, and livestock, crucial for economic growth and poverty reduction. Additionally, numerous small reservoirs play a critical role in water management, supporting irrigation, wildlife, and mitigating seasonal water shortages, thus enhancing the basin's sustainability and resilience.

Basin Insights

Basin area 419502 Km2

Population 30.6 million in 2021

Per capita water availability 13294 l/person/day

Water availability for future use 21km3

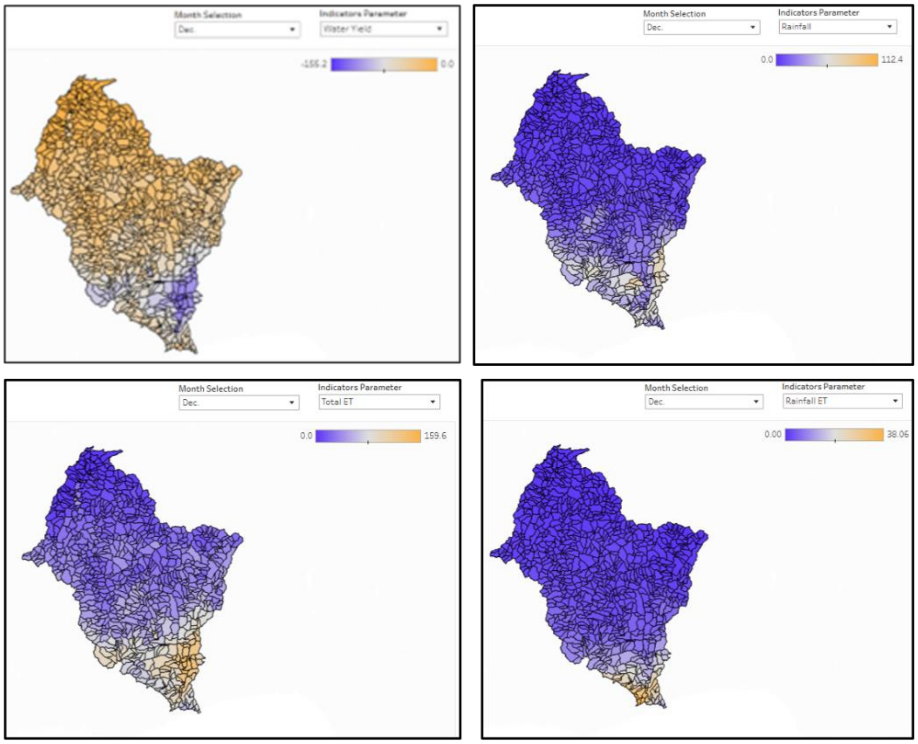
GH=Ghana, CIV=Cote d'Ivoire, TG=Togo, BN=Benin, MLI=Mali , BF=Burkina Faso

Figure 9 Basin overview Tab

Water Availability Tab: The Water Availability section of the dashboard highlights key indicators for assessing water resources in a river basin. It includes metrics such as water availability per capita (m^3), water available for future use (MCM), fractions of evapotranspiration (ET) from agriculture, irrigation, and land management, and the basing closure indicator (Figure 10). These indicators help evaluate the basin's ability to meet demands and how much of the available water is being used. Further technical details can be found in Annex 3.

Figure 10 Water Availability tab

WA Indicators Tab: The spatial variation of WA indicator tab on the dashboard presents the key indicators and variables. Visualization is offered in two data types: spatial and linear. Spatial visualization (Figure 11) is provided disaggregated at the sub-catchment level and at a monthly time scale for the following data: Rainfall, Rainfall ET, Blue ET, Total ET and water yield. In the linear visualization (Figure 12) are provided the following parameters/indicators: Rainfall, total ET, Basin Outflow, Utilized Outflow, and Utilizable Outflow (i.e. the water that can be reallocated for further uses after accounting for reserved flows and utilized flows). Moreover, a standardized anomaly analysis for these indicators is provided. Further details on the indicators and technical aspects can be found in Annex 3.



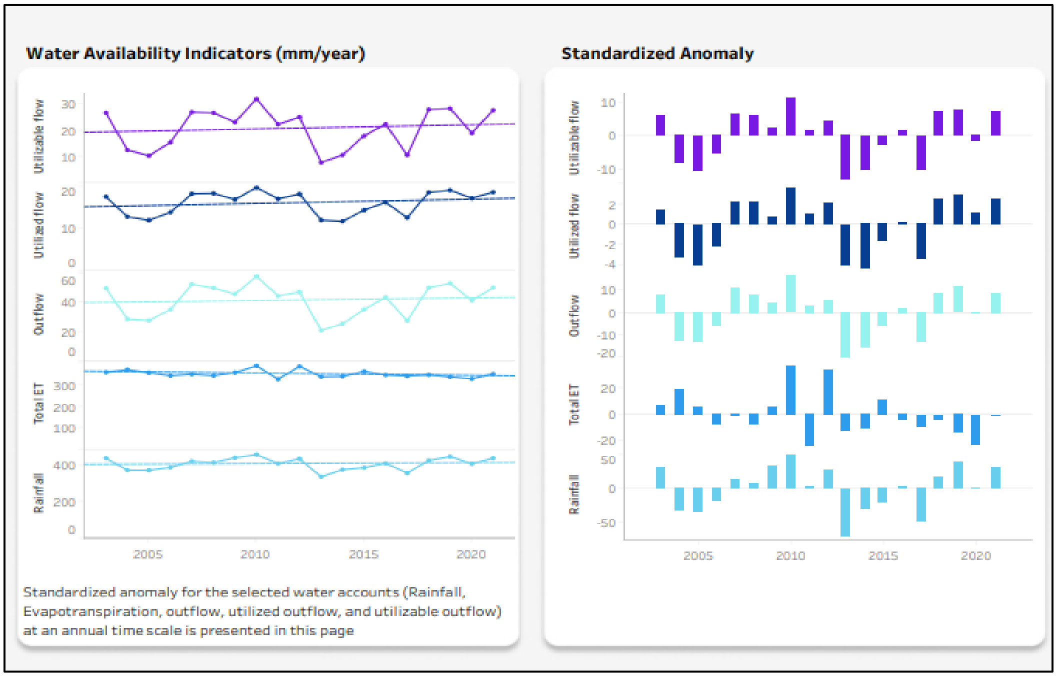
Month Selection: Dec.
Indicators Parameter: Water Yield

Month Selection: Dec.
Indicators Parameter: Rainfall

Month Selection: Dec.
Indicators Parameter: Total ET

Month Selection: Dec.
Indicators Parameter: Rainfall ET

Figure 11. *Spatial visualization of indicators*



Standardized anomaly for the selected water accounts (Rainfall, Evapotranspiration, outflow, utilized outflow, and utilizable outflow) at an annual time scale is presented in this page

Figure 12: Linear visualization of indicators

Water Balance Tab: The water balance figure shows modeled estimates of key water balance terms. Each figure is specific to the year selected on the year selection tab. It includes annual precipitation received by the basin, total evapotranspiration (ET), and its two sources: Blue ET from blue water sources (e.g., surface water bodies and groundwater) and Rainfall ET (or Green ET) from soil moisture replenished by rainfall. The figure also provides information on basin outflow and changes in basin storage due to groundwater abstraction or recharge. Moreover, the different water uses are considering, including for environmental purposes.

Figure 13 presents the water balance diagrams for the Volta and Incomati river basins. The thickness of each component represents the volume of water flow, with thicker sections corresponding to greater quantities. Notable differences between the two basins include the proportion of water used for natural pastures (represented under the "utilized land" component in the diagram). The Incomati basin shows a higher share of water allocated for this purpose compared to the Volta Basin, which aligns with the fact that the Incomati basin is characterized by extensive savannahs and natural reserves.

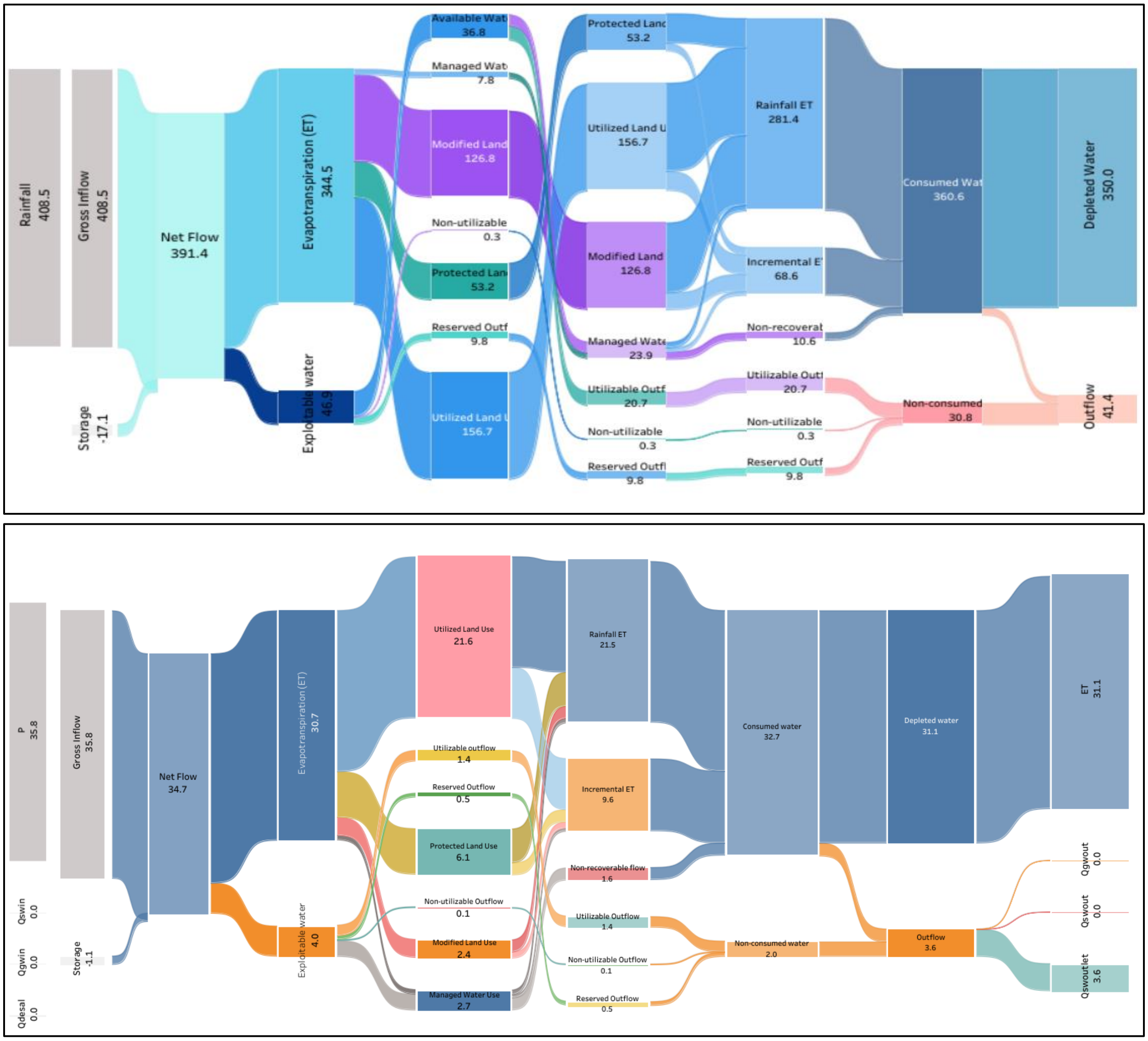


Figure 13 *Water Balance diagram for the Volta Basin (top) and Incomati Basin (bottom). A water balance Sankey diagram illustrates the inflows and outflows of water from the Volta Basin. Typically read from left to right, the thickness of each component is proportional to the quantity of water flow.*

Climate change Tab: The "Climate Change" tab offers an overview of projected future trends and potential impacts of climate change on key indicators of water availability (Figure 14).

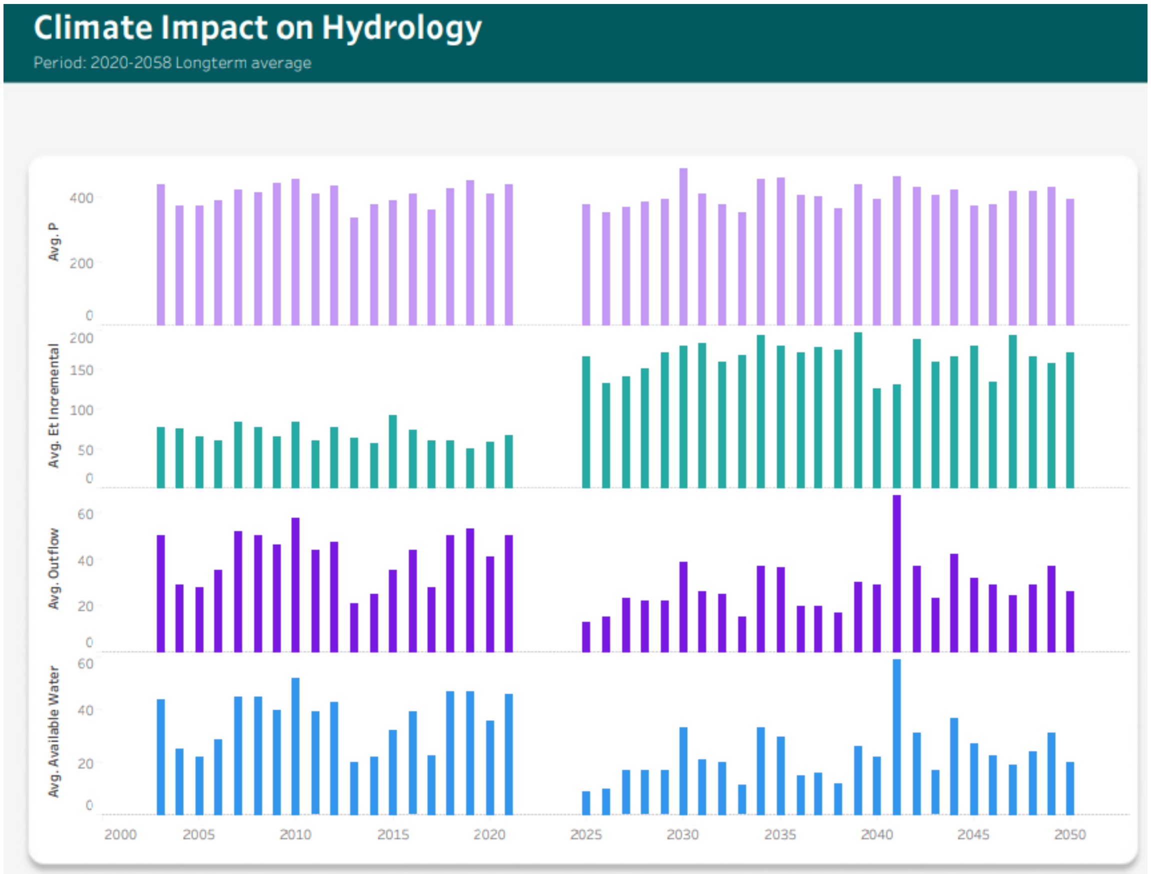


Figure 14 Climate Impact tab

All information generated by the WA Dashboards is publicly available and can be accessed through the following links. Making these outcomes accessible to the public ensures transparency and promotes informed decision-making by providing equal access to critical data. By offering input data, outputs, and final analytical products openly, this approach encourages collaboration, facilitates accountability, and empowers a wide range of stakeholders—from policymakers to researchers and community groups—to leverage the information for sustainable and equitable water management.

Volta Basin:
https://public.tableau.com/app/profile/iwmi.wa/viz/Voltabasinvertical/Merged

Incomati Basin:
https://public.tableau.com/app/profile/iwmi.wa/viz/IWMIIncomatiRiver/Landing

Maputo Basin:
https://public.tableau.com/app/profile/iwmi.wa/viz/IWMIMaputo/Landing

Zambezi Basin:
https://public.tableau.com/app/profile/resmun/viz/IWMIZambeziBasinWaterAccountingDashboard2025/Overview

6. Insights and Strategic Pathways from the Water Data Revolution Project

The WDR project has made substantial strides in addressing critical gaps in transboundary water data management. Through targeted capacity-building initiatives, specialized training programs, and development and adoption of advanced technologies such as WA dashboard, the project has established a robust foundation for the sustainable management of shared water resources. The following consolidated insights and recommendations provide a technical overview of the key achievements and findings under Pillars A, B, and C, highlighting the progress made in enhancing data accessibility, analytical capabilities, and regional cooperation.

1. Leveraging public domain data for enhancing regional collaboration and cooperation for improved decision-making

The use of public domain data offers substantial advantages, particularly for resource-limited RBOs. Public domain data is typically free to access, eliminating the financial barriers that often restrict organizations with limited resources from acquiring necessary information. This opens opportunities for RBOs to access critical data on water resources, climate patterns, land use, and other critical data without the high costs typically associated with proprietary data sources. For RBOs, this brings on the opportunity to carry out critical analytics (i.e. water accounting, flood forecasting, drought management, etc.) vital for sustainable water resource management.

However, a caveat to consider is that RBOs may still face challenges in terms of data quality due to the inherent limitations of open-data sources. This makes it essential for RBOs to implement robust validation processes to ensure the accuracy and reliability of the data.

Recent advances of cloud-based analytical tools and services enables RBOs to proceed with real-time storage, processing, and analysis of data on a global scale. These services, often available at little or no cost, allow RBOs to monitor key parameters more effectively and scale their operations to meet growing data demands. By leveraging cloud-based tools, RBOs can improve data-sharing transparency, streamline workflows, and enhance operational efficiency. This, in turn, strengthens their overall capacity to manage transboundary water resources more sustainably, fostering better decision-making and collaboration across borders.

The public domain model allows RBOs to make uniform decisions and can foster more consistent and transparent collaboration. Providing open access to data enables River Basin Organizations (RBOs) to establish a shared platform that uses a common data source and standardized format, facilitating seamless data access for all stakeholders. This ensures consistency in the information being utilized, eliminating discrepancies and enhancing decision-making. Furthermore, this approach fosters transparency by allowing any user to track, verify, and validate information; building trust among member countries. By ensuring that all parties work from a common data set, this process strengthens the collective capacity of RBOs to address transboundary water management challenges in a coordinated and informed manner.

2. Empowering RBOs through capacity building and data accessibility

RBOs are typically established by member states or countries to coordinate the management of shared water resources across borders, with the goal of promoting sustainable and equitable water use. These organizations are expected to have a comprehensive overview of the entire basin, considering both the water resources and the environmental, economic, and social factors that affect the basin. However, RBOs often face challenges in fulfilling this mandate due to limited resources, insufficient data, and limited technical capacity. In many cases, data gaps, such as the lack of consistent monitoring or limited access to reliable water quality and quantity data, hinder their ability to make fully informed, data-driven decisions. This often results in constraints on the RBOs' capacity to effectively coordinate management efforts and address the complex, multi-dimensional challenges of managing shared water resources across countries.

To overcome these limitations and support them in accomplishing their mandate, a key first step is providing RBOs with access to relevant data, starting with public domain data, which is cost-effective and can serve as a foundational resource for understanding the dynamics of shared water systems. In this context, the provision of WA systems becomes highly relevant as it provides a framework for assessing water availability, usage, and efficiency, helping RBOs plan for future demands, identify potential risks, and prioritize investments.

In the RBO's empowering process, capacity building is essential. Workshops and training sessions expose participants to accessible data products and analytical tools, equipping technical staff with the skills to conduct cost-effective water resource analysis. Particularly, hands-on sessions show effective results on build confidence, foster data ownership, and ensure that the knowledge gained is practical and applicable to real-world scenarios.

To ensure the long-term sustainability of capacity-building efforts, it is essential to adopt financially viable training models that are both cost-effective and scalable. A key strategy for this is the "train-the-trainer" approach, which empowers selected staff to train others, creating an internal, self-sustaining system of ongoing education that reduces reliance on external providers. Additionally, sharing training materials ensures that knowledge is retained within the organization, even amid staff turnover, allowing new staff to quickly acquire the necessary skills. These strategies help maintain and strengthen technical capacity over time. Moreover, this initiative underscored the importance of Tailoring training to meet specific organizational needs maximizes limited resources, while continuous engagement with RBO staff ensures training evolves with organizational demands. Accessible formats, like online sessions, further broaden access, particularly for underrepresented groups and those facing logistical barriers.

3. Leveraging basin-wide analytical tools for practical and integrated applications of data in decision-making

While data access is a critical aspect for supporting RBOs in accomplishing their mandates, data alone is not useful until it is analyzed and transformed into actionable insights. Analytical tools help convert data into meaningful information that ultimately supports decision-making on transboundary water resource management (Figure 2). In this context, the selection of analytical tools is crucial, as these tools must be tailored to the specific context of each RBO, considering factors such as data availability, the technical capacity of staff, and information needs. A poorly chosen tool can actually contribute to create significant gaps in information or even worse, misleading information. The right analytical tool is one that aligns with the RBO's capacity, the data it has access to, and the specific management objectives it seeks to achieve, ensuring that the data can be harnessed to drive informed, effective decisions.

Water accounting tools, or similar frameworks, serve as powerful instruments for connecting data to real-world applications, offering an integrated approach to managing water resources. These tools aggregate and analyze data from multiple sources, such as satellite imagery, climate models, and in-situ measurements, to provide a comprehensive overview of water availability and usage at the basin level. By stepping beyond sub-national level analysis, water accounting tools offer a broader perspective that allows decision-makers to assess the balance between water resources and demand across the entire basin, rather than isolated regions, which makes them ideal for a transboundary context. This holistic view enables users to track trends, identify potential water stress points, and assess the long-term sustainability of water use. By linking data directly to actionable insights, water accounting tools help stakeholders make informed decisions regarding resource allocation, conservation strategies, and investment planning, ensuring that water resources are managed effectively and equitably at the basin scale.

The work developed under this initiative establishes a foundation for the future implementation of basin-wide analytical tools, enabling the practical and integrated use of data in decision-making. Moving forward, a more focused approach will be required to address the specific and unique needs of each RBO, necessitating detailed assessments of their requirements. Additionally, future efforts must consider the significant variations in existing capacities among RBOs, ensuring that tools are developed with these differences in mind. This approach will facilitate the design of capacity-building programs that align with the tools' requirements, promoting effective implementation and use.

4. Promoting Cooperation and Collaboration Through Shared Data Practices and Joint Training

One of the most valuable lessons of this initiative is that by aligning data sharing, joint decision-making, and collaborative training efforts, RBOs can foster mutual understanding and strengthen regional partnerships and cooperation. Joint training sessions help bring together technical staff from different member states, enabling the exchange of expertise, building trust, and enhancing technical capacity within country members of RBOs and beyond across the African region. Additionally, unifying data sources and embracing open-access platforms, as highlighted in Pillar C, enhance transparency, facilitate evidence-based decision-making, and break down political and technical barriers. The shared use of open-access data further fosters cross-border collaboration by providing reliable insights that reduce the need for formalized agreements and build trust[19].

One key challenge identified through the initiative, however, is the frequent mismatch between the individual needs of RBO member countries and the services provided by the RBOs. This gap often stems from a lack of understanding of these disparities. It is recommended that future work involve selecting a few national governments as case studies to better understand this gap and develop targeted solutions.

Together, these initiatives lay the groundwork for sustained cooperation, ensuring equitable and effective management of transboundary water resources.

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[19] Christina Leb, "Data Innovations for Transboundary Freshwater Resources Management: Are Obligations Related to Information Exchange Still Needed?" in Data Innovations for Transboundary Freshwater Resources Management (2020): 3–78, https://doi.org/10.1163/9789004429000_002.

Annex 1

Assessment on the Current Status and Needs of Remote Sensing Data for Transboundary Water Management in Africa

Water Data Revolution: Closing the Data Gap for
Transboundary Water in Africa (P176348)

Africa (AFRICA)

June 2022

WORLD BANK GROUP

Contents

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1 Summary

Adequate management and allocation of water resources play a critical role in addressing major development challenges throughout Africa, including supporting agricultural production, addressing issues of food security, and reducing conflict and displacements. Collaborative management of transboundary water resources is essential in order to address cross-cutting issues influencing water decisions, such as climate change, fragility, violence, gender equality, social inclusion, human capital, and economic development. As a result, improved management of water resources and increased resilience to hydrological extremes across Africa requires understanding water resource dynamics at the basin level to ensure equitable and efficient use of the transboundary resource. To understand this problem, data and observations are a prerequisite for gaining better insight into the complex dynamics. However, hydrometeorological monitoring networks in Africa are often sparse, have large latency and encounter challenges with reliability, making them impractical and unreliable for real-time decision making. Moreover, the use of ground data for management of transboundary resources in Africa is complicated by insufficient quality control standards for data collection and management which is further compounded by a lack of data sharing practices as they pertain to shared resources among riparian countries. The use of remotely sensed (RS) data[1] acquired from satellites can help to address many of these concerns by collecting high-resolution data at regular intervals which can be used to inform policy-making in real time, while ensuring the data are made available in an open-source manner to all participating countries.

RS data is a continuous, reliable data source which can be used to cover vast amounts of land otherwise challenging to assess, which can then be used as an input into analytical tools[2] for cross-border water applications, such as flood forecasting, monitoring of surface water quality, tracking of water diversions and allocations, and quantification of water storage in reservoirs. Satellite-derived data is also advantageous technically because instrumentation does not vary across border, often requires less frequent maintenance practices and less likely to be disrupted by on-ground events. This data collection approach is also politically advantageous due to enhanced data transparency which facilitates cross-boundary discussion. There are many free or low-cost data products[3] which facilitate the collection, storage, and analysis of RS data. River and basin organizations across Africa can use these data products to translate RS data to enhance decision-making and to strengthen data exchange among riparian countries. However, many decision-makers lack the tools with which to access and adapt these products to provide solutions at the scale they need.

Therefore, the Cooperation in International Waters in Africa (CIWA) and World Bank supported *Water Data Revolution (WDR): Closing the Data Gap for Transboundary Water in Africa* project

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[1] RS data refers to space-based, remotely-sensed data (also known as earth observation data).

[2] Analytical tools refers to tools designed to analyze data to achieve specific objectives relevant for WRM (for example, flood forecasting).

[3] Data products refers to platforms, tools, or programs designed to collect, store, manage, and/or analyze data (for example, Google Earth Engine). Data products often transform raw RS data into an analysis-ready format. Data used in data products may be from remote sensing or other data sources (such as gauges or ground-based observations).

aims to build a platform which connects existing water demand-driven products and tools, which incorporate RS data, with water resource decision makers, while improving the capacity of water organizations to collect, store, and analyze their own RS data and information. The WDR project is combining a bottom-up approach with a more wholistic view to data management in order to address this challenge. The approach begins by considering user insight for data needs to identify shared preferences among all end-users. This is then combined with a wholistic view of the types of data which are available and an understanding of how innovative technologies such as RS tools, satellite imagery, and data products can be used to meet the needs of the users. In order to reach this end, interviews were conducted with African river basin organizations[4] (RBOs) and regional organizations[5] (ROs) to understand their needs and assess their capacity by evaluating the status, availability, and use of data, data products, and analytical tools.

Results from these assessments are described and synthesized in this report. This assessment allowed for the identification of data gaps for RBOs and Ros, and in response created a strategic plan for addressing these data needs through adoption of RS data, data products, and WRM analytical tools utilizing RS data. Moreover, the feedback from this assessment provided valuable insight on challenges associated with adopting RS technologies, such as financial constraints, technical capacity, and staffing shortages. Based on the assessment findings, recommendations are provided to ensure the WDR program provides training and capacity building opportunities which align with the needs and goals of the organizations.

2 Introduction

Africa's rapidly growing population, strengthening economy, and changing climate are increasing water demand across the continent, while a lack of data hinders the efficient management of this valuable resource. This complicates the political, institutional, economic, and financial challenges countries face as they manage and develop their transboundary rivers, lakes, and aquifers. These impediments affecting the water sector create a bottleneck to growth and prosperity in Africa. Climate variability and uncertainty resulting in damaging floods and droughts exacerbates vulnerability and makes sustainable water resource development a dynamic challenge. Extreme hydro-climatological events are of increasing concern across Africa. For example, in East Africa (Rwanda, Kenya, Somalia, Burundi, Ethiopia, Sudan, South Sudan, Uganda, Djibouti and Tanzania), the number of people affected by flooding increased from 1.1 million in 2016 to 4 million in 2019, and to close to 6 million in 2020[6]. Managing water-related hazards and risks (e.g., flood and drought) is a central obstacle to strengthening African resilience to climate change.

Many of the most water vulnerable places are also the most hydrologically data poor. Hydrometeorological and agricultural monitoring networks across Africa are often limited in

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[4] River basin organizations oversee activities that have basin-wide impacts, including at the transnational, national, or local scales.

[5] Regional organizations refers to organizations that service multiple rivers and basins, such a multi-governmental organizations focused on regional or continental operations.

[6] BBC. (2020, October 6). Flooding hits six million people in East Africa. BBC News. Retrieved April 26, 2022, from https://www.bbc.com/news/world-africa-54433904

scope, experience large latency in data reporting and require extensive maintenance attention in order to remain reliably in operation, reducing their practicality for real-time decision making. Where the need for information is arguably greatest, the data collection infrastructure and human capacity to monitor and forecast hazards is generally low because of a decline in hydro-meteorological monitoring networks over the past 30 years[7] and an ongoing lack of investment in infrastructure and training. A key limitation at the national, sub-regional, and continental levels is the paucity of data on water resources. This limitation is linked to inadequate human skills for the collection, assessment, and dissemination of data on water resources.

Information on quantity and quality of water resources is essential for equitable, efficient usage of transboundary water. This in turn is imperative for addressing other major development challenges in the region including agricultural production, enhancing food security and reducing conflict and displacements**.** 90 percent of water in Africa falls within 63 international river basin catchments crossed by multiple borders. As a result of this, water management in the region is inherently an international and cooperative endeavor. Management of water resources directly impacts various sectors, such as agriculture, energy, environment, and urban planning, all of which require sustainable and efficient transboundary water usage, practices, and policies to function optimally. However, data and observations on water resource dynamics are imperative for improving transboundary water resource management (WRM) and resiliency to hydrological extremes. Data provides a foundation for efficient and environmentally sound management of water with proper consideration for upstream and downstream users[8]. RBOs and water institutors are formed to collaborate on addressing these shared issues but often lack the tools with which to understand the complete situation. To face these challenges adequately, governments and regional organizations need data-driven decisions to inform cooperative transboundary water management**.** That is, sustainable transboundary water management requires timely, pragmatic decisions based on adequate information on the current status of resources, historical trends in their use, and future availability of the resource. This information includes measurements on rainfall and stocks and flows of surface and groundwater which are key to making decisions to improve water quality and water use, to ensure long-term environmental protection of these resources and to ensure local and regional economies are protected and their use of the resource.

Recent innovations in data collection and management create an opportunity for improved cross-border data and information sharing, enabling a near future where cooperative data-driven decision making can become standard practice in trans-boundary WRM. Most countries in Africa currently use data systems based in older technology and are therefore somewhat ‘locked-in’ to such outdated approaches. Data collection was historically, primarily, a physical activity which took place locally, installing hydro-meteorological meters, rain gauges and the like. However, there are challenges in the use of in-situ data, namely that it can be sparse due to inadequate

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[7] Lorenz, C., & Kunstmann, H. (2012). The hydrological cycle in three state-of-the-art reanalyses: Intercomparison and performance analysis. *Journal of Hydrometeorology*, *13* (5), 1397-1420.

[8] García, L.E, Rodríguez, D. J. , Wijnen, M., & Pakulski, I. (Eds.). (2016). *Earth observation for water resources management: Current use and future opportunities for the water sector*. Washington, DC: World Bank Group.

land-coverage of monitoring systems and it can be unreliable if not maintained properly, rendering it inadequate for informing decision-making processes. RS and other tools can provide more frequent data over larger areas to complement observations collected in-situ and from ground-based sensors. It is important to note that RS should not replace ground measurements because they are more effective combined, but it strengthens the manner through which water data collection can occur and expands the ability of countries to collect data on basins that extend past country borders. This combined data approach can provide continuous and reliable coverage to be used for water management and cross-border applications, such as flood forecasting, monitoring of surface water quality, tracking of water diversions and allocations, and quantification of water storage in reservoirs. Satellite-derived data is advantageous from a technical because instrumentation does not vary across borders. Furthermore, it also has political advantages because it allows for enhanced data transparency between all partners using the data. In the past, the best way to manage and combine data was to physically store it in a database. However, data can now be combined through living layers, potentially sourced from all over the world, and does not necessarily need to be 'owned' to be used by a single user. Cloud storage and expanding computing power have enabled a wide range of users to access, analyze, and restore many data, including public domain data, at a low cost.

These recent advances in the availability and storage of large-scale data, in addition to the subsequent interpretation of the data for decision-making, have not been realized by many governments and organizations across Africa. The continent has the opportunity to leapfrog over decades of incremental advances in the capacity to make data-driven decisions by proactively incorporating RS tools with existing ground-based observation, data storage from physical to virtual products, and data analysis to fit-for-purpose analytical tools. In order for this to occur however, there needs to be a pragmatic, easy-to-use interface which facilitates and enables this process.

3 Objectives of the Water Data Revolution (WDR)

CIWA aims to assist riparian governments in Africa in unlocking potential for sustainable, climate-resilient growth by addressing constraints to cooperative water resource management and development. Transboundary cooperation is strengthened by improving access to information and through identifying, preparing, or mobilizing sustainable investments. In alignment with this, CIWA is building the capacity of its partners to make evidence-based decisions regarding water resources by utilizing cutting-edge technologies through the *Water Data Revolution (WDR): Closing the Data Gap for Transboundary Water in Africa.*

The objective of the WDR is to build regional institutional capacity and demonstrate applications of RS data platforms to improve management of transboundary water in Africa. Accordingly, the WDR is connecting demand-driven analytical tools and products using RS data to decision-makers of water resources that will strengthen the cooperative management of transboundary waters in Africa, while additionally improving the capacity of water organizations to collect, store, and analyse RS data and information. The WDR is applying a user-driven approach to identify and support common needs among African RBOs and ROs, while connecting them with innovative technologies such as RS data. This data includes products for the collection, management, and analysis of RS data and fit-for-purpose water management analytical tools. This initiative will help countries across Africa to improve their capacity to collect, store, and analyse information and to make evidence-based decisions regarding water by reducing the cost and complexity of using water data and by establishing connections with data products and tools that facilitate the translation of information to improved decisions. A schematic demonstrating linkages from RS data to data platforms, analytical tools, and end users is provided in Figure 1.

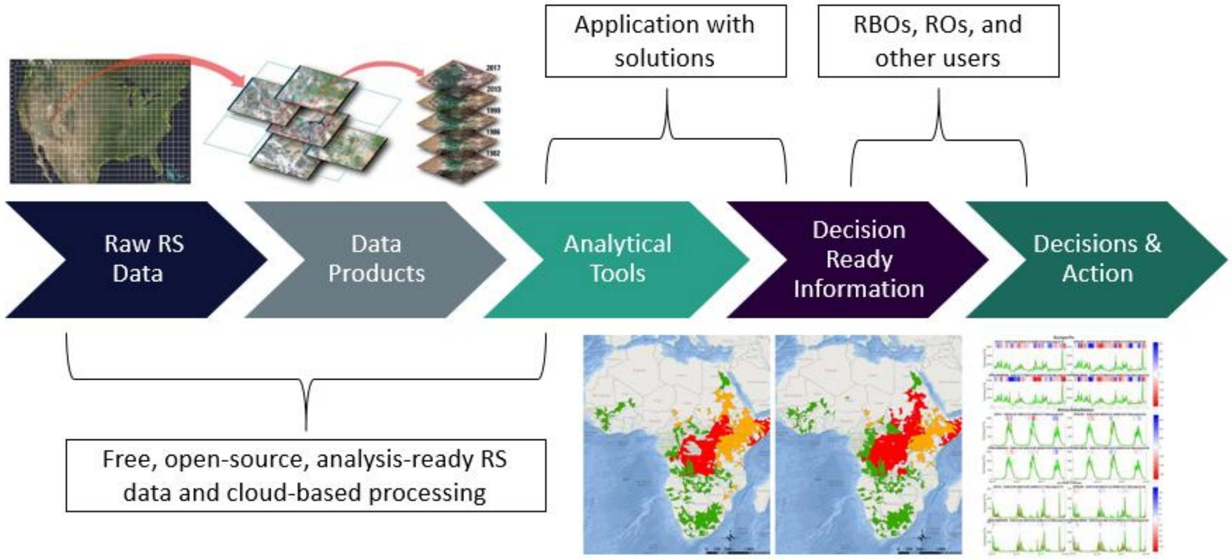

Figure 1: Data products and analytical tools assist in the translation of raw RS data into decisions and actions as depicted in this step-by-step sequence. Data products facilitate the collect of RS data and transform raw RS data into analysis-ready formats, which is then used as an input into fit-for-purpose analytical tools, such as for flood forecasting and drought monitoring. Decision makers use the output information from the analytical tools to formulate decisions and strategize action plans.

The WDR is organized into three strategic pillars to accomplish its objective. Pillar A is an assessment on the status, availability, and use of data among African RBOs and ROs. This assessment is designed to elucidate current data uses and needs for effective transboundary water management as identified by organizations. Pillar B is focused on improving the use of RS data and to build more user-friendly data products and analytical tools. Trainings and workshops, developed based on the needs of organizations, will build capacity of organizations to use existing and developed technologies and platforms for data collection, management, and analysis. Lastly, Pillar C involves assisting specific organizations with applying data products or analytical tools using RS data. This component will facilitate the adoption of low-cost technologies for data collection, storage, and analysis based on prior findings of organizations' priorities and needs for data-driven decision-making for transboundary WRM (Pillar A), while promoting the sustainable use of data products and analytical tools presented in the workshops and capacity building sessions (Pillar B).

4 Assessment Overview

Many water institutions in Africa are underutilizing products and tools designed to collect, store, and analyse RS data. Data science experts with extensive knowledge on using RS technologies develop data products and analytical tools for users such as RBOs and ROs. However, the users of these emerging platforms may face challenges with applying them proficiently. Technologies using RS data are often developed with insufficient consultation of organizations like RBOs and ROs to ensure they are designed according to user needs and context. Consequentially, decision-makers may lack the resources to access and adapt the new platforms to provide solutions at the scale they require. Constraints related to financial resources, staffing, reliable internet connection, computational hardware, supplemental ground data requirements, technical knowledge, and capacity may affect the ability of institutions to use new products or tools. To improve the usage of innovative platforms for transboundary WRM, these constraints must be better understood, conveyed to technology developers, and accounted for in trainings and capacity building around using data products and tools. Therefore, to reduce the current divide that exists between developers of RS tools and user groups, the WDR applied a user-centred approach to determine the leading issues inhibiting the use of RS data, data products, and analytical tools for WRM by African RBOs and ROs. This approach was used to connect organizations with innovative products and tools according to user-identified data needs, water management goals, and constraints.

Specifically, an assessment was conducted to evaluate the status, availability, and use of data, data products, and analytical tools among transboundary African RBOs and ROs. This assessment is in line with Pillar A of the WDR, as described in Section 3. Assessing data practices and needs is crucial for ensuring that the WDR applies a user-driven approach to support commonalities among African water organizations. Data needs as identified by the organizations will facilitate determining impactful capacity building trainings under Pillar B and fit-for-purpose technical assistance at scale in Pillar C.

Surveys were administered to 15 RBOs and 3 ROs, followed by interviews with select organizations, to determine their priority data needs that may be mitigated through adoption of RS data, data products, and analytical tools for WRM. This assessment provided key insight into challenges with adopting platforms using RS data, capacity building needs to strengthen the use of data products, and an overview on the types of analytical tools that would be most useful according to the organizations. Results from this assessment are informing the design of capacity building workshops and information sessions to facilitate transboundary and regional organizations with using RS data and applying tools for WRM that align with their goals and objectives.

5 Background

The following subsections provide an overview of RS data, data products, and analytical tools in the context of water resource management in Africa.

5.1 RS data for Water Management

Data obtained from RS can be used to address issues in transboundary WRM that are difficult to address using other methods given the necessity for a broad array of sensors which are well-maintained in order to collect such data. As depicted in Figure 2, RS data can be used to characterize or collect information on the following water cycle attributes for water management applications: precipitation; evaporation and evapotranspiration (ET); soil moisture; vegetation and land cover; groundwater; surface water; snow and ice; and water quality.

Figure 2: Data and information on water cycle attributes obtained from remote sensing.

In the context of Africa, data on all these attributes, except for snow and ice in rare cases, are crucial for managing water issues. Several key data analytics of interest for transboundary water management can be conducted using exclusively RS data, thus making these types of analyses possible across regions lacking ground-based observation. For example, the extent which is impacted by a flood can be predicted using data collected on the following attributes obtained using only RS: precipitation, soil moisture, surface water, and elevation. Table 1 describes the RS data types relevant for various water resource management analytics. Moreover, several sources of RS data are available at free or low cost with large spatial coverage, making RS an attractive data source for resource-constrained areas. For information on available RS data, please refer to *Earth Observation for Water Resources Management*[8] and *Disrupting Hydroinformatics*[9]. To browse additional RS datasets, please view the Land Processes Distributed Active Archive Center (LP DAAC) data catalog[10] and Earth Engine data catalog[11].

Table 1: RS data collected on water cycle attributes relevant for various water management applications. This table describes the link between the data collected from RS and the analytical application for which it can be used. For example, in order to map the extent of a flooded area, an understanding of the rate of precipitation in the area must

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[9] World Bank Group. (n.d.). *"Disrupting" HydroInformatics: An Interactive E-book.* Hydroinformatics eBook. Retrieved April 15, 2022, from https://spatialagent.org/HydroInformaticsEbook/index.html.

[10] "Data." *LP DAAC - Data*, https://lpdaac.usgs.gov/data/.

[11] "Earth Engine Data Catalog | Google Developers." *Earth Engine Data Catalog*, Google, https://developers.google.com/earth-engine/datasets.

be combined with the existing soil moisture and surface water in the area in order to understand what the resulting flood rates are.

Adapted from Table 5.2 of García et al. (2016)[8].

Analytical Application	**Precip-itation**	**ET**	**Soil Moisture**	**Vegetation and Land Cover**	**Ground-water**	**Surface Water**	**Snow and Ice**	**Water Quality**
Identifying and monitoring water reservoirs						■		
Monitoring and prediction of water quality in basins						■		■
Mapping and predicting flood extent	■		■			■		
Assessing water use efficiency	■	■	■	■	■			
Monitoring and mapping water use for irrigation	■	■	■	■		■		
Monitoring rates of groundwater extraction		■			■			
Monitoring crop production	■	■		■				
Monitoring and forecasting drought	■	■	■	■	■	■	■	
Identifying and monitoring groundwater-dependent ecosystems	■	■		■		■		
Monitoring river flow	■	■	■		■		■	
Conducting integrated assessment of water availability under climate change scenarios	■	■	■	■	■	■	■	

RS data allows riparian countries to address transboundary water problems, such as drought and flood forecasting on transnational rivers, and facilitates broader discussion on sharing of water resources. Several activities funded by CIWA have explored and demonstrated these advantages of using RS to address critical issues in transboundary water management. For example, the Lake Chad Basin Commission (LCBC) monitors surface water using RS, the Great Lakes Water Quality project uses RS to analyze water pollution drivers in East Africa, and the Nile Basin Initiative (NBI) hosted regional workshops using RS for flood mapping. Additionally, the Nile Cooperation for Climate Resilience project is developing a regional cloud-based platform that will include a toolkit to facilitate the use of RS data across the Nile Basin. These case studies underscore the potential for widespread adoption of RS data and tools to improve water management across Africa.

5.2 Data Platforms and Analytical Tools for Water Management

RS data is available from various sources and space agencies, such as the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA), in a variety of resolutions (both temporal and spatial). However, the data must be downloaded and transformed into an analysis-ready format to be usable in models, tools, or applications for WRM. Users of the raw RS data must be familiar with working with various data formats, which often requires expertise in data analysis. In addition, downloading and processing the large-scale data requires substantial storage and computational capacity. These challenges can inhibit the ability of decision-makers to access and utilize RS data. Moreover, the procedure for collecting and processing the RS data must be done continuously for real-time decision-making to occur using the data. This in-depth process of acquiring the RS data from the source continuously and transforming the RS data into an analysis-ready format is a critical, necessary function of data products that enables decision-makers across Africa to utilize RS data.

New data platforms offer open-source data hosting and analysis opportunities. Google Earth Engine (GEE), for example, is a cloud-based platform providing access to large-scale, geospatial datasets in analysis-ready formats. The Engine provides users with high performance computing power necessary for processing and analysing large-scale datasets. A variety of global issues have been investigated via GEE, such as investigations into the changing rates of deforestation globally and efforts to characterize global surface water resources over time and space. Digital Earth Africa (DEA) is another leading operational data product which aims to assist decision-makers in Africa with accessing current and historical analysis-ready RS data. Similar to GEE, DEA is a cloud-based platform which provides access to analysis-ready RS data, computational power, and analytics. Through the Water Observation from Space (WOfS) service, DEA facilitates decision-makers with mapping the temporal and spatial distribution of water sources across Africa. DEA also provides decision-makers with analysis tools to assist with understanding various environmental scenarios, including changes to water quality due to algal blooms and monitoring of crop health.[12]

In addition to data platforms (such as GEE and DEA) which are providing access to analysis-ready data, many organizations are developing analytical tools to translate RS data into information for decision-making. Table 2 describes differences between data platforms and analytical tools.

Table 2: Comparison of data platforms and analytical tools.

Data Platforms	Analytical Tools
Facilitate the collection, storage, and management of RS data. May also transform RS data into analysis-ready formats. Some also offer analytical capacity for WRM.	Provide analysis of data to achieve specific objectives relevant for WRM.

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[12] https://www.digitalearthafrica.org/platform-resources/analysis-tools

The International Water Management Institute (IWMI), for example, has made available several digital datasets and analytical applications using RS, including mapping of global irrigated areas, drought patterns, and flood risk. IWMI has also developed the Water Accounting (WA+) framework which uses hydrological models and RS data to track the status and trends of water supply, demand, accessibility, and use for a user-specified water source. Enhanced decision-making facilitated by RS data in WRM improves the resiliency, sustainability, and efficiency of sectors linked to water, such as agriculture, energy, environment, and urban development. Examples of water management application tools using RS, as well as their relevance to other sectors, are provided in Table 3. A list of example data platforms and analytical tools for WRM are provided in Appendix 10.1. Additional info on relevant data products and tools can be found at in *Earth Observation for Water Resources Management*[8] and *Disrupting Hydroinformatic*[9].

Table 3: Applications of RS Data for WRM as they are provided through various analytical tools (addressed further in Appendix 10.1).

Focus Area	Analytical Tool	Specific Techniques	Relevance to Other Sectors
Resilience & Climate Change	Drought and flood forecasting	Flood management; Mapping of flood prone areas; Assessment of risk; Early warning systems	Agriculture, Climate Change, Urban & Rural Planning/Development
		Drought management; Mapping of areas prone to drought	
	Climate monitoring	Resilient decision-making under climate change uncertainty	Agriculture, Energy, Environment, Climate Change, Urban & Rural Development
Water Accounting & Storage	Water accounting	Efficiency of water resource use	Agriculture, Energy, Environment, Climate Change, Urban Planning
		Water allocation management	
		Investment planning	
		Sustainability of surface water and groundwater sources through monitoring of use and extraction	
	Water storage monitoring	Mapping and quantification of water storage	
Surface Water Pollution	Surface water quality monitoring	Sustainability of water quality through monitoring of quality degradation	Environment, Urban Planning

6 Assessment Description

6.1 Surveys

Written surveys were distributed to 15 RBOs and 3 ROs to understand their current uses and needs for data, data products, and tools to improve the management of their water resources. Surveys collected information on RBOs and ROs status of data, data product, and analytical tool usage; practices for collecting, storing, managing, and analyzing RS data; and their views on current and future challenges associated with using RS data in products and tools. Surveys were distributed in English and French. An example form is provided in Appendix 10.2.

Surveys were comprised of three sections. Section 1 collected general information on the organization, such as contacts; their organization type (governmental, basin, regional, or research/academic); and a list of countries, river basins, and aquifers the organization works within. Sections 2 and 3 evaluated data practices and needs. Section 2 gauged the familiarity, interest, and capacity of staff at these organizations to work with RS data and data products, while section 3 focused on analytical tools and applications related to water resources management. Questions in section 3 were designed to better understand the types of analytics organizations apply, opportunities to expand their usage of analytical tools requiring only RS data inputs, and constraints limiting their ability to benefit from fit-for-purpose tools. Additionally, section 3 assessed needs and levels of interest for various trainings around applying RS tools.

Section 2 included 14 questions to assess the current and past use of RS data, data products, and familiarity with data platforms. To understand if organizations collect RS data with relevance for WRM, respondents were asked if they use RS to characterize any of the following water cycle attributes: precipitation, evapotranspiration, soil moisture, vegetation and land cover, groundwater, surface water, snow and ice, water quality, and topography. Follow up questions asked for additional details on the types of RS data used, such as the source, resolution, cost, and primary use of the data. This information was collected to provide insight on what types of RS are most commonly used by various institutions across Africa and what types of data are perhaps the easiest to access. Subsequently, respondents were asked if they used, or were familiar with, the following data platforms and tools: GEE, DEA, IWMI data and tools, Dartmouth Flood Observatory Flood Portal, EarthMap.org, Aquastat, Global Flood Monitoring System, Aqueduct Water Risk Atlas, and World Bank Spatial Agent Hydroinformatics. These platforms were included in the survey because they can facilitate the use of RS data and assist with water-related operations, but they have differing utilities for organizations based on their needs. For example, GEE and DEA primarily provide analysis-ready data from RS, where GEE is a commonly used product worldwide and DEA is a far newer product catered to the African context. Earth Map functions as a complimentary tool to GEE by providing access to the GEE data without requiring coding expertise. Aquastat and the Aqueduct Water Risk Atlas also provide water-related data and information, whereas the Global Flood Monitoring System and Dartmouth Flood Observatory enable flood analyses using open-access data. Of the IWMI Digital Data and Tools, the most applicable tool for using RS in Africa is the water accounting tool. Unlike the other platforms in the survey, this tool is not open access. And finally, the Spatial Agent Hydroinformatics platform provides access to information from various providers applicable for harnessing RS data, mainly through the form of visualization. To further determine the status of using data products and platforms, follow up questions were given to understand the types of data products organizations use, as well as the main purpose or application and required input data per product. Lastly, section 2 included questions to measure the capacity and interest of RBOs and ROs to develop the WDR capacity building strategy under Pillar B. Questions assessed inhouse expertise with RS data/data products, areas of interest for potential usage of RS data/data products, and training and institutional development needs around RS data/data products.

Section 3 was comprised of 10 questions on the application of data collected and operational tools for the purpose of water resources management. Four questions were focused on tools performing the following analysis: tracking of status and trends in water supply, demand, accessibility, and use; flood monitoring (including hazard mapping and forecasting); flood early warning systems; drought monitoring (including hazard mapping and forecasting); monitoring of surface water quality (e.g., clarity and chlorophyll-a); and quantification of water storage in reservoirs. These specific applications of the tools were included in this assessment due to their applicability to assist with water management across Africa and the wide availability of open access tools existing with these functionalities, making them ideal candidates for the WDR capacity building workshops. To conclude this third section and the full survey, RBOs and ROs were asked to describe their constraints in working with general analytical tools that primarily utilize RS data. This information will be used throughout the WDR to ensure that organizations can sustainably access and adopt RS data and tools included in the capacity building components of the project. Furthermore, to better understand the types of trainings that would be most beneficial to the users, respondents were asked to indicate their priority areas in receiving various types of trainings or resources ranging from workshops on using RS data and data products to a knowledge hub for African institutions on RS data, data products, and analytical tools using RS for WRM.

6.2 Respondents

Survey results were collected from 15 RBOs and 3 ROs. The RBOs included in this assessment are listed in Table 4. The Nile Basin Initiative (NBI) is comprised of three sub-RBOs working in collaboration: the Nile Bin initiative Secretariate (Nile-SEC), the Nile Equatorial Lakes Subsidiary Action Program (NELSAP), and Eastern Nile Technical Regional Office (ENTRO). Due to the various functions and data needs of the three RBOs housed within NBI, information for Nile-SEC, NELSAP, and ENTRO is represented as three separate organizations. On average, each RBO is comprised of 4 to 5 member states, with a total of 37 countries represented within the RBOs. ROs included in this assessment are described in Table 5. These ROs provided insight from operations spanning the continent. Figure 3 depicts the countries included within the RBOs and ROs in this assessment. Survey responses were consolidated for organizations that submitted more than one response.

Figure 3: RBOs and ROs included in this assessment manage transboundary water resources spanning the countries highlighted above.

Table 4: RBOs included in the assessment.

RBO	Members	Water Resource	Website
Cuvelai Watercourse Commission (CUVECOM)	Angola, Namibia	Cuvelia River Basin	Website
Incomati and Maputo Watercourse Commission (INMACOM)	South Africa, Mozambique, Eswatini	Incomati and Maputo Watercourses	Website
Komati Basin Water Authority (KOBWA)	Eswatini, South Africa	Komati River Basin	Website

Lake Chad Basin Commission (LCBC)	Cameroon, Chad, Niger, Nigeria, Central African Republic, Libya	Lake Chad Basin	Website
Lake Kivu and Ruzizi River Basin Authority (ABAKIR)	Rwanda, Burundi, Democratic Republic of the Congo	Lake Kivu and the Ruzizi River Basin	Website
Lake Victoria Basin Commission (LVBC)	Burundi, Rwanda, Kenya, Tanzania, Uganda	Lake Victoria Basin	Website
Mano River Union (MRU)	Guinea, Liberia, Cote d'Ivoire, Sierra Leone	Mano River Region	Website
Niger Basin Authority (NBA)	Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Guinea, Mali, Niger, Nigeria, Chad	Niger Basin	Website
Nile Basin Initiative (NBI) (Nile-SEC, NELSAP, and ENTRO)	Burundi, Democratic Republic of the Congo, Ethiopia, Egypt, Kenya, Rwanda, South Sudan, Sudan, Tanzania, Uganda	Nile River, Mount Algon Aquifer, Gadaref Adegrad Aquifer, and Kagera Aquifer	Website
Okavango River Basin Water Commission (OKACOM)	Angola, Botswana, Namibia	Cubango-Okavango River Basin	Website
Organization for the Development of the Gambia River (OMVG)	Gambia, Guinea, Guinea-Bissau, Senegal	Gambia Basin, Kayanga-Geba Basin, and Koliba-Corubal Basin	Website
Volta Basin Authority (VBA)	Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Togo	Volta River Basin	Website
Zambezi River Authority (ZRA)	Zambia, Zimbabwe	Zambezi River Basin	Website

Table 5: ROs included in the assessment.

RO	Members
Sahara and Sahel Observatory (OSS)	▪26 African Member States: Algeria, Benin, Burkina Faso, Cameroon, Cape Verde, Central African Republic, Chad, Côte d'Ivoire, Djibouti, Egypt, Eritrea, Ethiopia, Gambia, Guinea-Bissau, Kenya, Libya, Mali, Mauritania, Morocco, Niger, Nigeria, Senegal, Somalia, Sudan, Tunisia, Uganda ▪7 Non-African Member States: Belgium, Canada, France, Germany, Italy, Luxemburg, Switzerland ▪13 organizations (representing West, East, and North Africa, and UN organizations)
Southern African Development Community (SADC)	▪16 Member States: Angola, Botswana, Comoros, Democratic Republic of the Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia, Zimbabwe ▪Includes the RBOs: Zambezi Watercourse Authority (ZAMCOM), CUVECOM, Orange Senqu River Commission (ORASECOM), Limpopo Watercourse Commission (LIMCOM), OKACOM, BUPUSA, INMACOM
Economic Community of West African States (ECOWAS)	▪15 Member States: Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, the Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo ▪Includes the RBOs: Mono Basin Authority (MBA), NBA, VBA, Organization for the Development of the Senegal River (OMVS), OMVG, MRU, LCBC

6.3 Interviews

Interviews were conducted with 10 RBOs and 1 RO, including CUVECOM, ENTRO, INMACOM, LCBC, LVBC, MRU, Nile-SEC, OKACOM, SADC, VBA, and ZRA, to supplement survey findings and elucidate critical data and service gaps. Interview questions were designed using the survey responses. Organizations interviewed ranged from newly to well established organizations and covered a range of staffing scenarios, from organizations with one or two staff members to those with a larger workforce. Interviews were also selected to represent diverse regions within Africa (e.g., West versus East Africa). Additionally, there was a range of prior WB engagements with the interviewed organizations, where some have ongoing projects and others had no history of working with the WB.

7 Assessment Results

Surveys and interviews were combined to present holistic conclusions representing both RBOs and ROs. The data needs and usage from both types of organizations are comparable and motivated by similar objectives. That is, RBOs and ROs are focused on improving the management of their transboundary water resources and reducing the impact of water-related crises in their respective areas of interest. The data products and analytical tools required to achieve these objectives are analogous. For example, organizations interested in mitigated drought-related emergencies in their watersheds would utilize data products to transform RS data into an analysis-ready format, which would then be input into analytical tools that perform analyses related to drought monitoring. Thus, the responses from RBOs and ROs were merged and implications from this assessment apply to RBOs and ROs collectively.

Results from this assessment are presented in the sub-sections below. The status of RS data, data products, and analytical tools used by RBOs and ROs is described in 7.1, 7.2, and 7.3, respectively. In 7.4, the expressed interest of the organizations to expand their capacity through workshops and trainings is discussed. Constraints inhibiting the uptake of RS data and tools are provided in 7.5.

Questions in these subsections correspond to the following survey sections and questions numbers (Appendix 10.2): 7.1: Section 2 questions 1 – 4; 7.2: Section 2 questions 5 – 8; 7.3: Section 3 questions 1 – 3; 7.4: Section 2 questions 11 – 14 and Section 3 questions 4 – 6, 8, and 9; and 7.5: Section 2 questions 9 – 10 and Section 3 question 7.

7.1 Use of RS Data

RS data is currently used by 17 of the 18 organizations, indicating high levels of familiarity and existing expertise with data sets. To better determine the use RS data with relevance for WRM, respondents were asked if they collected information on precipitation; surface water; vegetation and land cover; evapotranspiration; topography; snow and ice; water quality; soil moisture; and/or groundwater using RS. Figure 4 presents the frequency of RS data collected by the organizations for these variables and water cycle attributes.

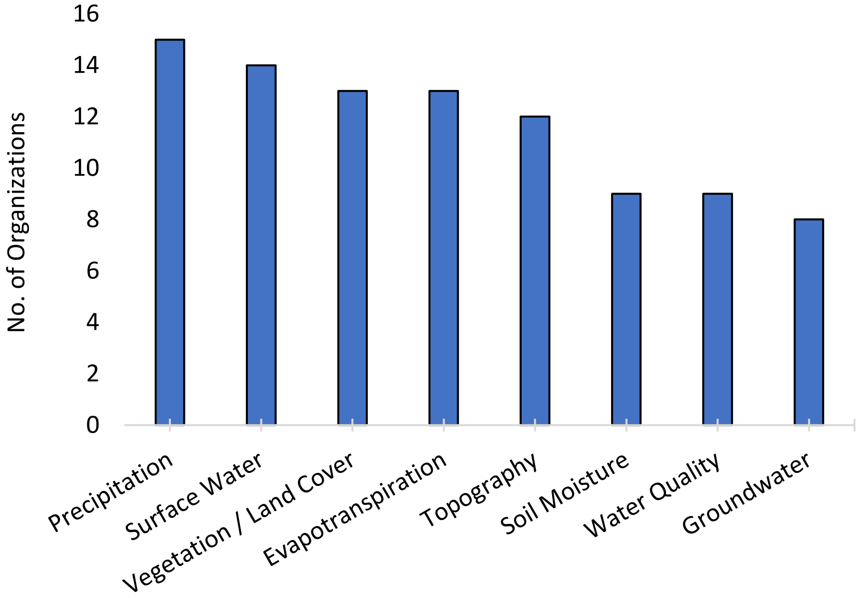

Figure 4: RS data collected by the organizations for information on specific variables and water cycle attributes.

Two-thirds of the respondents reportedly used RS to collect data on each variable and water cycle attribute, except for soil moisture (n = 9), water quality (n = 9), and groundwater (n = 8). The lower quantity of organizations using RS for soil moisture, water quality, and groundwater data was expected. RS for water quality generally is limited to observation of large water bodies and oceans, thus reducing the water resources in Africa that may benefit from using water quality-related RS data. Sub-surface properties, such as groundwater storage or soil moisture, are also difficult to assess using satellite-based technologies, thus reducing the utility of RS for collection of data related to these attributes. This challenge was underscored through interviews with organizations that reported using RS to collect groundwater information. Discussions clarified that a majority of the respondents did not collect direct information on groundwater due to the poor quality of available RS data pertaining to aquifer storage. One organization also described a process for approximating fluctuations to groundwater using more reliable RS variables, such as precipitation. Overall, precipitation is the most collected variable using RS (n = 15), followed by using RS to characterize surface water sources (n = 14). RS data on vegetation and land cover, as well as evapotranspiration, were also highly collected by the organizations (n = 13). No respondents collected RS data related to snow and ice cover.

RS was reportedly collected for the purposes outlined in Figure 5. At most, three organizations used RS for the same utility. The most reported uses of RS were for flood monitoring and early warning; drought monitoring and forecast; basin monitoring and planning; and water allocation for WRM. There was also overlap in organizations using RS for land use/land cover (LULC) assessments, groundwater assessments, and rainfall forecasting. Lastly, at least one organization used RS for rainfall – runoff modeling; ecosystem accounting; and wetlands monitoring.

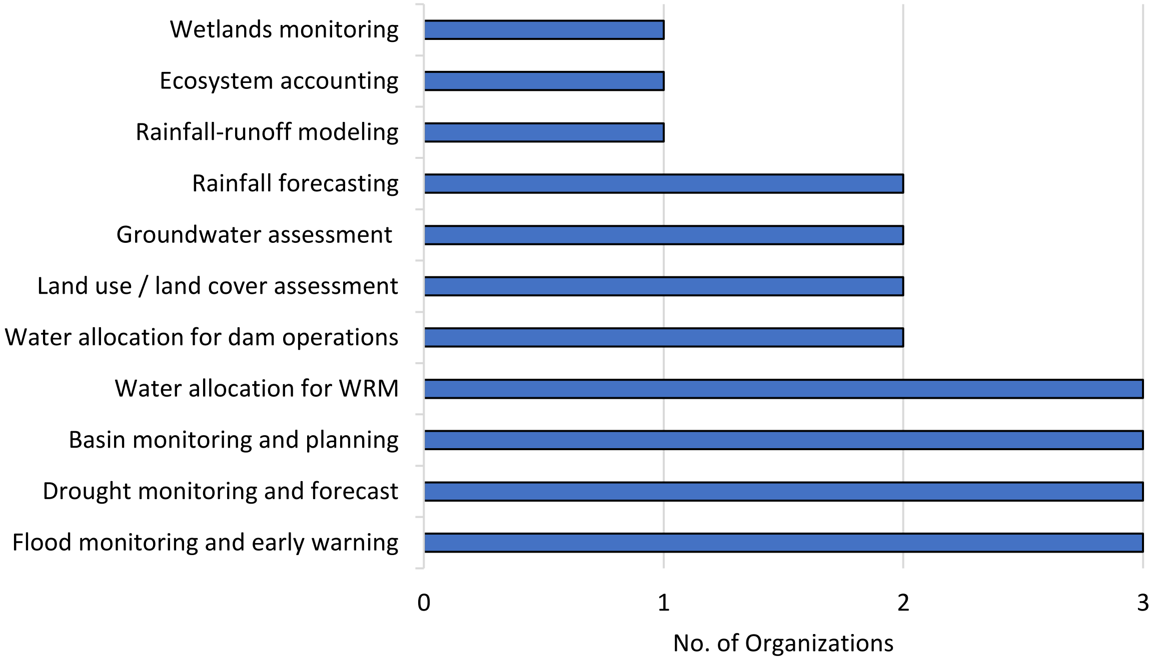

Figure 5: Primary use of the collected RS data by the organizations.

The highly reported usage of RS for collection of at least one type of data indicates strong potential to further expand the current use. When asked about data collection practices, many organizations stated in their interviews that they rarely collected, or had not officially started collecting, RS data. Although this leads to ambiguity in the current usage rates, this existing familiarity with RS can be leveraged through trainings to increase the quantity of data used by the organizations. Moreover, some organizations are already using RS data and information systems to perform essential water management operations, such as flood and drought assessments, tracking of water allocations, and basin monitoring. This prior knowledge of using RS for water management applications can be harnessed to improve data-informed decision making by expanding the types of RS data organizations are able to work with within specific analytical tools. This can be accomplished through trainings on acquiring, managing, and storing various free or low-cost RS datasets.

7.2 Use of Data Products

Of the 18 organizations in this assessment, data products are reportedly used by 16. Only one organization stated they did not use data products, indicating that the use of data products is commonplace among RBOs and ROs. To evaluate if organizations are aware of data products using RS, organizations were asked if they used, or were familiar with, any of the following platforms: Google Earth Engine, Global Flood Monitoring System, IWMI Data and Tools, Earth Map, Aquastat, Spatial Agent Hydroinformatics, Digital Earth Africa, Aqueduct Water Risk Atlas, and Dartmouth Flood Observatory. The number of organizations using each type of data product is illustrated in Figure 6.

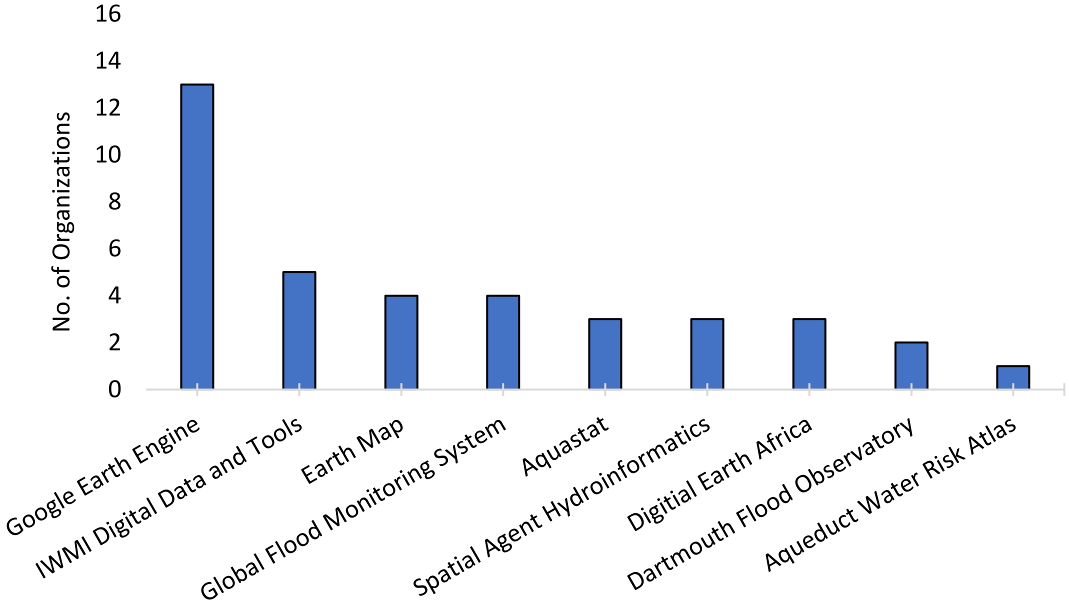

Figure 6: Data products respondents are familiar with or have used at their organization.

GEE is the dominantly utilized data platform with the greatest familiarity, compared to the others included in the survey. 13 organizations stated they used or are familiar with GEE, compared to 5 or less organizations for the other data products in the questionnaire (Figure 6). GEE is a well-established, free, and customizable data product which provides access to analysis-ready data that can be used for a variety of purposes, thus potentially increasing its favorability among the respondents compared to the other data products. Interestingly, DEA, which has very similar capabilities as GEE, was used by only 3 of the organizations in this assessment. This may be due to the relative newness of the DEA product.

Organizations described using the data products from Figure 6 for a variety of purposes. GEE was directly mentioned as being used for feasibility studies of hydro power schemes and assessments on forest degradation. Timeseries data processing was stated to be done using GEE and DEA. More generally, respondents indicated that they used the products for the following purposes: flood risk management, water allocation, development of basin monitoring reports, collection of rainfall data, rainfall-runoff simulation, assessments on rural versus urban assets, geolocation of risk sites, access to water resource-related data, monitoring of water sources (including groundwater), and mapping purposes. Data required to use the products, or attained via the products, varied per organization. Variables mentioned included precipitation, temperature, topography, LULC, water levels, and water quality parameters. Data was listed as supplied by ground stations, member countries, through purchase from suppliers, and by GEE. They also indicated their use of data products outside of those specifically asked about in the survey, which included in-house information knowledge portals and data products used by individual member states within their organization.

The status of data product usage by RBOs and ROs indicates a familiarity with products designed to harness RS, especially GEE. However, the overall usage of data platforms and products can be increased. According to the interviews, several organizations indicated that they were familiar with certain data products but were unable to apply them in routine practice, primarily due to lack of trained technical staff. Moreover, the respondents indicated limited ability to apply data products to a diverse set of scenarios. For example, some organizations stated they used GEE, but they only used it rarely to assess one specific watershed disturbance, like deforestation. Among the constraints identified through this assessment (described in 7.5), a lack of staffing with the necessary expertise to utilize data products and financial constraints were key issues preventing organizations from incorporating data products into their routine operations. Based on the follow-up interviews, there also appears to be a lack of awareness regarding existing, free, or public-domain data products, such as those included in this assessment (with the exception of the IWMI Digital Data and Tools). Building the capacity of technical staff to utilize analysis-ready RS data platforms for a range of scenarios and applications, as well increasing staff exposure to free or low-cost tools, will enable RBOs and ROs to increase their ability to effectively and economically make data-driven and informed decisions on their shared resources at a basin level.

7.3 Use of Analytical Tools

RBOs and ROs were asked if they use analytical tools to perform the following functions: tracking of the status and trends in water supply, demand, accessibility, and use (referred to as water accounting); flood monitoring (including hazard mapping and forecasting); flood early warning systems (FEWS); drought monitoring (including hazard mapping and forecasting); monitoring of surface water quality (e.g., clarity and chlorophyll-a); and quantification of water storage in reservoirs. 14 of the 18 organizations stated they used an analytical tool for at least one of these functions. Figure 7 depicts the responses by the organizations.

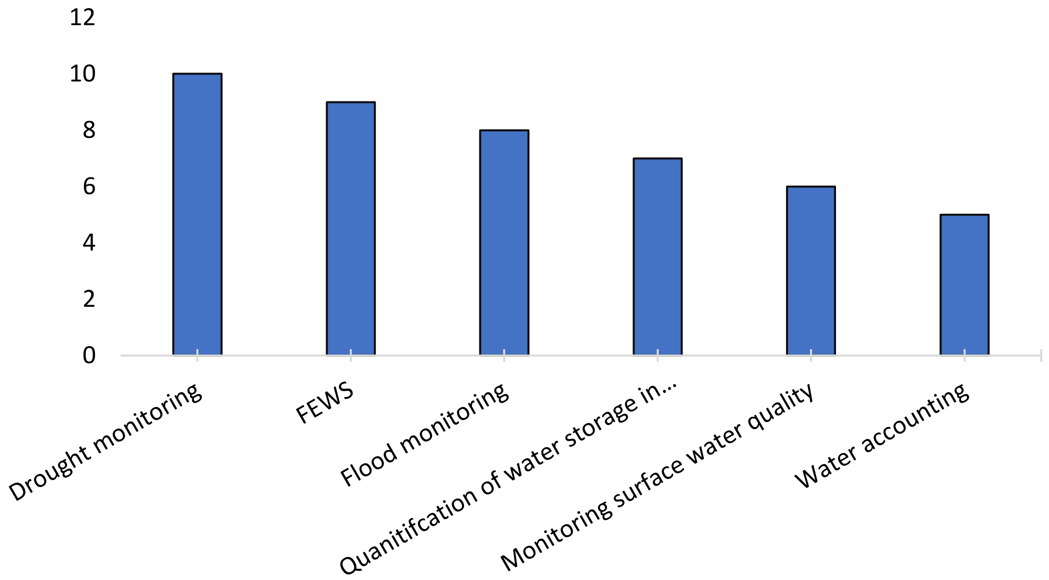

Figure 7: Analytics currently used by respondents.

Drought monitoring is the most used diagnostic by the organizations interviewed, followed by FEWS, flood monitoring, quantification of water storage in reservoirs, monitoring of surface water quality, and water accounting. Drought monitoring, FEWS, and flood monitoring may be the top applications used by the respondents for several reasons. Foremost, droughts and floods are captured relatively well using RS-based data, negating the need to incorporate extensive ground-based data. This enables users to apply these analyses in regions lacking station data and ground monitoring. As mentioned in 7.2, there are also data products available for free or at low-cost that include applications for drought and flood monitoring, making these types of analyses cost effective. Additionally, extreme natural events such as floods and droughts can trigger disasters, underscoring the need to forecast future events. Floods and droughts are increasing in Africa due to climate change[13], thus making forecasting of these events imperative across the continent for sustainable development. While quantification of water storage in reservoirs may not be relevant or of interest for all the organizations, it is highly applicable for organizations operating dams or managing lake resources which play a big when considering flooding threats. For monitoring of surface water quality, ground-based measurements of water parameters are typically required, which are often expensive, laborious, and time consuming to attain and maintain over time, thus reducing the likelihood of organizations to employ analytical tools for water quality monitoring. Lastly, water accounting can be difficult to perform without purchasing a product that collects relevant RS data, executes the calculations, and delivers extensive

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[13] White, T. (2022, March 9). *Increasing droughts and floods on the African continent*. Brookings. Retrieved April 29, 2022, from https://www.brookings.edu/blog/africa-in-focus/2021/10/08/increasing-droughts-and-floods-on-the-african-continent/

trainings on using the product. Therefore, financial constraints may reduce the ability of organizations to acquire and use water accounting tools which can impact decisions for both current and future scenarios.

Organizations reported using a variety of tools to capture the measurements described in Figure 7. For example, organizations stated they used GEE, DEA, DHI tools (such as MIKE), U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) products, Water Evaluation and Planning System (WEAP) software, Excel, geographic information systems (GIS), and UNESCO's Global Network on Water and Development Information for Arid Lands (G-WADI). Some organizations also used or have been using tools that were developed for a specific basin and their needs. Data required by this wide array of tools also ranged greatly. For example, the respondents reported using the following specific variables: precipitation (current and projected), evapotranspiration, temperature, discharge, water levels, NDVI, LULC data, soil moisture, water quality parameters, piezometric data, topography, and dam attributes (levels, inflows, and releases). Although many of these variables can be collected using RS, several organizations are relying only on ground observations to utilize analytics.

Many of the analytical tools currently being used by respondents require ground-based data, which can present limitations in terms of sustainability of water management operations. Often, limitations in the ability to collect ground-based data and financial constraints associated with continuous monitoring can result in inability to establish long-term use of tools that require constant and frequent input data. Additionally, the cost of acquiring the types of tools listed by respondents can be a prohibitory factor for many organizations. The high cost associated with many of the mainstream, common tools described by the respondents can push organizations to prioritize which types of analytics they can afford. Finally, the long-term maintenance and upkeep of these devices can be challenging for ensuring high-quality data and reliability throughout a temporal resolution. As all the analytics listed in Figure 7 are highly important for effective and efficient WRM, prioritizing only certain types of functionality can be immensely problematic for holistic water management, especially at the basin level. The issues of ground data requirements and high capital costs can be reduced by organizations moving toward using available RS data in free or low-cost data products and analytical tools. Majority of organizations recognize that RS can assist with their data coverage needs and fill the gap when ground data is scarce. From the interviews, organizations clearly articulated a desire to use RS to fill these data gaps. Furthermore, increasing the uptake of free or low-cost platforms using RS data allows for harmonization of tools across Africa despite ground data and financial constraints. Harmonization of RS data tools can increase transparency among states, foster collaborative dialogues, and facilitate transboundary cooperation. Moreover, it can allow for knowledge exchange across regional organizations, thus improving the connectivity of the water sector across all of Africa.

7.4 Potential for Trainings and Capacity Building on RS Data, Data Platforms, and Analytical Tools

The potential for utilizing RS data, data platforms and products, and analytical tools using RS to improve water management practices is evident to the organizations that participated in this assessment. Sector-wide limitations inhibiting the uptake of conventional, often costly, data tools and expansive in-situ monitoring networks has led majority of organizations to the conclusion that RS data and tools are necessary for a long-term sustainable, data-informed decision making on transboundary water resources. Key areas where organizations see potential for expanding their use of RS data and tools are described in Figure 8. Nine organizations stated there was potential to expand their use of RS technologies for data collection, including on water levels, water quality, precipitation, evapotranspiration, and topography. Five see this potential with regards to performing flood analyses, followed by 4 with drought analyses and water resource monitoring. More than one organization also stated there was potential to improve their aptitude with processing and downscaling data to the basin level, in addition to expanding their use of RS technologies for LULC assessments, water accounting, pollution monitoring, and water quality monitoring.

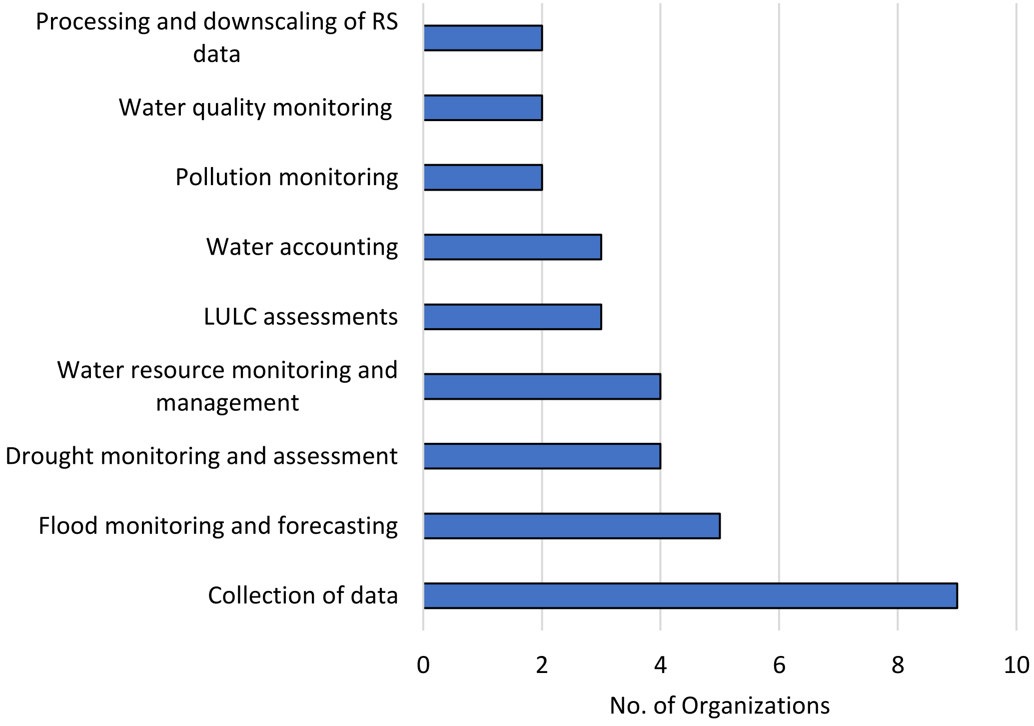

Figure 8: Areas in which organizations see potential for expanding their usage of RS data and tools using RS.

This potential can be harnessed through trainings around RS data, data products, and analytical tools using RS. Most respondents indicated that trainings and institutional development on using RS technologies were required to improve the management of water resources at the basin level. Figure 9 highlights the areas of interest for training and capacity building according to the survey respondents. A majority of the organizations require training and institutional development on the acquisition, processing, and interpretation of RS data (n = 14), followed by applying these data for water resource monitoring (n = 6). At least 2 organizations also stated trainings or institutional development were needed around using RS data and tools for specific applications, such as drought and flood analyses, LULC assessments, and water accounting.

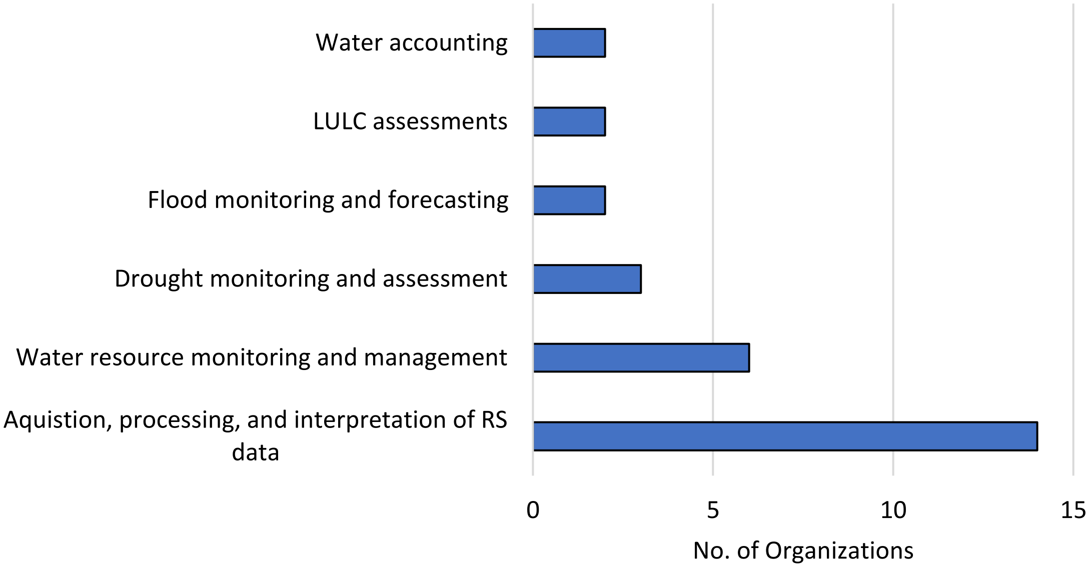

Figure 9: Areas in which organizations see a need for training or institutional development related to RS data and tools.

Although there are a range of analytical tools using RS data, the WDR needs to prioritize which tools are of greatest interest to the largest number of organizations for the capacity building elements of the project. Thus, organizations were asked to rank their priorities to receive trainings on the following tools that are widely applicable for cross-border water management across Africa: FEWS, flood monitoring, drought monitoring, quantification of water storage in reservoirs, water accounting, and monitoring of surface water quality. Each of these analytical tools were of high interest to the organizations, as they can be used to improve the management of shared resources while assisting organizations with meeting their mandates and objectives. However, FEWS, flood monitoring, and drought monitoring gathered the greatest interest. As explained in 7.3, these three types of analytical applications may be most sought after because these tools enable organizations to prepare for increasingly common climate-related disasters. In addition, respondents were asked to describe other tools they would like to be trained on that were not explicitly named in the survey. Types of analytical tools and applications mentioned by respondents included precipitation forecasting, monitoring of land use impacts on water resources, and analyzes on aqueous sediment transport.

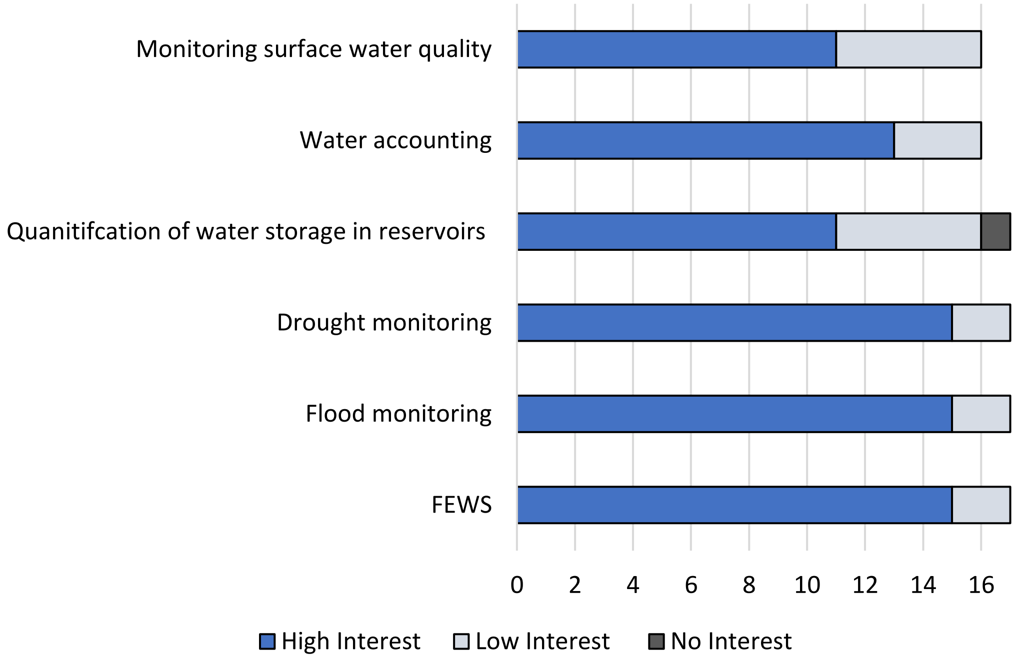

Figure 10: Level of interest by organizations to receive trainings on analytical tools using RS to perform monitoring of surface water quality, water accounting, quantification of water storage, drought monitoring, flood monitoring, and FEWS.

To determine the most suitable types of trainings to incorporate into the WDR, organizations were asked to select their interest in various trainings from acquisition of RS data to use of analysis-ready data platforms or specific analytical tools. Options for capacity building and institutional development included in the survey are listed in Figure 11. All types of trainings acquired high interest from the respondents, with an emphasis on hands-on approach to applying the tools to specific cases and watersheds.

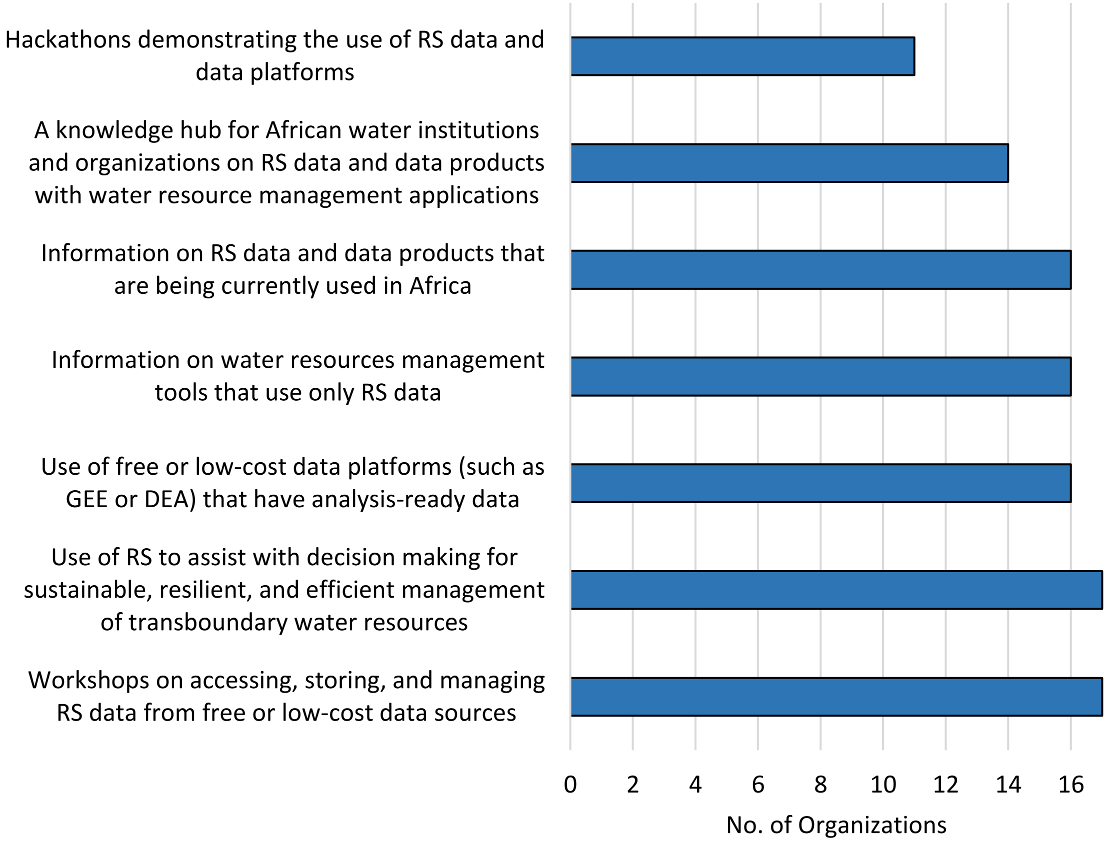

Figure 11: Number of organization interested in receiving trainings of various types.

Overall, organizations view RS data, data products, and analytical tools using RS as opportunities to improve their management of transboundary water resources, while alleviating common constraints plaguing conventional data collection and analysis methods (i.e., financial constraints and limited access to in-situ data collection). A majority of organizations would like to expand their use of RS data and analysis-ready data platforms; learn about methods for cost effective RS data collection; and improve their capacity to apply analytical tools that perform flood forecasting or monitoring and drought analyses.

7.5 Constraints for Expanding the Use of RS Data, Data Platforms, and Analytical Tools

Identifying the leading constraints inhibiting the current use of RS data, data products, and analytical tools using RS is of immense importance for understanding how to build capacity and sustainable adoption of RS technologies by the RBOs and ROs. As explained in 7.4 organizations are highly interested in using RS data and tools, so the constraints to adopting these tools must be carefully considered to achieve the WDR objectives. The list of constraints identified by the RBOs and ROs are provided in Figure 12. As highlighted below, the dominant factors inhibiting the usage of RS technologies are due to limited financial and human resources and lack of adequate technical capacity (n = 10 and n = 9, respectively). Four organizations also stated their ability to work with RS data was hindered by challenges related to data accessibility, availability, and accuracy, and three organizations mentioned internet connectivity and equipment (e.g., hardware) as causes limiting their usage of RS data, data products, and analytical tools using RS. During a follow-up interview, one organization highlighted previous attempts in utilizing global RS data but lack of accuracy to downscale the data sets hindered further investment and discontinued its use. Furthermore, an interviewed organization described how the constraints listed in Figure 12 compounded, through an example where improving technical capacity via trainings was challenged by internet connectivity for online workshops or hindered by funding requirements to attend or facilitate in-person events.

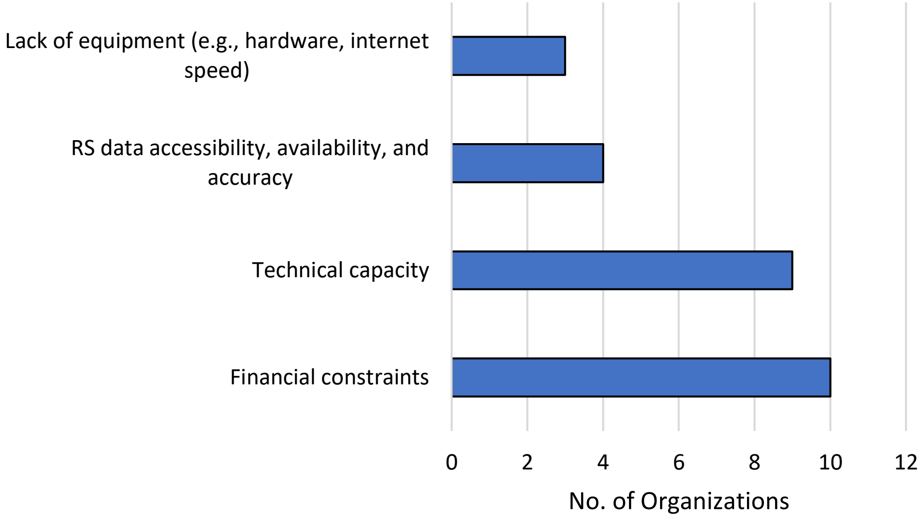

Figure 12: Constraints identified by respondents that inhibit working with tools using RS data for WRM.

Organizations were also asked to provide an overview on the capabilities of their technical staff to utilize RS data and tools. When asked about in-house staffing capacity to collect, manage, and analyze RS data, roughly half of respondents stated they had staff to perform these duties. Organizations were also asked if they had staff trained specifically to use RS data or data products; 5 reported having more than 1 person, 6 reported having 1 person, and 4 reported having none. From the interviews, organizations indicated the importance of having more than 1 person on their staff with technical skills. Running basin-wide data analytics while maintaining databases or information systems that span multiple countries, in addition to other responsibilities and duties, often becomes cumbersome for one staff member. Thus, increasing the number of technical teams among RBO or RO staff can vastly change the quantity of basin monitoring analytics that are possible within the organization.

The constraints identified by organizations can be partially overcome through capacity building and institutional development. The technical capacity constraint can be mitigated through trainings on using RS data, data products, and applications for WRM. Likewise, constraints related to RS data accessibility, availability, and accuracy can be reduced through trainings on the pros and cons of different RS datasets, as well as information on methods for routine extraction of RS data from a variety of sources. Additionally, trainings focused on free or low-cost RS data and tools will assist organizations in partially overcoming financial constraints by exposing RBOs and Ros to economical alternatives to the mainstream, often expensive, data collection and analysis tools. Of all the constraints identified by organizations in this assessment, the constraints that are not potentially reduced through capacity building on RS technologies are the requirements for hardware and internet access, as well as staffing shortages. These limitations require investments in equipment and human resources, which can pose a challenge for organizations with constrained financial resources.

8 Conclusions from the Assessment

The WDR will focus on a demand-driven approach to provide the assistance needed by partner organizations, while remaining cognizant of their context. To successfully assist organizations, the WDR will support the RBOs and ROs in ways they have self-identified as being priorities for their mission, objectives, and mandates. That is, for organizations to successfully adopt new technologies into their routine operations, they must have the need and the desire to improve their access and capacity to new technologies, the need to apply them, and the will to troubleshoot when issues arise. Through this assessment, the types of technologies and applications which are best suited to the needs of the organizations were identified. To achieve continuous use and application, RBOs and ROs must be connected with data, products, and tools that can be sustainably utilized given the constraints they are facing when applying new technologies.

Majority of the organizations included in this assessment are tasked with facilitating economic prosperity and poverty reduction through sustainable management of transboundary water resources. Throughout this assessment, organizations indicated strong interest to participate in the WDR program due to its potential to support them in accomplishing this mandate. Many organizations voiced their intention to begin using, or to increase their use of, RS data. Their motivation to use RS data was a consequence of financial constraints, awareness around limitations related to in-situ data collection, and obstacles arising from sharing of cross-border data by member states. These motivations were discussed in detail throughout interviews. For example, an organization emphasized their need for RS data due to regional conflicts affecting their ability to safely collect data in their watershed, while others described national policies as hindrances to sharing of data regionally among member states, where some countries require payment for data. In addition, organizations explained hesitancy in sharing of certain types of data that could potentially cause contention among states (e.g., upstream pollution). Moreover, organizations are eager to increase their capabilities with using data products and analytical tools. RBOs and ROs see data products facilitating access to analysis-ready data as opportunities to expand their usage of RS by reducing the time and skills required by their staff to collect and manage raw RS data. Furthermore, organizations were enthusiastic to increase their capacity to work with analytical tools using RS data. Data analytics are a crucial component when creating productive and sustainable water management operations, thus motivating organizations to want to apply analytical tools using open-access RS data is critical. RBOs and ROs see potential in learning more about tools that primarily use RS data, as they will allow them to perform informed decision analysis that would have been otherwise impossible due to many constraints, including high costs and limited input data.

This assessment provided valuable insight to guide the WDR planning and implementation. Through this assessment, the following areas were explored and implications and recommendations for the WDR were identified. Figure 13 shows the overlap of these recommendations across the categories of data management and products, analytical tools, trainings and capacity building.

RS data: Many RBOs and ROs do currently have expansive experience with RS data, but several of them are unable to routinely access RS data for their operations. *Recommendation 1:* We suggest that trainings on acquiring, managing, and storing various free or low-cost RS data to assist with establishing routine usage of such data are essential for RBOs and ROs.

Data products and analysis ready data platforms: Organizations are generally familiar with data products that facilitate access to analysis-ready RS data, such as GEE. However, some are unaware of these low-cost or freely available products. RBOs and ROs experience difficulties with using data products due to a lack of technical staff with the expertise and time to routinely collect data via these tools. For products and platforms that include data analysis mechanics, many organizations also struggle with utilizing them to perform various types of analyses. *Recommendation 2:* Instituting trainings focused on exposure to a range of affordable data products, while building the capacity of technical staff to apply them efficiently and effectively for various analyzes, is necessary.

Analytical tools: Using analytical tools is commonplace for most organizations, though there are some that function primarily as agents coordinating communication among member states as it pertains to transboundary water resources. That is, there are organizations that do not provide any analytical services at the basin level. However, a majority of organizations do use analytical tools to assist with understanding the basin-wide implications of various scenarios, such as development projects within the basin, climate change impacts on the region, and disaster risks from floods, droughts, and pollution. Currently, organizations mainly rely on tools that require ground observations and may be costly to acquire or sparse.

Recommendation 3: We recommend to build the capacity of organizations to use analytical tools that rely on free or low-cost RS data, at least as a complementary data source, thus allowing organizations to perform data analytics in regions where in situ monitoring is lacking. We also recommend providing trainings on analytical tools that are low cost or free, as these can be used long term by RBOs and Ros despite financial constraints. Finally, facilitating knowledge exchange among organizations that are interested in the same types of analytical tools using open-access RS will increase transparency and cooperation among states, while improving the connectivity of the water sector across Africa.

Trainings and capacity building: Organizations see initiatives such as the WDR as an opportunity to expand their technical capacity and skills with using RS technologies for data collection or analysis. RBOs and Ros are most interested in trainings on acquiring, processing, and interpreting RS data, as well as using analytical tools that perform drought and flood analyzes.
Recommendation 4: We suggest it is important to prioritize capacity building around using RS data and tools that facilitate the collection, management, and analysis of RS data, with particular focus on tools that perform drought and flood analytics. Of the types of analytics and applications that were incorporated into the survey questions, organizations most commonly use tools on droughts and floods over quantification of water storage in reservoirs, monitoring of surface water quality, and water accounting. Although RBOs and ROs were most interested in trainings on using RS for flood and drought analyses, they were also highly interested in trainings on using RS for these other types of analytics. Interestingly, water accounting is the least used tool currently, even though it has the potential to be immensely useful for assisting organizations in achieving their mandates and is universally applicable for water organizations (unlike analytics focused on reservoirs or surface water quality monitoring, which are mainly applied to reservoirs when using RS data). Hence, it would be beneficial to introduce applications of RS data for water accounting via trainings and gauge interest for further capacity building around water accounting tools relative to drought and flood tools, which are already being used. Additionally, any trainings offered should elicit feedback from attendees to ensure that analytical tools of focus in the trainings are fitting to the organizations in terms of their analysis needs and staffing capacity.

Constraints to using data technologies: RS data, data products, and analytical tools using RS are underutilized by RBOs and ROs mainly due to financial constraints and technical capacity limitations.
Recommendation 5: We recommend working within the financial constraints of organizations, and providing increased focus trainings and capacity development around using low-cost or free RS data, data products, and analytical tools is necessary.

Staffing: Staffing shortages are another constraint that was underscored in interviews with organizations. Many organizations have limited technical staff, if any at all. *Recommendation 6:* Due to staffing shortages, for any training and workshop, it is recommended to work with organizations to understand the most impactful data products or tools that can efficiently assist specific needs, so as to utilize their staff in the most effective manner.

Data Sharing: The degree to which data is freely shared by member states within RBOs and ROs varied greatly. However, majority of organizations are in the process of establishing or improving data portals that provide member states access to transboundary data.

Recommendation 7: Though RS data is not the solution to all data gaps, including them into data portals will greatly increase the quantity and quality of continuous data available to member states, as well as to the transboundary organization itself. This will allow for improved management of water resources within country borders by the member states and across the basin by the RBO or RO. Therefore, in addition to improving the capacity of organizations to collect and use RS data, it is recommended to support organizations with inputting RS into their data portals. Sharing of data across states is often complicated by geo-political concerns and considerations. Through RBOs and ROs, member states are electing to share data for the benefit of transboundary water management. However, issues with sharing of data can also be technical. Interviews with organizations elucidated issues such as inconsistencies with formats of shared data across countries and mechanisms for sharing of data. These issues complicate the development of shared data portals. However, they can be addressed through standardizing data sharing practices. This is accomplished throug2h a data sharing protocol implemented by some of the organizations participated in the assessment (for an example, please see the protocol developed by OKACOM[14]). Thus, for organizations that currently do not have a structure to reduce technical issues with transboundary data sharing, trainings on inputting RS data into regional or basin-wide data portals should additionally highlight the benefits of data sharing protocols.

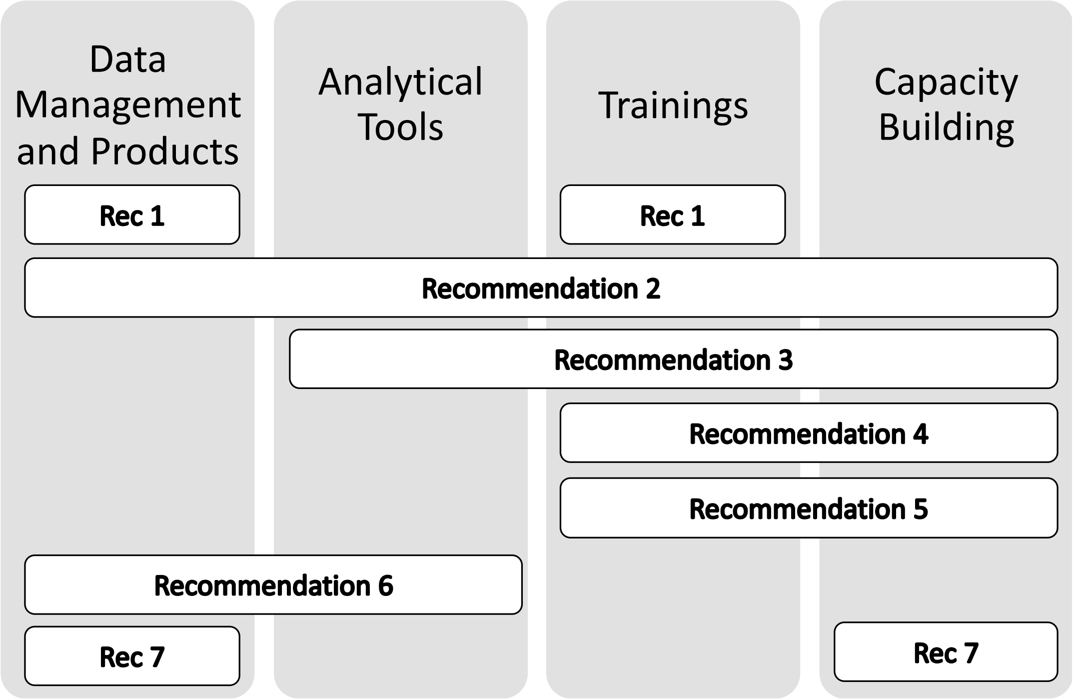

Figure 13: Overlapping areas of contribution from the identified recommendations.

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[14] Okavango River Basin Water Commission (OKACOM). (2020). *Rules and Procedures on the Sharing of Data & Information for the Cubango-Okavango River Basin*. Gaborone, Botswana: OKACOM Secretariat. https://www.okacom.org/sites/default/files/documents/Rules_and_Procedures_on_Sharing_of_Information_on_the_CORB_2020.pdf.

As Figure 13 demonstrates, these recommendations reach across four key considerations with varying degrees of intensity. While there are a combination of a potential solutions which could achieve several of these objectives, one application that responds to this needs assessment is the development of an analytical data-based dashboard, paired with the training through which to manage and use the dashboard. The dashboard would incorporate a variety of open-source RS data through an API which could result in being able to run internal water accounting in a more real-time approach. Establishing such a tool would help RBOs and ROs assess their current water balances using state of the art data in a uniform approach across the continent, enabling real-time decision support without the need for intensive technical skills. Ideally the use of such a tool would directly enable the sustainable development of the water resources RBOs and ROs manage.

9 Closing

RS data, data products, and analytical tools are currently underutilized by many regional or basin organizations across Africa that manage transboundary water resources. However, these types of technologies can greatly enhance their capability to make data-informed decisions despite challenges in the collection of data and acquisition of analytical tools that are common across Africa. Through trainings and capacity building, the WDR is striving to support organizations with increasing their ability to utilize data innovations based on their current demands and needs for operations. This assessment was conducted to determine the data gaps at organizations, as well as to understand which types of data products and analytical tools would be of greatest use for RBOs and ROs. Moreover, this assessment identified constraints that inhibit the use of data technologies, so that trainings and capacity development can be provided around tools that have a high potential of being sustainably used. Based on this assessment, recommendations were constructed as outlined in the section above. These recommendations consider the status and needs of organizations for RS data, data products, and analytical tools; prioritize trainings and capacity building initiatives; account for constraints to using RS data and tools; consider staffing capacity; and work within the context of common data sharing practices across Africa. These recommendations should be utilized to ensure the needs and aspirations of the organizations are prioritized.

10 Appendix

10.1 Examples of Data Products and Analytical Tools using RS for WRM

Table A1: Examples of data products, analytical tools, and other tools using RS for WRM, including information on the developer or provider, cost, and a link to access its website. A brief overview of the potential uses per product/tool is provided according to its website in February and March of 2022.

Product or Tool	**Developer/ Provider**	**Brief Overview of Potential Uses***											**Cost**	**Link**
		Access to analysis-ready RS data from various sources for several variables	**Tracking of status and trends in water supply, demand, accessibility, and use**	**Flood monitoring (including hazard mapping and forecasting)**	**Flood early warning systems**	**Drought monitoring (including hazard mapping and forecasting)**	**Monitoring of surface water quality**	**Quantification of water storage in reservoirs**	**Monitoring of wetlands**	**Monitoring of LULC change**	**Monitoring of dams and inventory**	**Monitoring of coastal erosion**		
Google Earth Engine	Google	🟥											Free for academic and research use	Link
Digital Earth Africa	Digital Earth Africa	🟥		🟦			🟥			🟩		🟪	Free	Link
Water Accounting +	IWMI, CGIAR, IHE Delft, UNESCO WWAP, and FAO		🟨										Unknown	Link
Dartmouth Flood Observatory	University of Colorado, INSTAAR, CSDMS			🟦									Free	Link
Earth Map	Food and Agricultural Organization of the United Nations	🟥		🟦						🟩	🟨		Free	Link

Global Flood Monitoring System	University of Maryland			■	■			■					Free	Link
Aqueduct Water Risk Atlas	World Resources Institute			■		■							Free	Link
Hydrological Resources Analyses Model (HydroRAM)	RTI International		■				■	■					Unknown	Link
DHI Flood and Drought Portal	DHI and the International Water Association			■	■	■				■			Unknown	Link
Princeton Flood and Drought Monitors	Princeton Climate Institute and the University of Southampton			■	■	■							Free	Link
GlobWetland Africa (GW-A)	GlobWetland Africa						■	■	■				Free	Link
WMO Global Hydrological Status and Outlook System (HydroSOS) (in pilot stage)	World Meteorological Organization			■	■	■		■					Unknown	Link
Water Productivity through Open-access of Remotely sensed derived data (WaPOR)	Food and Agricultural Organization of the United Nations		■							■			Free	Link
Weather Research and Forecasting Model (WRF)	National Center for Atmospheric Research (NCAR)			■	■	■		■		■			Free	Link
World Bank Climate Change	World Bank Group	■											Free	Link

Knowledge Portal														

10.2 English Survey Form

Water Data Revolution - Survey of Water Institutions

This survey is being conducted for the *Water Data Revolution (WDR): Closing the Data Gap for Transboundary Water in Africa* Program supported by the Cooperation in International Waters in Africa (CIWA) and the World Bank.

About the Cooperation in International Waters in Africa:

The CIWA program assists riparian governments in Africa in unlocking the potential for sustainable, climate-resilient growth by addressing constraints to cooperative water resource management and development. CIWA achieves its goals by focusing on information, institutions, and investments. Managed by the World Bank, CIWA provides technical and analytical support to foster solutions to transboundary issues by making informed decisions. Through the WDR project, CIWA aims to utilize a user-driven approach to identify and support commonalities among all while connecting all with innovation and technologies, such as satellite-derived remote sensing (RS) data and products to collect, store, manage, and analyze RS data.

About the Water Data Revolution:

The WDR is focused on connecting demand-driven analytical products using RS data[15] to decision-makers of water resources that will strengthen the cooperative management of transboundary waters in Africa, while additionally improving the capacity of water institutions to collect, store, and analyze RS data and information. We are assessing the uses and needs of data products[16] using RS for water management applications via this survey.

We would like to thank you for your collaboration, and we look forward to engaging with you further on this activity. We appreciate your feedback and response to this survey, as it will be used to guide the design of the WDR program. We strongly believe that the WDR will contribute towards helping countries across Africa to improve their capacity to collect, store, and analyze data and information and to make evidence-based decisions about water, essentially by reducing the cost and complexity of water data and by establishing connections between water institutions and data products, to facilitate the translation of information to improved decisions.

Privacy Notice:

The World Bank is conducting this survey to determine the data gaps and needs of basin organizations and water institutions in Africa to improve their decision-making process. These questions will help identify approaches for improving the use of RS data and data products for water resource management. We are asking questions regarding data and data product usage, gaps, and needs at your organization. Any response you provide will be kept confidential, and your personal information will be kept for future communication. No specific information about you will be shared with third parties. The World Bank will conduct its analysis based on an

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[15] ***RS data*** *refers to space-based, remotely-sensed data (also known as earth observation data).*

[16] ***Data products*** *refers to platforms, tools, or programs designed to collect, store, manage, and/or analyze data (for example, Google Earth Engine). Data used in data products may be from remote sensing or other data sources (such as gauges or ground-based observations).*

anonymized dataset. If you have any questions about the WDR, about this survey, or about the processing of your personal data, please contact Noosha Tayebi, Water Resources Management Specialist and WDR Task Team Leader, at ntayebi@worldbank.org or Kelsey Reeves, Water Resources Consultant, at kreeves@worldbank.org. If at any point you do not want to receive further communication from us, you can opt out by messaging ntayebi@worldbank.org or kreeves@worldbank.org.

It would be our pleasure to share the summaries and conclusions derived from this survey with survey participants and collaborators of the WDR project. We kindly request your response by December 21st. We appreciate your participation in this survey, and we thank you for your time.

Do you consent to the processing of your personal data according to this Privacy Notice?

☐Yes
☐No

Section 1: General questions

1) Your name:

2) Preferred email to contact you:

3) Organization/department:

4) What country are you based in?

5) Organization type:
    ☐Governmental
    ☐Basin organization
    ☐Regional organization
    ☐Research/academic

6) List of countries, river basins, or aquifers your organization works most in:

7) Name and email of the person within your organization who is responsible for collecting, analyzing, or managing your digital data:

Section 2: Data - Current and past use of RS data and data products

RS data refers to space-based, remotely-sensed data (also known as earth observation data).

Data products refers to platforms, tools, or programs designed to collect, store, manage, and/or analyze data (for example, Google Earth Engine). Data used in data products may be from remote sensing or other data sources (such as gauges or ground-based observations).

1) Does your organization use **RS data**?
   - ☐Yes
   - ☐No

2) Does your organization use **RS data** to characterize or collect information on any of the following variables or water cycle attributes? Please mark all that apply.
   - ☐Precipitation
   - ☐Evapotranspiration
   - ☐Soil moisture
   - ☐Vegetation and land cover
   - ☐Groundwater
   - ☐Surface water
   - ☐Snow and ice
   - ☐Water quality
   - ☐Topography

3) Please list and describe **RS data** your organization uses (or has used). Please include the following per RS dataset: the variable used; source/provider of the data; the spatial resolution, temporal resolution, and extent of the data provided by the source; website for the data; and a brief description of the cost to access the data.

   Examples:
   Variable: Precipitation
   Source: CHIRPS version 2.0
   Spatial Resolution: 0.05 degree, 30m x 30m
   Temporal Resolution: Hourly, daily, monthly, annually
   Extent of Data from Source: Global, continental, regional, national, basin level

Website: https://data.chc.ucsb.edu/products/CHIRPS-2.0/
Cost: Open-access, free to download, low-cost, paid for use

4) Please describe the main purpose or primary use of each set of **RS data** listed in question 3.

5) Does your organization use **data products**?
    - ☐Yes
    - ☐No

6) Has your organization used, or is your organization familiar with, any of the following **data products**? Please mark all that apply.
    - ☐Google Earth Engine (GEE)
    - ☐Digital Earth Africa (DEA)
    - ☐International Water Management Institute (IWMI) Digital Data and Tools
    - ☐Dartmouth Flood Observatory Flood Portal
    - ☐EarthMap.org
    - ☐Aquastat
    - ☐Global Flood Monitoring System
    - ☐Our World in Data
    - ☐Aqueduct Water Risk Atlas
    - ☐WB Spatial Agent Hydroinformatics

7) Please list **data product(s)** your organization uses (or has used) and the key purpose of use for each product.

8) For the **data products** you currently use (listed in question 7), please describe the data used per data product, where you collect this data from, and how frequently it is collected.

9) Do you have in-house expertise to collect, manage, and analyze **RS data**?
    - ☐Yes
    - ☐No

10) How many people in your organization use or are trained to use **RS data** or any **data products**?

11) Do you see potential for expanding the use of **RS data/data products** in your organization?

☐Yes
☐No

12) If yes, please describe in which areas would most interest you. If no, please explain why.

13) Do you see a need for training and institutional development in your organization around the use of **RS data/data products** for water resources management?

☐Yes
☐No

14) If yes, please indicate areas or topics that would most benefit you.

Section 3: Tools - Use of RS data/data products with water resource management applications

1) Please indicate tools/applications your organization uses (or has used):

☐Tracking of status and trends in water supply, demand, accessibility, and use
☐Flood monitoring (including hazard mapping and forecasting)
☐Flood early warning systems
☐Drought monitoring (including hazard mapping and forecasting)
☐Monitoring of surface water quality (e.g., clarity and chlorophyll-a)
☐Quantification of water storage in reservoirs

2) For each application you marked in question 1 above, please specify the name of the application you use.

3) What data is required for each tool/application? Please indicate the source of the data (for example, RS, ground station, etc.).

4) Please indicate your level of interest to receive training on the following applications using RS data.

Application	**High Interest**	**Low Interest**	**No Interest**
Tracking of status and trends in water supply, demand, accessibility, and use	☐	☐	☐
Flood monitoring (including hazard mapping and forecasting)	☐	☐	☐
Flood early warning systems	☐	☐	☐
Drought monitoring (including hazard mapping and forecasting)	☐	☐	☐
Monitoring of surface water quality (e.g., clarity and chlorophyll a)	☐	☐	☐
Quantification of water storage in reservoirs	☐	☐	☐

5) Are there any applications that use RS data and are not listed in question 4 above that your organization would like to receive trainings and information on?

☐Yes
☐No

6) If yes, which applications are you interested in?

7) What constraints do you see to working with applications using RS data for water resource management? For example, costs, technical capacity, etc.

8) Would your organization be interested in any of the following types of trainings? Please mark all options your organization would be interested in.

☐Workshops on accessing, storing, and managing RS data from free or low-cost data sources
☐Use of RS to assist with decision-making for sustainable, resilient, and efficient management of transboundary water resources
☐Use of free or low-cost data platforms (such as GEE or DEA) that have analysis-ready data
☐Information on water resources management tools that use only RS data

☐Hackathons demonstrating the use of RS data and data platforms
☐A knowledge hub for African water institutions and organizations on RS data and data products with water resource management applications
☐Information on RS data and data products that are being currently used in Africa

9) Do you have a suggestion for a training or resource on RS data, data products, or tools/applications that you/your organization could benefit from?

10) The WB has an online hub for water data and applications for water management at wbwaterdata.org. Are you familiar with this resource? If you haven't used it before, we encourage you to visit the website to see if there are data or data products of interest to you!
☐Yes
☐No

Thank you for taking this survey.

Annex 2

Capacity building on the use of Remote Sensing-based technologies and platforms for data collection, management, and analysis for Transboundary Water Management in Africa

Water Data Revolution: Closing the Data Gap for
Transboundary Water in Africa (P176348)

Africa (AFRICA)

2023

WORLD BANK GROUP

Contents

1 Introduction

Africa's growing population, economic development, and changing climate are driving up demand for water resources, while the lack of accessible, reliable data complicates efforts in water management across international boundaries. This scarcity of water data presents a significant obstacle to sustainable development, impacting food security, economic stability, and regional cooperation, as most of Africa's water resources span international borders.

The *Water Data Revolution (WDR): Closing the Data Gap for Transboundary Water in Africa*, a program led by CIWA, aims to assist riparian governments in Africa in unlocking the potential for sustainable, climate-resilient growth by addressing constraints to cooperative water resource management and development. By leveraging state-of-the-art Remote Sensing (RS) technology and tailored analytical tools, WDR empowers African River Basin Organizations (RBOs) and Regional Organizations (ROs) to make data-driven, climate-resilient decisions.

RS is a key technology within WDR, offering broad, continuous data coverage that complements ground-based observations. By combining RS and ground data, African institutions can make informed, cooperative decisions, building resilience against climate challenges like floods and droughts and ensuring sustainable use of shared water resources for both upstream and downstream communities.

2 WDR's structure and current progress

To accomplish its objectives, the WDR is organized into three strategic pillars: Pillar A – Data Status and Needs Assessment; Pillar B – Enhancing RS Data and Capacity Building; and Pillar C – Application of RS Data and Tools. Pillar A conducted an in-depth assessment of the current data landscape within African RBOs and ROs. This evaluation identifies gaps in data availability, infrastructure, and technical capacity, informing future data needs for efficient transboundary water management.

Building on Pillar A's results, Pillar B focuses on improving RS data use and showcasing accessible data products and tools. It provides training and workshops to strengthen organizational capacity in data collection, management, and analysis, ensuring that decision-makers have the necessary tools to apply data in managing water resources cooperatively and sustainably. Finally, Pillar C supports selected organizations in adopting low-cost, practical RS data solutions for day-to-day management of shared water resources. By implementing these technologies, organizations are better equipped to handle challenges related to water storage, allocation, and management.

The initial assessment conducted under Pillar A highlighted significant data gaps within RBOs and ROs. Many organizations face limitations due to inadequate technical resources and financial constraints, which impede their ability to manage transboundary water resources effectively. Key recommendations include providing trainings on acquiring, managing, and utilizing RS data, data products, and analytical tools, particularly focusing on affordability and effectiveness. In addition, the assessment provided valuable insights into specific needs, such as increased accessibility to data on water accounting, drought forecasting, and flood management. Among these, water accounting was found as a key topic, as it helps RBOs to meet their goals and improve transboundary water resources management.

The findings from Pillar A shaped the approach of Pillar B by identifying priority areas where data tools and training are most needed. With a clearer understanding of these gaps, Pillar B aims at addressing these limitations by equipping organizations with RS data tools and analytical capabilities. Tailored training sessions, aligned with the specific needs identified in Pillar A, gives organizations the necessary knowledge to manage data collection, analysis, and application, promoting sustainable WRM practices across the continent.

Pillar C builds on the findings of the previous pillars, helping organizations adopt RS data tools in their daily water resource management practices. Insights from Pillar A guide the targeted use of these tools, while the capacity developed through Pillar B's training ensures effective application. This cohesive approach enables RBOs and ROs to integrate data-driven decision-making, addressing challenges like flood forecasting, drought monitoring, and water allocation. By promoting sustainable practices, Pillar C enhances Africa's resilience to water challenges and supports cooperative transboundary water management.

3 Capacity-building activities

The outcomes and recommendations of Pillar A's assessment established a baseline for developing training workshops for addressing the information and institutional capacity-building needs of RBOs across Africa, aimed at enhancing transboundary basins management. Due to logistics and travel restrictions limitations, the training activities took place online, facilitating the participation of a broader range of trainees. The workshops focused on exploring and showcasing the use of state-of-the-art technologies and tools related to data and analytics that can support RBOs in enhancing water resources management practices. Key details of the workshops are summarized in the table below.

Workshop title	Dates	Overview
Water Data Revolution: Modernizing Transboundary Water Data and Analytics	June 13th - 14th, 2023 (2 days)	Introduction of a spectrum of technologies related to data/analytics and knowledge/ learning for generating insights on transboundary waters. Deeper dives were done in selected cutting-edge aspects of the use of technology including modern cloud analytics, interactive dashboards, artificial intelligence, and leveraging new open services for historical information
Water Data Revolution: Data and analytics for Water Resources Management	November 29th, 2023 (1 day)	Showcasing the use and application of selected tools with the potential of empowering water planners with reliable tools to facilitate an informed decision-making process for WRM, with focus on allocation planning and water productivity for irrigation.
Complementary trainings led by Water GP.		The Water GP, through its global unit, has conducted several training sessions focused on modern data and analytical tools for water resources management. These sessions were designed for a broad audience of water specialists and included participation from the RBOs.

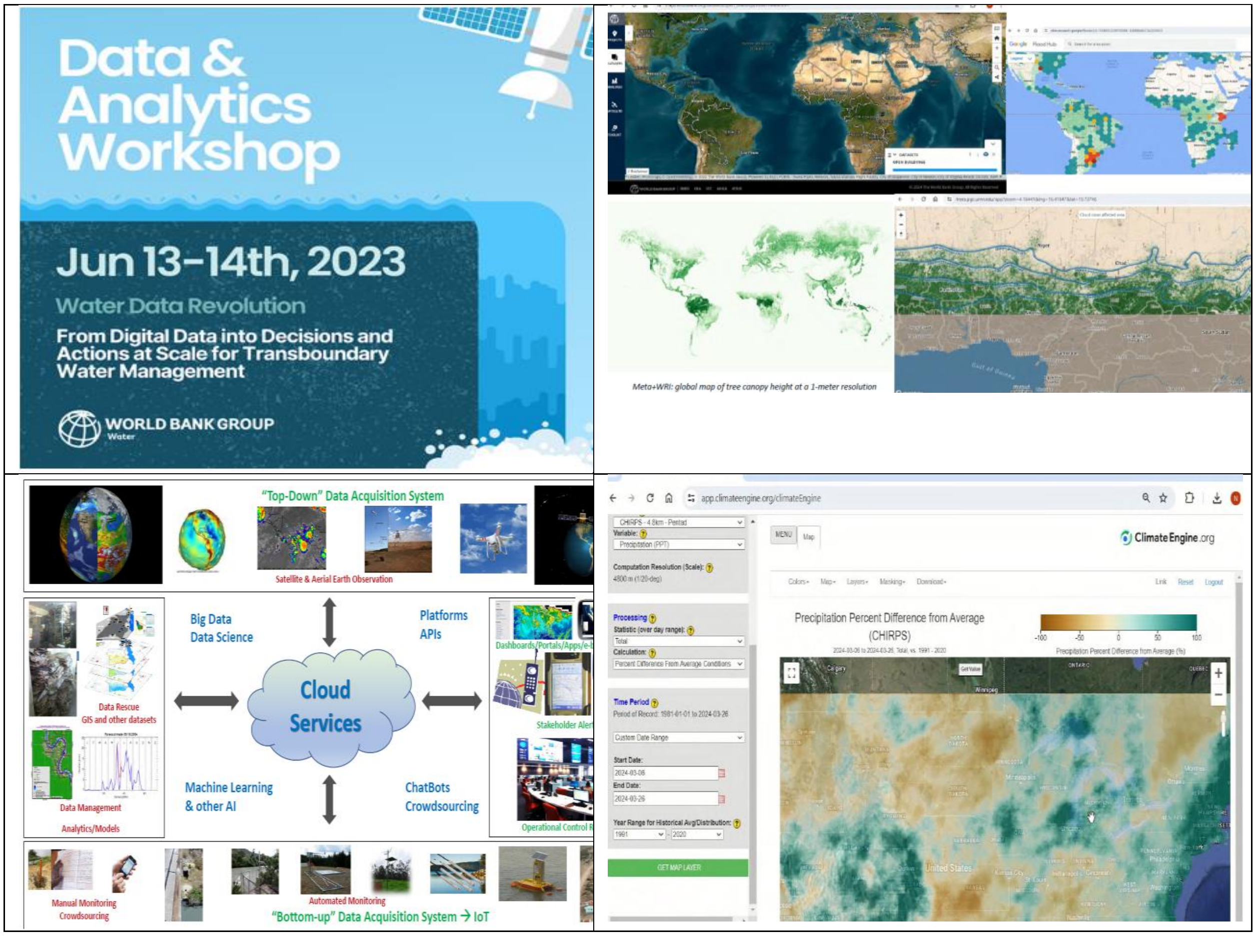

Figure 1 A sneak peek on the trainings that were carried out under Pillar B

The selection of technologies/tools presented in the workshops was based on the following criteria:

- *Relevance for RBO's work.* The technologies/tools were chosen based on their direct relevance to the specific mandates and objectives of RBOs in the context of WRM. Emphasis was placed on selecting tools that align with the operational and decision-making needs of RBOs, ensuring that they provide essential information and analytical capabilities to enhance water resource management practices.
- *Ability to address transboundary WRM aspects*. Priority was given to tools that offered solutions and insights applicable to cross-border challenges, fostering collaboration and coordination within and among RBOs.
- *Cost-free accessibility.* The workshops prioritized technologies/tools that are available for use without any associated costs in order to eliminate the financial barriers that usually emerge when using cutting-edge data and technology, consequently demonstrating RBOs how they can benefit from them without incurring expenses.

- *Leveraging cutting-edge technologies.* Technologies/tools aligned with the latest advancements in data and analytics were prioritized.

4 Topics, technologies and tools covered during training workshops

a) *Collecting & Organizing Data for Transboundary Basins (In-Situ, Earth Observation, Apps)*

Presented various methodologies for gathering and structuring data pertinent to transboundary basins. It explored traditional in-situ measurements, advancements in Earth Observation technologies, and the role of innovative applications in collecting and organizing essential data for comprehensive water management.

On knowledge aspects, platforms where knowledge of available tools for modeling different aspects related to water resources were also showcased.

- *World Bank Disrupting hydroinformatics e-book*. Interactive resource introducing modern hydroinformatics concepts through multimedia, providing users with a quick overview and the ability to explore specific areas in depth, while also offering access to recent knowledge resources, reports, articles, and technologies in the field of HydroInformatics.
- *Model Primer.* A foundational guide introducing common numerical models used in water and natural resources management. It assists users in identifying and selecting the most appropriate model for specific questions related to water and/or natural resource management.
- *World Bank Spatial Agent Hydroinformatics Data portal:* A comprehensive collection of mapped indicators covering water, disaster, climate, environment, and socio-economic aspects from diverse sources, providing valuable insights for informed decision-making.

b) *Access to data and Analytics*

The workshop addressed the importance of robust platforms designed for seamless access, efficient analytics, and intuitive visualization of water-related data. Insights were provided into the selection and utilization of platforms that facilitate comprehensive data management and analysis in the context of transboundary water resources.

- *Sentinel imagery Hub.* Engine for processing of petabytes of satellite data. It is opening the doors for machine learning and helping hundreds of application developers worldwide. It makes Sentinel, Landsat, and other Earth observation imagery easily accessible for browsing, visualization, and analysis.
- *World Bank's geospatial platform.* User-friendly web-based tool for spatial analysis, seamless dataset exploration, and mapping. Users can define areas of interest, apply

analyses for in-depth insights, and browse satellite collections with direct visualization on the map.

- *Open aerial map.* Set of tools for searching, sharing, and using openly licensed satellite and unmanned aerial vehicle (UAV) imagery. Built on top of the Open Imagery Network (OIN), OAM is an open service that provides search and access to this imagery.
- *Hydrosheds.* Database offers a suite of global digital data layers at multiple resolutions and scales to support of hydro-ecological research and applications worldwide. Provides free data in GIS formats that can serve a broad range of assessments, including hydrological, environmental, and socioeconomic, among others.
- *Google Earth Engine data catalog*. A comprehensive repository within the Google Earth Engine platform, providing users with access to a diverse collection of geospatial datasets and imagery. It serves as a centralized catalog, allowing users to explore and discover a wide range of datasets for their geospatial needs, from satellite imagery to climate data.

c) Interactive Dashboards and visualization

Participants learned about the design and implementation of interactive dashboards for enhanced data representation. This segment highlighted the role of dashboards in transforming complex datasets into visually intuitive displays, and how these outputs can allow stakeholders to interpret and make informed decisions regarding transboundary water issues. Insights and examples on the latest developments and available tools for improving data visualization were provided, including some taste in virtual and augmented reality visualization tools.

- *Site Scan for Arc GIS* Cloud-based drone mapping software, a part of the ArcGIS Reality suite, optimizing drone imagery data collection, processing, and analysis. Features include automatic fleet management, repeatable flight plans, secure cloud processing, and seamless integration with advanced analytics.
- *Flourish studio.* Enables the creation of interactive graphs, charts, and unique visualizations from uploaded datasets. Flourish offers diverse visualization options beyond traditional graphing from spreadsheets, catering to various presentation needs.
- *Story maps ArcGIS.* A web-based application facilitating the creation of interactive narratives by seamlessly blending maps with multimedia content. Allows users to author, present dynamic presentations, and publish/share stories and collections effortlessly.

d) Cloud Analytics

Advantages and functionalities of cloud analytics in handling vast datasets related to water management were portraited. It explored how cloud-based solutions enhance scalability, accessibility, and real-time analysis, promoting efficiency and accuracy in water data management.

- *Google Earth Engine.* A computing platform that allows users to run geospatial analysis on Google's infrastructure to assess a variety of issues such as deforestation, drought, disaster, disease, food security, water management, climate monitoring, and environmental protection.
- *World Bank's geospatial platform.* User-friendly web-based tool for spatial analysis, seamless dataset exploration, and mapping. Users can define areas of interest, apply analyses for in-depth insights, and browse satellite collections with direct visualization on the map.
- *Arc GIS web app* Web-based application on the ArcGIS platform for creating, sharing, and interacting with maps and spatial data. Offers functionalities such as mapping, data visualization, and analysis tools, providing an accessible interface for exploring geospatial information.
- *Hydroweb* Provides information on continental surface hydrology state variables from various satellite data for users, whether scientific or not.
- *Geo Aquawatch* Offers global-scale, open-access water quality information for inland and coastal waters. Targets users in the science community, water resource managers, and the general public.
- *Earth map.* Facilitates quick historical environmental and climate analysis on Google Earth Engine, providing access to complex land monitoring without coding.
- *Climate engine.* Powered by Google Earth Engine, creates on-demand maps and charts from publicly available satellite and climate data using a standard web browser.

e) Use of Artificial Intelligence (AI)

This session covered the integration of Artificial Intelligence (AI) in water data analysis. This included a specific focus on the ChatGPT family of Generative AI, showcasing its capabilities in interpreting and generating insights from water-related data and information.

ChatGPT possesses advanced language processing and generation capabilities, enabling it to understand context, provide detailed responses, and even generate complex technical content. It can assist water resources specialists by providing technical information, answering conceptual questions, drafting reports, summarizing information and more. It also possesses coding capabilities that allow users to obtain assistance with coding tasks related to water resources management, such as developing algorithms for hydrological modeling, analyzing datasets, or implementing specific features in software tools.

f) *Open Streamflow Services*

This session explored the utilization of open services for accessing and utilizing historical and forecasted information on stream flows. It was introduced to the concept of open streamflow services, emphasizing the benefits of leveraging shared data resources for comprehensive analysis and planning in the context of transboundary water systems.

GeoGLOWS, which stands for Geo Global Streamflow Services, is a system that provides global-scale streamflow predictions. It's a project that combines hydrologic modeling with satellite and meteorological data to produce near real-time and future streamflow forecasts. The tool is designed to improve water-related decision-making by offering reliable information about river discharge, which is crucial for managing water resources, especially in regions vulnerable to floods or droughts.

g) Water accounting for water resources planning using the WA+ framework

To maximize the effectiveness of investment in Water Resources Management, two crucial factors come into play: the availability of accurate and appropriate data and a shared understanding and acceptance of management options among diverse stakeholders. This requires the establishment of a suitable framework for planning, monitoring, and evaluating water resources within river basins. Many analytical frameworks tend to focus on specific hydrological processes but fail to establish connections between these processes and their broader implications. As such, the water accounting (WA+) framework becomes a fundamental building block for various water resources management and sustainability applications. This framework provides essential data and insights into water availability, usage, and distribution, enabling informed decision-making and policy formulation. Water accounting integrates hydrological processes with land use, managed water flows, and the services that result from water consumption in river basins. Its objective is to strive to achieve equitable and transparent water governance for all users and a sustainable water balance. Users can provide value assessments of certain processes, and more accurate data sets, that replace the default data collected from open-access sources that represent best estimates. The WA+ is applied to river basins and utilizes open-access remote sensing datasets. WA+ provides independent estimates of water fluxes and stocks of water resources availability, consumption, and derived services.

Participants were familiarized with the WA+ framework, gaining insights into its capabilities and diverse applications. The session featured compelling examples of its implementation across various regions globally.

h) Water productivity for irrigation using WaPOR

WaPOR is a publicly accessible spatial database and analytics portal monitoring agriculture water productivity across Africa and the Near East. Offering open access to a comprehensive water productivity database and its myriad underlying map layers, WaPOR enables direct data queries, time series analyses, area statistics, and data downloads for key variables associated with water and land productivity assessments. Developed using open-access remote-sensing data and open source algorithms, this tool provides near real-time information spanning from 2009 to the present at three resolutions: continental (250 m ground resolution), national or basin (100 m), and sub-national (30 m). The information provided by the portal can be used for a variety of applications such as:

- The monitoring of (i) impact of stressors on agriculture (drought, pests, etc.); (ii) Water consumption of fields or specific crops, (iii) changes in agricultural production over time; (iv) water resources through water accounting and auditing
- The provision of advisory services to farmers
- The understanding of the spatial variability of water and crop-related variables
- The support of solutions to increase yield and irrigation and reduce productivity gaps.

Participants were familiarized with the WaPOR platform, gaining insights into its capabilities and diverse applications. The session featured some examples on the use of the information generated by the tool and how data can be extracted.

5 Participants

The workshops were attended by professionals representing RBOs across Africa. The first session had 85 attendees and the second wa attended by 65 participants, primarily comprising professionals with technical expertise in hydrology and related water resources domains.

The large number of participants and their strong engagement demonstrate the relevance and interest among RBO technical staff in building capaciy with state-of-the-art tools, underscoring the importance of these skills in their work in water resources management.

6 Recommendations and Next Steps

The capacity-building activities undertaken during Pillar B of the WDR initiative have enhanced the capabilities of RBOs and ROs in using RS data for transboundary water resources management. Building upon the findings from Pillar A—which assessed the status, availability, and use of data among these organizations—the workshops were successfully designed to address the specific needs and challenges identified.

The training workshops focused on introducing a range of relevant, cost-free, user-friendly, and state-of-the-art RS technologies and analytical tools. These included platforms for data collection and organization, access to data and analytics, interactive dashboards and visualization tools, cloud analytics, artificial intelligence applications, open streamflow services, and frameworks for water accounting. The capacity-building activities were designed to align the objectives of RBOs and ROs, tailoring the workshops to their needs and ensuring that participants acquired practical skills relevant and applicable to their work. Further, the high number of participants from various RBOs across Africa highlights the relevance and immediate applicability of the training.

By improving proficiency in use RS data and analysis ready data platforms, RBOs and ROs will be better equipped to collect, manage, and analyze water-related data. The skills acquired enable organizations to better monitor water availability, predict and mitigate water-related hazards like floods and droughts, and facilitate fair water allocation. This competency strength will lead to more informed, data-driven decision-making processes, contributing to more efficient and sustainable management of transboundary water resources.

Due to the rapid pace of technological advancements in RS data, continuous training will be essential to keep participants up-to-date and equipped with the latest tools and methodologies. Regular workshops and capacity-building initiatives are recommended to ensure that regional entities can stay aligned with technological advancements and maintain effective data-driven practices. Emphasis should be placed on training in tools and services that the World Bank practices, including systems for constant data collection and presentation through dashboards, to strengthen skills in data management, visualization, and interpretation.

Looking forward, Pillar C will build upon this foundation by assisting three pilot transboundary river basins in applying these tools and technologies to their operations. This next phase is crucial for reinforcing and solidifying the practical application of the skills learned in these river basin’s context. It will also identify tangible improvements in water resource management practices that can be achieved with the application of RS data. By providing tailored support, Pillar C’s goal is to ensure the sustainability and long-term impact of the WDR initiative's efforts.

In summary, the WDR initiative represents a joint effort to close the data gap that slows down effective transboundary water management in Africa. Integrating cutting-edge RS technologies and enhancing institutional capacities are fundamental steps to achieving sustainable and fair water resource management. Continued collaboration, capacity-building, and the practical application of advanced technologies are vital in promoting resilience against climate variability, supporting cooperative management efforts, and contributing to the continent's overall growth and prosperity.

Annex 3

Technical assistance for the capacity building of use of remote sensing data and water accounting for River Basin Organizations (RBOs) in Africa

Water Data Revolution: Closing the Data Gap for
Transboundary Water in Africa (P176348)

Africa (AFRICA)

2024

WORLD BANK GROUP

Table of Contents

List of Abbreviations

AET	Actual Evapotranspiration
API	Application Programming Interface
ARC	African Rainfall Climatology
BDE	Boundary Data Extractor
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CIWA	Cooperation in International Waters in Africa
CMIP6	Coupled Model Intercomparison Project Phase 6
DDE	desalination data extraction
DEA	Digital Earth Africa
DEM	Digital Elevation Model
DISE	Discharge Extractor
DIWASA	Digital Innovation for a Water Secure Africa
ESA	European Space Agency
ET	Actual Evapotranspiration
GLEAM	Global Land Evaporation Amsterdam Model
GMIA	Global Map of Irrigated Areas
GPP	Gross Primary Product
GRDC	Global Runoff Data Centre
INMACOM	Incomati and Maputo Watercourse Commission
IWMI	International Water Management Institute
LAI	Leaf Area Index
LUWA	Land use for water accounting
MCM	Million Cubic Meter
NDM	Net Dry Matter
NEX-GDDP	NASA Earth Exchange Global Daily Downscaled Projections
NPP	Net Primary Productivity
P	Precipitation
PET	Potential Actual Evapotranspiration
RBO	River Basin Organization
RFE	Rainfall Estimate
ROSE	Rapid Optimized Sheet Extractor
RS	Remote Sensing
SIWA	Scale Invariant Water Accounting
SSEBop	Operational Simplified Surface Energy Balance
SSP	Shared Socio-economic Pathways
SWAT	Soil Water Assessment Tool
VBA	Volta Basin Authority
WA+	Water Accounting + Framework
WDPA	World Database on Protected Areas
WPL	Water Pollutant Load
WRM	Water Resources Management

Executive Summary

IWMI established agreements with World Bank Group (Grant #: 7211504, 7213101, 7214958) titled "Development of an online Water Accounting dashboard for Volta Basin Authority", 'Water accounting application and capacity building for INMACOM' and "Technical assistance for the use of remote sensing data and water accounting for water resources management in the Zambezi River Basin".

The Cooperation in International Waters in Africa (CIWA) through its *Water Data Revolution* program aims at building regional institutional capacity to demonstrate applications of remote sensing-based water accounting tools to improve management of transboundary water in Africa. The goal is to showcase how continental-scale products can be transformed into a practical and actionable tools for water accounting applications, customized to meet the needs and requirements and to provide valuable insights into water availability, usage, and trends for specific river basin contexts. The process involves developing user-friendly, open-access visualization platforms that enable River Basin Organizations (RBOs) to access and interpret the water resources related data effectively, while offering the possibility to customize access levels according to the distinct needs of various user groups within the RBO. The development of user-friendly dashboards is crucial as it simplifies complex data into visually engaging and easy-to-understand formats. This ensures that stakeholders with varying levels of technical expertise can utilize the information efficiently for decision-making and planning purposes.

The objectives of these projects are to support the Volta Basin Authority (VBA), the Incomati and Maputo Watercourse Commission (INMACOM) in developing WA dashboards tailored to the specific context and needs of the basin, to provide essential data and insights into water availability, usage, and distribution, enabling informed decision-making and policy formulation. In addition, for Zambezi River Basin, the objectives are to generate knowledge to support and enhance an informed policy dialogue about water resources management at transboundary basin scale.

Through this project, we (1) enabled seamless and cost-free generation of water accounting information for the respective RBOs that can be easily updated on a seasonal basis and (2) designed and delivered training and capacity-building programs (VBA and INMACOM), customized to the respective transboundary RBO(s) both virtually and in-person on the use and maintenance of the water accounting dashboard.

The major reflections from the study are the following:

In the **Volta Basin Authority (VBA)**,

- **Importance of Collective Action:** The emphasis on the necessity of collective action in water management was a recurring theme. Stakeholders underscored the critical role of collaboration among various entities, including IWMI, the World Bank, and the Volta Basin Authority, in achieving water security goals.
- **Diverse Skill Levels Among Participants:** The workshop highlighted the varying levels of understanding, skills, and experiences among participants, particularly in the use of remote sensing data and programming tools. This diversity necessitates tailored training and support to ensure all participants can effectively engage with the tools and concepts introduced.
- **Need for Additional Stakeholder Inclusion:** Participants noted the importance of including additional relevant stakeholders in the co-development process. This inclusion will ensure a more comprehensive approach to water management that integrates diverse perspectives and expertise.
- **Focus on Capacity Building:** Capacity building, including training programs and internships, is necessary to increase knowledge transfer and develop local expertise in water resource management.

In the **Incomati and Maputo Watercourse Commission (INMACOM)**,

- **WA+ Dashboard as a tool for water resources communication:** Participants particularly praised the tool’s visualization capabilities and expressed a desire for more interaction to explore its capacities.
- **Longer stakeholder engagements and deliberation:** Participants noted the short period of engagement on the project, felt the training sessions were too short and

would have benefited from longer sessions to be more familiar with the tools and methods.

- **Continuous capacity building:** Continuous capacity building at the local level is urgently needed. This includes training programs and internships to increase knowledge transfer and develop local expertise. Further it was suggested to involve local master's and PhD students in studying the dashboard's applicability at a local scale.

Tools such as the water accounting dashboard can support RBOs and national agencies in managing, planning water resources while communicating water resources related information to relevant stakeholders. The data and information can be used for identifying regional water availability, water use patterns, and the impacts of climate change on available water resources.

1.0 Introduction

About 40% of the global population is facing water scarcity challenges. Climate change, one of the most significant challenges of time, is accelerating catastrophic water events at an unprecedented rate. While the increasing global population is tipping the balance towards high demands and water scarcity, it is essential to understand how much water is available, how much we use, and how much we can conserve and use efficiently. Furthermore, as the agricultural sector represents, on average, 70% of water withdrawals globally, relevant agricultural water management and planning decisions must be based on good quality information and a sound understanding of the local context. However, such information is often unavailable in Africa. Water Accounting serves as a tool for addressing this knowledge gap by providing quantitative estimates of the different components of the water balance, which is critical for understanding and managing water resources.

Water accounting is a vital component of planning procedures for water resource management, particularly under water scarcity conditions and in the face of increasing risks and uncertainties. Water resources strategies and investment planning for effective water resources management (WRM) requires the establishment of suitable frameworks for planning, monitoring, and evaluating water resources within river basins. Water accounting addresses these needs; water accounting is the systematic study of the status of, and trends in, water supply, demand, accessibility, and use, enabling the quantitative assessment of the state of the water resources in a geographic region over a particular period of time. Water accounts are typically used to communicate water resources-related information and the services generated from use in a geographical domain (e.g., a river basin) to users such as policymakers and water authorities, as well as international financing institutions seeking to determine the impact of investments and to ensure environmental and social safeguards are being met. Water accounting is seen as a tool to inform the discussion required with political leadership to begin to establish rational investments in the creation of the food, water, energy, and environmental systems required to sustain current and future populations.

1.1 Why Water Accounting

For transboundary river basins, water accounting offers several additional advantages. A comprehensive and consistent water accounting framework applicable across multiple spatial scales is critical to a) allocating water between competing users, b) understanding the impacts of management decisions, c) setting the limits of sustainable extraction, d) supporting investment decisions in water infrastructure for agricultural and urban development, e) understanding future impacts of climate on water availability and f) the overarching sustainability of the resource,

Moreover, from a basin perspective, water accounting is used as a tool to ensure that available water resources are managed most effectively and equitably and to generate the most “value” for society, understanding synergies (and often trade-offs) land management practices. For example, water interventions upstream affect both the quantity and quality of water reaching downstream and may affect economic benefits derived from water resource development throughout the river basin. When water was plentiful, with a water allocation system and water rights in place, water use changes in one place did not substantially affect other users. However, as water becomes scarce, coupled with the changes in interdependence, basin-level water accounting will provide a basis to understand the consequences of these changes and the need to adjust current water allocations, water management processes, and investment decisions accordingly.

1.2. Water Accounting Plus (WA+)

A water accounting system is implemented using a standardized methodology and nomenclature. The approach developed by the International Water Management Institute[1], "Water Accounting +" (WA+), is one such approach. In contrast to other approaches that rely heavily on national-level hydro-meteorological data and statistics, WA+ is a framework that recognizes the limited availability of these data in many countries and relies instead on remote sensing derived data, hydrological models, and open source global data sets to i) calculate consistent water accounts for a particular location; ii) avoid data discrepancy between adjacent regions/across national borders; iii) provide estimates where local data is insufficient. The information provided through this approach gives a solid understanding of the state of the resource and how competing sectors use water. However, it is to be noted that, to ensure the reliability of the WA+ framework, it is essential to validate remote sensing and model-derived data with ground-based observations wherever possible.

With recent advances in earth observation sensors, it has been demonstrated and widely accepted that accurate measurements of key water balance parameters (e.g. evapotranspiration and precipitation) can be derived from satellite data. Remote sensing offers consistent and continuous (gridded) field-to-basin scale information on hydrological fluxes. Because of the improvements in the technological and computing capabilities, the application and reliability of remote sensing datasets in hydrological studies is constantly increasing and becoming more and more common. Over the past few years, the increasing availability of data from earth observation satellites has dramatically changed our ability to quantify water resources at different scales, as demonstrated by IWMI and its partners through the WA+ approach (Batchelor et al., 2016; www.wateraccounting.org).

The major advantage of a water accounting approach which is based on actual ET measurements, such as WA+, is that water withdrawals and return flows do not need to be

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[1] In collaboration with its partners UNESCO IHE and FAO

measured directly, because the depletion of water (through ET) can be obtained from the satellite measurements. The WA+ approach relies on a range of open access remote sensing datasets, in conjunction with open access GIS data and global hydrological model outputs to calculate basin water balances on a regular basis, and to communicate water resource related information for different land use categories. Consistent water balance parameters and water accounts can be calculated through the framework for a river basin and its sub-basins, avoiding data discrepancies between adjacent regions (or across transboundary river basins), and quantifying indicators related to water use and availability based on measured data where local data is insufficient.

2.0 The Scale Invariant Water Accounting Plus (SIWA+) Approach

Water accounting requires complete accounting for all sources (rainfall, groundwater, surface water, runoff, other climate-resilient sources such as wastewater, recycled, desalination), uses of water (evaporation, transpiration, runoff, recharge, flow to sinks, inter-basin diversions, industrial users, irrigation and environmental uses) and change in storage capacity (including soil moisture and surface and groundwater reserves) as water assets for further accessibility.

The Scale-Invariant Water Accounting Plus (SIWA+) approach is designed to generate water accounts for any boundary, including catchments, counties, countries, or continents.

Built on the conventional WA+ method, SIWA+ allows users to avoid rerunning complex models by clipping data based on user-defined boundaries using a Boundary Data Extractor (BDE). Additionally, it includes a Discharge Extractor (DISE) for managing inflow and outflow data, especially in cases where in-situ data is unavailable. The DISE features sub-modules to manage discharge for various boundaries, from river basins to administrative regions. The SIWA+ also incorporates desalination data extraction (DDE) for regions with desalination plants, and it streamlines the creation of water sheets through the Rapid Optimized Sheet Extractor (ROSE). This approach provides flexibility and scalability, enabling efficient water accounting at various scales.

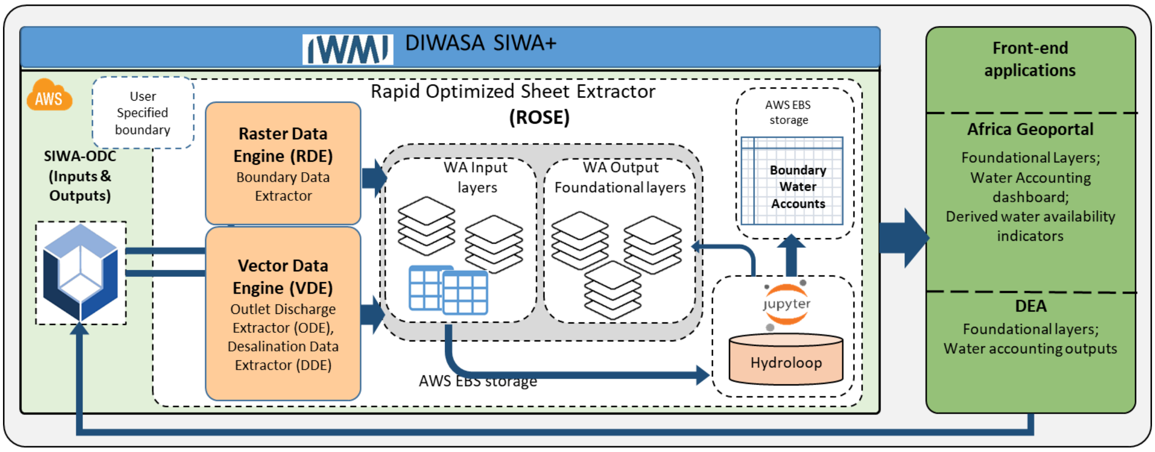

Figure 1. The Scale Invariant Water Accounting Plus (SIWA+) framework. (Velpuri et al., 2024).

3.0 Implementation of the SIWA+ Approach in the Volta, Incomati and Maputo basins

The first step in the implementation of the SIWA+ approach for water accounting assessment involves the collection of remote sensing, geospatial and other data sets. These were acquired from several sources, pre-processed, and reorganized into a consistent format for input into the WA+ framework.

3.1 Summary input data for the Volta, Incomati and Maputo basins

In developing the water accounts for the Volta, Incomati and Maputo basins, a similar set of dynamic and static data are used, providing a standardized approach to monitoring key water resource metrics across regions. Dynamic inputs include data such as precipitation from CHIRPS v2 product for the Volta basin while Incomati and Maputo used precipitation from ARC v2. The selection of the ARC product was based on validation with available station data and subsequent bias correction.

Actual ET, and reference ET, were drawn from SSEBop v5, and GLEAM v3.6a respectively for all basins. Additional data like Leaf Area Index (LAI) and Net Primary Productivity (NPP) are also used for all the basins. Static data sources, including soil moisture, digital elevation, and landcover, were common across basins as well. All datasets cover the period from 2003 to 2021 for each basin. The remote sensing-based actual ET was only available from 2003, and 2021 was the last full year for which data was available when the generated discharge data for the water accounting model was developed. However, with more recent data are now being available, this is easily updated. A comprehensive table of these data sources is available in Annex 3.1.

3.2 Summary input data for the Volta River Basin

The Volta River Basin extends from the Sahel to the Atlantic Ocean across six riparian countries: Burkina Faso, Ghana, Togo, Benin, Mali and Côte d'Ivoire (Williams et al., 2016). It stretches from approximately latitude 14°30'N in Mali to 5°30'N in Ghana and at its widest point, longitude 5°30'W in Burkina Faso to 2°00'E along the Togo-Benin border. Flowing in a north-southwards direction, the total length of the Volta River is about 1,850 km and the drainage area of the basin is approximately 407,850 km2 with parts of Burkina Faso making up about 42%; Ghana, 41%; Togo, 6%; Mali, 4%; Benin, 4%, and Côte d'Ivoire, 3% of the basin (Boubacar et al., 2005). The Volta Basin consists of four main sub-basins: the Black Volta (or Mouhoun, as it is referred to in Burkina Faso), White Volta (Nakambé), Oti (Pendjari), and Lower Volta sub-basins. These subbasins make up 38%, 27%, 18% and 17% respectively of the basin.

The population of the Volta Basin is largely rural and is projected to increase to over 56 million by 2050- more than double what it was in 2010 (Williams et al., 2016). Economic activity is largely reliant on natural resources, particularly water resources, with agriculture, fisheries and livestock rearing being the dominant activities (Williams et al., 2016). Hydropower is an important source of electricity in the basin and major hydropower plants in the basin are the Akosombo (1020 MW), Bui (400 MW) and Kpong (160 MW) dams in Ghana, and the Bagre Dam (16 MW) in Burkina Faso which have historically provided most of the riparian nations' electricity (Ntiamoa-Baidu et al., 2017; Tsikata, 2008).

3.3 Summary input data for the Zambezi River basin

In developing the water accounts for the Zambezi basin, a range of dynamic and static data was utilized to monitor key water resource metrics in the basin. Precipitation data for the Zambezi basin was sourced from the CHIRPS v2 product, validated using available station data, and was then bias-corrected. Actual evapotranspiration (ET) and reference ET were obtained from the SSEBop v5 and GLEAM v3.6a datasets, respectively.

Additional data like Leaf Area Index (LAI) and Net Primary Productivity (NPP) are also used. Static data sources, including soil moisture, digital elevation, and landcover, were also incorporated. The availability of measured discharge and precipitation data for the Zambezi basin provided a basis for extensive validation of the water accounting model. All datasets used for Zambezi basin, cover the period from 2003 to 2023. This is because, remote sensing-based actual ET was only available from 2003, and 2023 was the last full year for which data was available when the generated discharge data for the water accounting model was developed. However, with more recent data are now being available, this is easily updated. A comprehensive table of these data sources is available in Annex 3.1.

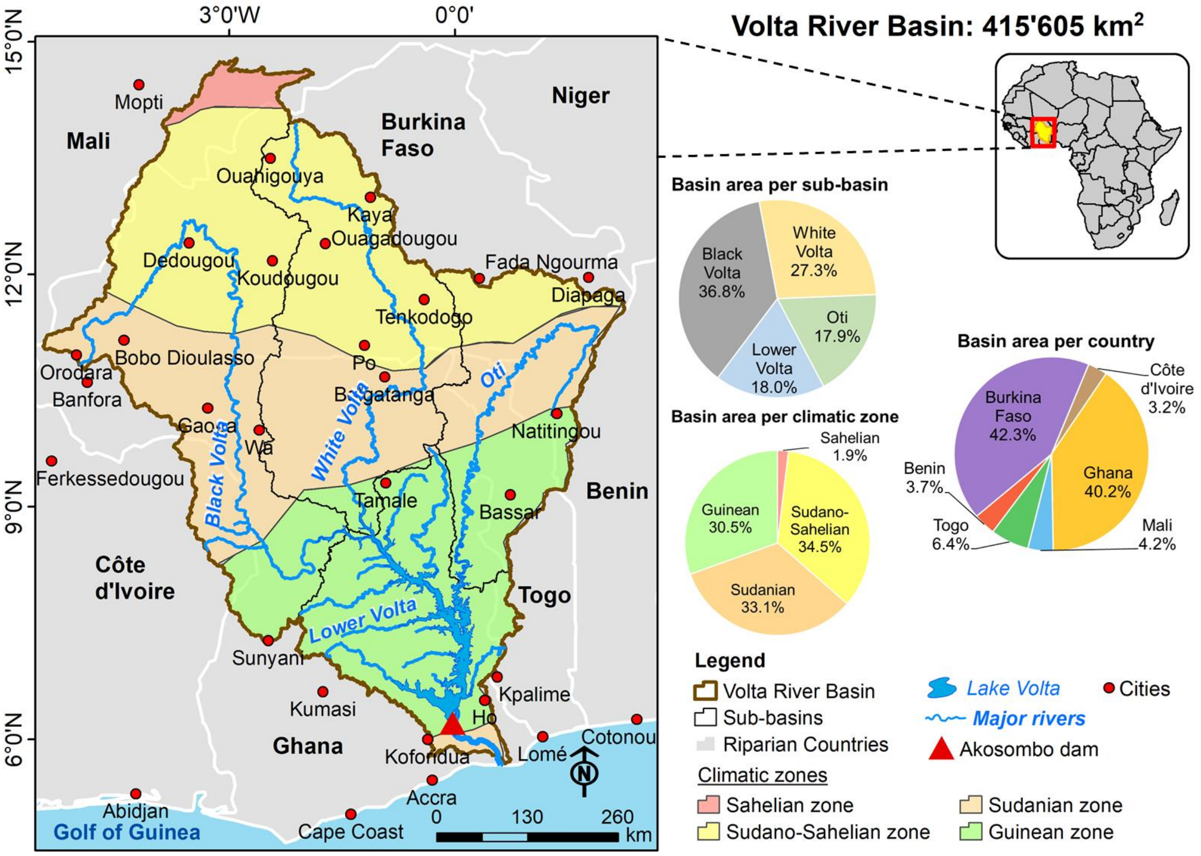

Figure 2. Volta River Basin in West Africa (Dembélé et al., 2023.)

3.4 Running the Water Accounting Plus Model for the Volta Basin

The Volta SIWA+ model was run for the period 2003-2021 with the first couple of years used for "model warm-up". Outputs from the VegET model of (Akpoti et al., 2024) served as input to the pixel-based water balance model. The model was used to generate the water accounts for the basin under current conditions.

3.5 Summary Water Accounting Results for the Volta River basin

A sample WA+ output, the resource base sheet averaged for 2003 to 2021 for Volta River Basin is presented in Figure 3. For this period a number of indicators are calculated: the average annual rainfall over the basin was approximately 410 km3/year (1,000 mm/year), actual ET was 350 km3/year (860 mm/year) while the average annual flow out of the basin was 41 km3/year (1,300 m3/s). Overall, from 2003 to 2021, the basin is recharging surface and groundwater storage at an average rate of 17 km^3/year.

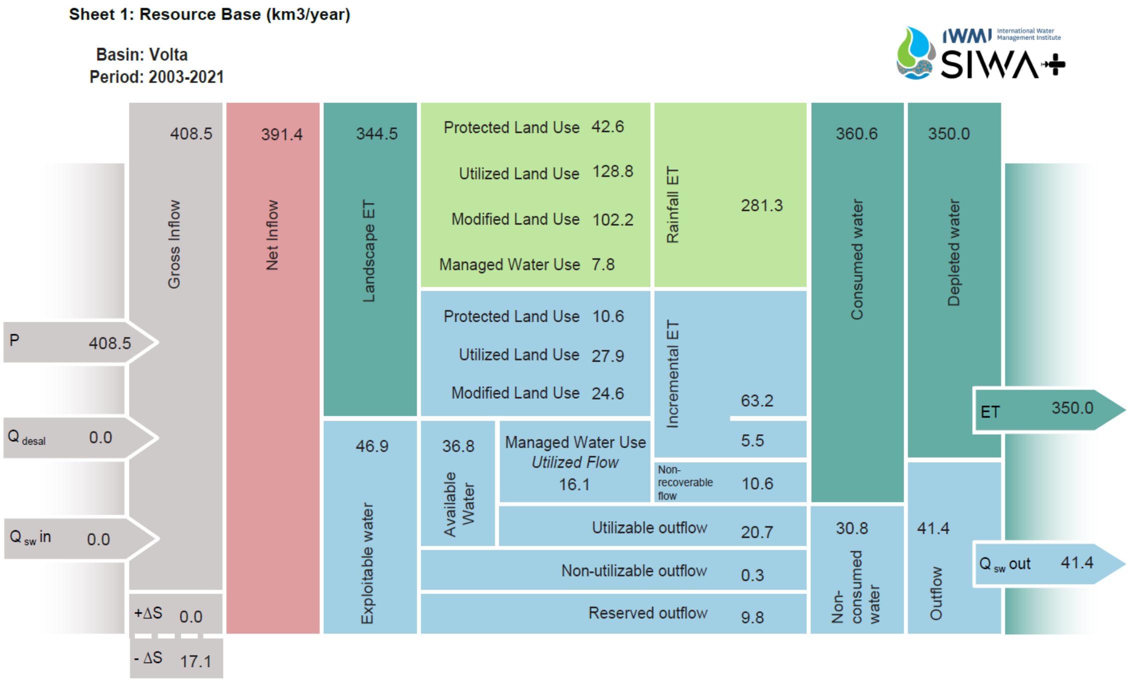

Figure 3. Sample WA output showing resource base sheet of long term WA indicators.

Time series plots of key water balance parameters of the basin from 2003 to 2021 highlight years such as 2004 to 2006 and 2013 to 2016 when there was generally low water availability. Such periods are represented by the constriction and dip in the graphs and vice versa in years such as 2010 and 2019 to 2020 when there was high water availability. In the case of 2010 high flows, this resulted in emergency spilling from the Akosombo Dam.

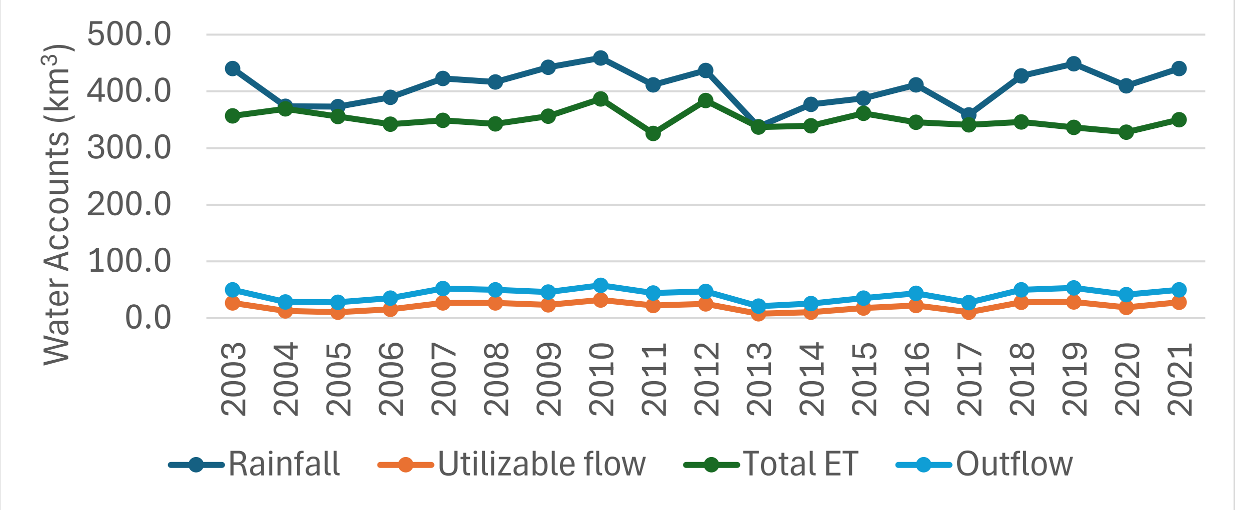

Figure 4: Inter- annual variability of water accounts-Volta basin (2003-2021).

3.6 Implementing the SIWA+ framework under future climate scenarios in the Volta River Basin

The Scale Invariant Water Accounting Plus (WA+) framework was implemented in the Volta River Basin under future climate scenarios following a request from stakeholders. The methodology and data adopted for implementing the WA+ framework under future climate scenarios is briefly described below.

3.7 Data and Methodology

Precipitation and temperature data from climate modelling are the basis for the input data for future scenario WA+ water balance assessment. The primary WA+ input data required for the future climate assessment are projected scenarios for precipitation (P), potential (PET) and actual evapotranspiration (ET). The bias corrected climate data obtained for Socio Economic Pathways: SSP585 consisted of two CMIP6 models: MPI-ESM1-2 and GFDL-ESM4. Projections were analyzed for the time horizon:

2025–2050: Short-term (near future) climate

Daily time series data for precipitation (P), minimum and maximum temperature (Tmin, Tmax), and downward shortwave radiation were downloaded from the NEX-GDDP dataset for both models.

Daily potential evapotranspiration (PET) was calculated using the Modified Hargreaves Equation for daily data [Farmer et al, 2011]:

$$PET_j = 0.0019 \cdot S_0 \cdot (T_{avg} + 21.0584) \cdot (TD_j - 0.0874 \cdot P_j)^{0.6278}$$

Where:

- Tavg: Daily average temperature (°C)
- T Dj: Daily difference between maximum and minimum temperature (°C)
- Pj: Daily precipitation (mm)
- S0: Extraterrestrial solar radiation (mm/day)

The daily PET estimates were aggregated to annual values for further analysis. Current climate data used in baseline modelling (ET and PET from the SSEBop v5[2], GLEAM v4[3] and precipitation from CHIRPS[4] database) were used to derive a relationship between precipitation, ET, and PET under current conditions following the Budyko framework as detailed by Gunkel and Lange (2017):

$$\frac{AET}{P} = 1 + \frac{PET}{P} - \left[1 + \left(\frac{PET}{P}\right)^{\omega}\right]^{\frac{1}{\omega}}$$

Where ω is a dimensionless parameter that reflects basin-specific characteristics. For the Volta River Basin, ω was calibrated to 1.8, consistent with the literature for semi-arid regions.

3.8 Analysis of Projected Climate Scenarios

Figure 5 depicts the monthly mean precipitation trends for the baseline period (2003–2021) and future projections (2025–2050) based on the GFDL-ESM4 and MPI-ESM1-2-HR models. The uni-modal distribution is evident across all scenarios, with a peak in August, reflecting the region's characteristic rainy season. A dip is observed during November–December and January–February, corresponding to the drier periods of the year.

The GFDL-ESM4 model projects a slightly reduced precipitation peak in August compared to the baseline, suggesting a decrease in overall wet season rainfall. Conversely, the MPI-ESM1-2-HR model projects an increased peak rainfall in August, indicating a wetter wet season relative to the baseline. Despite these variations in magnitude, both models maintain similar seasonal patterns, reinforcing the persistence of uni-modal precipitation dynamics in the Volta River Basin.

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[2] Actual ET (ETa) is produced using the operational Simplified Surface Energy Balance (SSEBop) model (USGS - FEWS NET Daily Actual Evapotranspiration (ET))

[3] https://www.gleam.eu/

[4] The Climate Hazards Group, The University of California, Santa Barbara, (https://www.chc.ucsb.edu/data/chirps)

These differences highlight the uncertainty across climate models, with GFDL-ESM4 suggesting a drying trend and MPI-ESM1-2-HR suggesting a more optimistic outlook for wet season rainfall. Such variations underline the importance of ensemble analysis when assessing future climate impacts on water availability in the region.

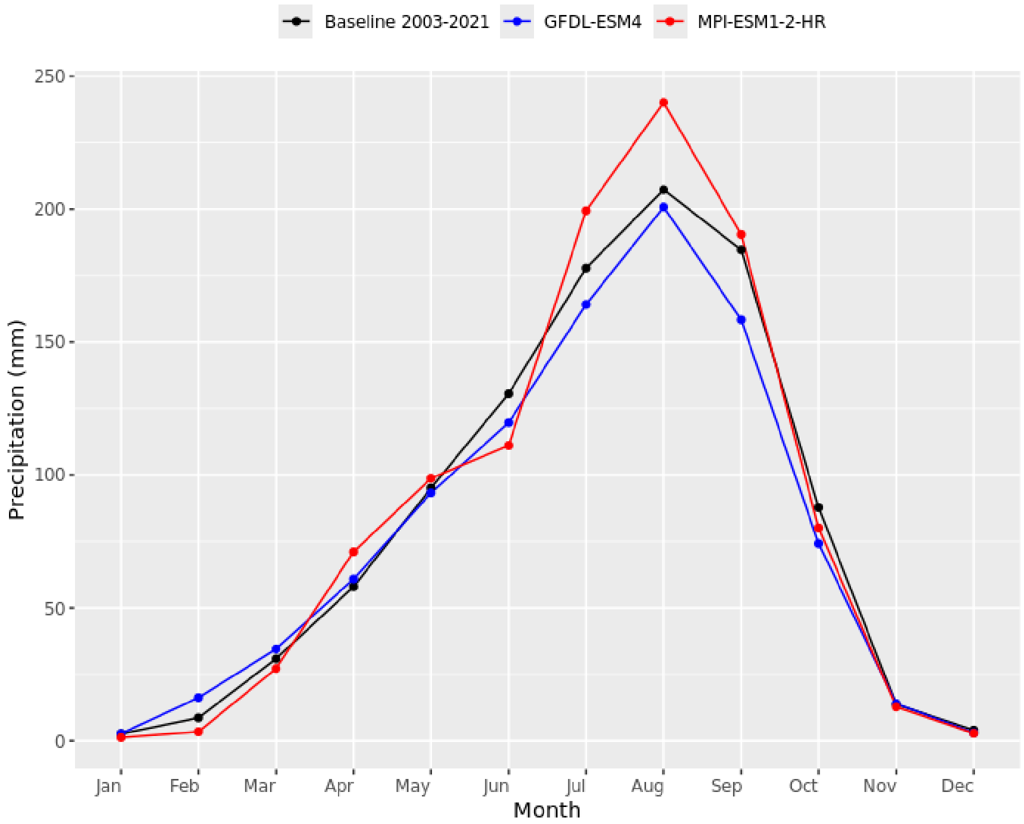

Figure 5.Comparison of monthly mean precipitation between baseline period (2003–2021) for GFDL-ESM4 Model and MPI-ESM1-2-HR Model.

Table 1 provides a comparative analysis of projected seasonal and annual rainfall changes in the Volta Basin for the 2025–2050 period relative to the baseline (2003–2021). The projections were derived from two climate models, GFDL-ESM4 and MPI-ESM1-2-HR, and reveal contrasting rainfall trends across the wet and dry seasons:

GFDL-ESM4 Model:

- **Wet Season:** Rainfall is projected to decrease by 8.47%, reducing wet-season totals from 885.5 mm to 810.5 mm. This suggests a significant drying trend during the primary period of water availability in the region.
- **Dry Season:** Rainfall is expected to increase by 11.69%, rising from 117.5 mm to 131.23 mm. While this increase could alleviate dry-season water stress, the magnitude remains insufficient to offset wet-season declines.

- **Annual Rainfall:** An overall annual decrease of 5.89% is projected, with totals dropping from 1000.7 mm to 941.73 mm. This highlights a net reduction in water availability under this scenario.

MPI-ESM1-2-HR Model:

- **Wet Season:** Rainfall is projected to increase by 16.21%, boosting totals to 1029 mm. This suggests a wetter wet season, which could improve water resource availability during critical agricultural periods.
- **Dry Season:** A marginal increase of 0.43% is anticipated, with dry-season totals rising slightly to 118 mm. This negligible change indicates limited improvement in dry-season water conditions.
- **Annual Rainfall:** An overall annual increase of 3.52% is projected, raising totals to 1035.9 mm. This indicates a more favorable outlook for water availability compared to the GFDL-ESM4 model.

The contrasting projections underscore significant uncertainty in future rainfall patterns, with the GFDL-ESM4 model indicating a drying trend and the MPI-ESM1-2-HR model suggesting increased water availability. These variations highlight potential challenges for water management in the Volta Basin, necessitating adaptive strategies to address seasonal shifts and ensure water security under future climate conditions.

Table 1:Comparison of projected seasonal and annual precipitation totals with baseline for two Models and three time horizons in the Volta Basin.

Period	Baseline (2003-2021)	GFDL-ESM4	MPI-ESM1-2-HR
		2025-2050	2025-2050
Wet season[5] (mm)	885.5	810.5	1029
Dry season[6] (mm)	117.5	131.23	118
Annual (mm)	1000.7	941.73	1035.9
Wet season change (%)		-8.47	16.21
Dry season change (%)		11.69	0.43
Annual change (%)		-5.89	3.52

Table 2 presents a comparison of projected annual precipitation (P), actual evapotranspiration (ET), and potential evapotranspiration (PET) for the Volta Basin under the two climate models (GFDL-ESM4 and MPI-ESM1-2-HR) across three future time horizons

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[5] Wet season is defined as the period May 1 through October 31.

[6] The dry season is defined as the period from November 1 through April 31.

(2025–2030, 2025–2040, and 2025–2050), relative to the baseline period (2003–2021). Key observations include:

Precipitation (P):

- **GFDL-ESM4 Model**: Precipitation is projected to decrease across all time horizons, with annual totals declining from the baseline value of 1000.7 mm to 941.7 mm by 2025–2050. This reduction aligns with the model's overall drying trend for the region.
- **MPI-ESM1-2-HR Model**: In contrast, this model projects an increase in precipitation, with annual totals rising to 1035.9 mm by 2025–2050. This highlights a wetter outlook under this scenario.

Actual Evapotranspiration (ET):

- **GFDL-ESM4 Model**: ET is projected to decline slightly by 2025–2050 (893.0 mm), suggesting that reduced water availability limits actual evaporation and transpiration processes despite the potential for higher ET.
- **MPI-ESM1-2-HR Model**: ET is projected to increase slightly, reaching 983.6 mm by 2025–2050, indicating better water availability and higher evaporation rates in this scenario.

Potential Evapotranspiration (PET):

For both models, PET is consistently projected to increase significantly compared to the baseline (922.3 mm). By 2025–2050, PET rises to 2245.1 mm for the GFDL-ESM4 model and 2144.0 mm for the MPI-ESM1-2-HR model. This increase reflects rising temperatures and solar radiation under future climate conditions, leading to greater atmospheric demand for moisture.

Water Balance: The decline in ET for the GFDL-ESM4 model indicates a transition towards a more water-limited and arid environment, driven by reduced precipitation. Despite higher PET, the lack of sufficient rainfall constrains ET, reflecting water scarcity.

Water Availability: The MPI-ESM1-2-HR model presents a more favorable scenario, with increased precipitation supporting higher ET and partially offsetting the rising PET demand.

Uncertainty: The divergence in projections between the two models underscores the inherent uncertainty in climate change impacts, necessitating robust and adaptive water resource management strategies for the Volta Basin. These findings emphasize the need to prepare for both wetter and drier future scenarios.

Table 2: Comparison of projected annual precipitation, ET and PET totals with baseline for two Models and three-time horizons in the Volta Basin.

Period	**GFDL-ESM4**	**MPI-ESM1-2-HR**

	Baseline[7]	2025-2030	2025-2040	2025-2050	2025-2030	2025-2040	2025-2050
ET (mm)	858.7	891.0	914.8	893.0	953.9	950.0	983.6
PET (mm)	922.3	2249.1	2244.0	2245.1	2192.5	2194.9	2144.0
P (mm)	1000.7	932.3	970.7	941.7	996.2	996.1	1035.9

3.9 Running WA+ Under Climate change scenarios

Water accounts for the Volta Basin were generated using the ensemble means from the GFDL-ESM4 and MPI-ESM1-2-HR models, covering the period 2025–2050. The inputs for the WA+ framework included data for projected precipitation and derived parameters, such as actual evapotranspiration (ET) and potential evapotranspiration (PET), alongside other inputs consistent with the current conditions. This approach assumes that variables such as land cover and land use remain unchanged in the future.

3.10 Summary Water Accounting Results for the Volta River basin under climate change scenarios

The WA+ framework utilizes the "Resource Base" thematic sheet to provide a comprehensive overview of water resource status in the basin. This sheet summarizes inflows on the left, water usage in the middle, and outflows on the right, as shown in Figure 6. The following can be summarized from the figure:

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[7] Baseline period for AET, PET, and P is 2003-2021

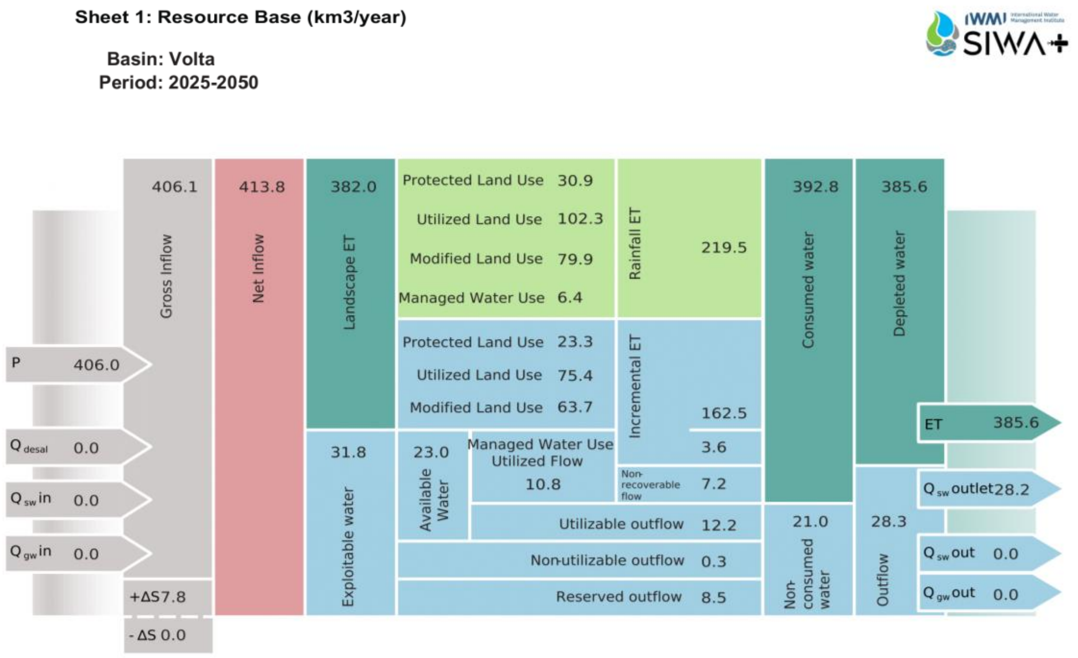


Figure 6: Water accounts for the Volta basin for the period 2025-2050 for the ensemble mean of GFDL-ESM4 Model and MPI-ESM1-2-HR Model.

- **Inflows:** The gross inflow into the basin predominantly precipitation is expected to be 406.0 km³/year. Storage changes, including variations in surface water, groundwater, and soil moisture, will contribute an additional 7.8 km³/year, resulting in a net inflow of 413.8 km³/year.
- **Landscape AET:** A significant portion of the net inflow (382.0 km³/year) will be consumed across the landscape as actual evapotranspiration (AET). This includes:
    - **Rainfall AET** (Green Water): 219.5 km³/year, directly derived from rainfall.
    - **Incremental AET** (Blue Water): 162.5 km³/year, sourced from irrigation and other water uses.
- **Exploitable Water**: The remaining 31.8 km³/year represents the portion of net inflow not lost to evaporation. This exploitable water is available for withdrawals or downstream use but is subject to constraints:
- **Reserved Outflow**: 8.5 km³/year is set aside for environmental flow requirements and downstream commitments.
- **Available Water**: After accounting for reserved and non-utilizable outflows, 23.0 km³/year remains for potential use.
- **Utilized Flow**: Of the available water, 10.8 km³/year is consumed, while 7.2 km³/year is lost as non-recoverable flow due to degradation. The remaining 12.2 km³/year constitutes utilizable outflows for future allocation.

- **Consumed Water**: A total of 392.8 km³/year is consumed within the basin, comprising Rainfall AET, Incremental AET, and non-recoverable flows.
- **Non-Consumed Water**: 21.0 km³/year is water that exits the basin without being utilized, which includes utilizable, non-utilizable, and reserved outflows.
- **Depleted Water**: Evapotranspiration accounts for 385.6 km³/year of permanently lost water.
- **Surface Outflow (Qswoutlet)**: Surface outflows from the basin will average 28.2 km³/year.

Time series plots of key water balance parameters of the basin under climate scenario from 2025 to 2050 highlights years such as 2030, 2034-2035, 2039 and 2041 as high precipitation and total ET periods. These correspond to generally higher water availability periods also. On the other hand, periods of low water availability correspond to years such as 2033,2038 and 2040 represented by the constriction and dip in the graphs.

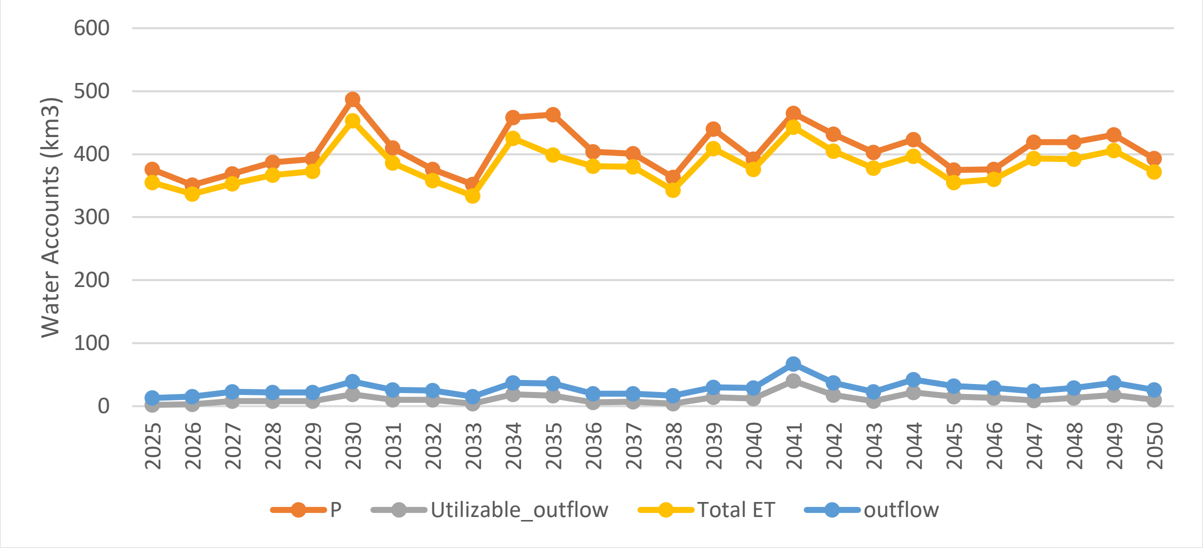
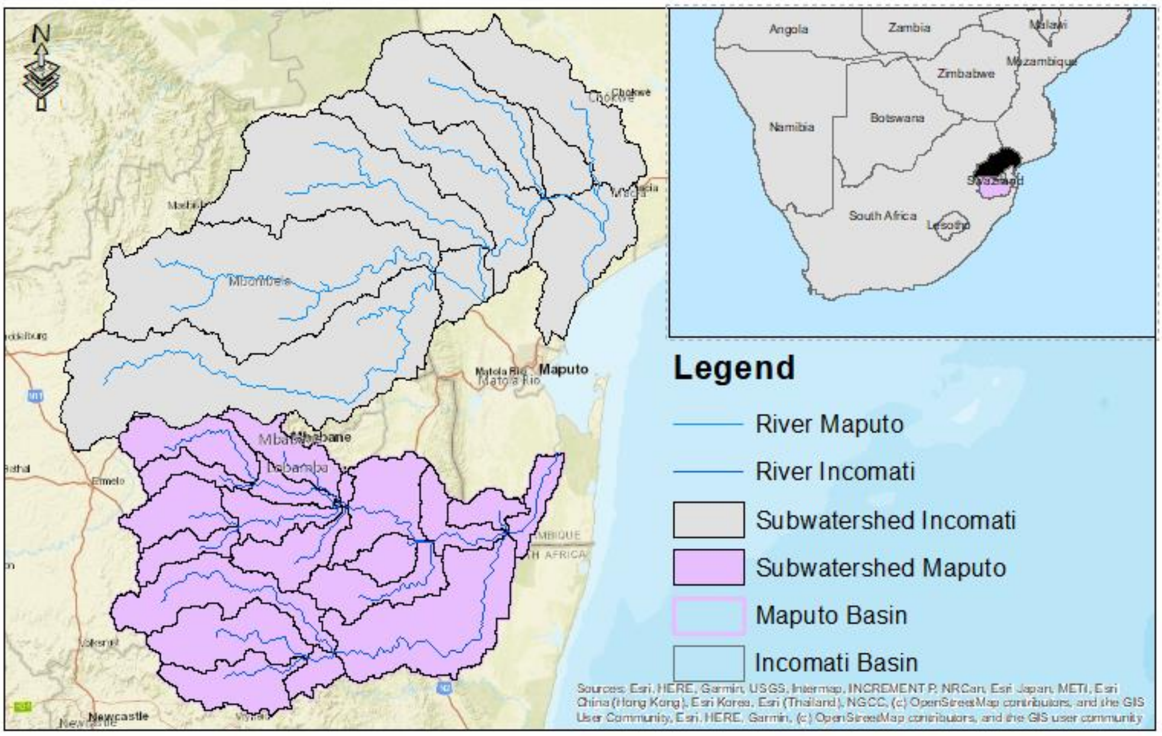


Figure 7: Inter- annual variability of water accounts in the Volta basin under climate change scenarios (2025-2050).

3.11 The Incomati and Maputo River Basins

The Incomati River Basin located in Eastern Southern Africa is a transboundary basin shared by 3 countries - Eswatini, Mozambique and South Africa - that are dependent on their natural resources for their socio-economic development. The basin covers approximately 49,000 km^2 and is home to nearly 2.3 million people. Water plays a vital role in the livelihoods of people in the basin and in the promotion of economic growth. Agriculture, which employs the majority of the basin's inhabitants and generates most of the basin's economic output, is heavily reliant on available water resources specialty though irrigation services. Irrigation developed for cash crops such as sugarcane has catalyzed economic growth in the region, with a sugarcane processing industry growing in tandem and providing livelihood opportunities. Water is also essential for hydropower generation, as two hydropower dams have been constructed on the river system to meet growing energy needs. In addition, the basin contains southern portions of the environmentally important Kruger National Park – one of Africa's largest game reserves and home to several endangered species. Other uses include forest plantations and for domestic and industrial use.



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 8. Incomati and Maputo River Basins in southern Africa.

The Maputo River Basin is located south of the Incomati Basin to the north, and is also a transboundary basin shared by Eswatini, Mozambique and South Africa. The land area of the basin is about 30 000 km^2. The major water users in the Maputo Basin are irrigation, afforestation and transfers from the Upper Usuthu catchment to the Vaal and Olifants catchments. Irrigated agriculture and commercial forestry the largest water users in the basin, have expanded by about 1.4% and 0.6% per annum on average over the past 25 years, and now cover about 55 000ha and 367 000ha respectively.

3.12 Running the Water Accounting Plus Model for the Incomati and Maputo River Basins

The Incomati and Maputo SIWA+ model runs were conducted for the period 2003-2021 with the first couple of years used for “model warm-up”. Outputs from the VegET model of (Akpoti et al., 2024) served as input to the pixel-based water balance model. The model was used to generate the water accounts for each basin under current conditions 2001-2021.

3.13 Summary WA Results for the Incomati Basin

The Incomati River Basin resource base sheet averaged for 2003 to 2021 and is presented in Figure 6. For this period a number of indicators are calculated: the average annual rainfall over the basin was approximately 25.7 km^3/year, actual ET was 35.1 km^3/year, while the average annual flow out of the basin was 3.6 km^3/year. Overall, from 2003 to 2021, the basin is recharging surface and groundwater storage at an average rate of 8.6 km^3/year.

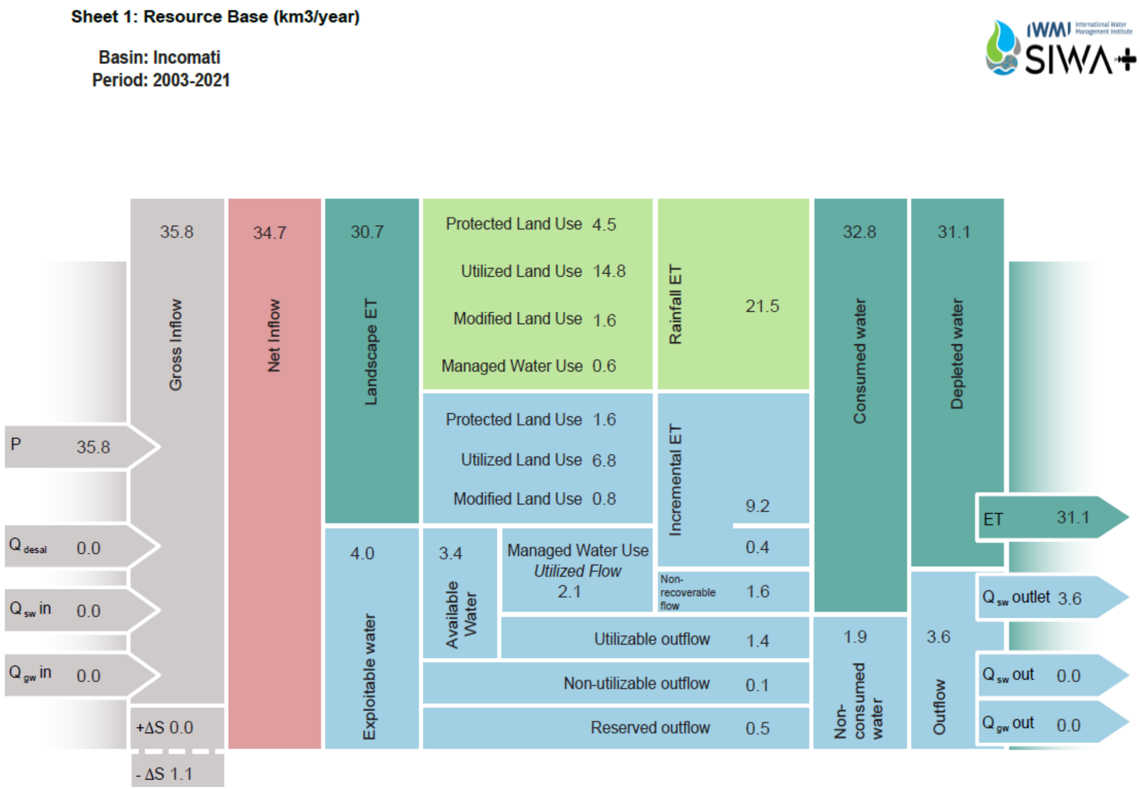


Figure 9:. Sample WA output showing resource base sheet of long term (2003-2021) WA indicators for Incomati Basin

The Incomati Basin has shown significant inter-annual variability in its water accounts over the years (Figure 7). Notably, 2003, 2005, and 2015 were marked by severe droughts, which impacted water availability and stressed resources within the basin. Conversely, 2013 and 2021 experienced wet conditions, providing higher water availability and contributing to different hydrological patterns. This variability highlights the basin's fluctuating water dynamics, influenced by changing climatic conditions across different years.

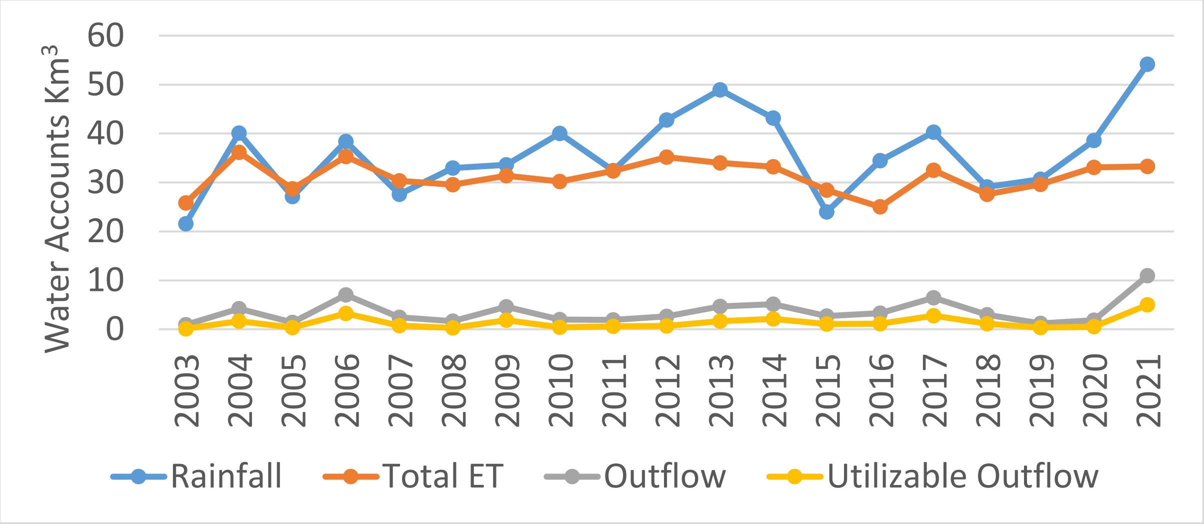


Figure 10:Inter- annual variability of water accounts-Incomati basin (2003-2021).

3.14 Summary WA Results for the Maputo Basin

The resource base sheet for the Maputo River Basin, averaged from 2003 to 2021, is presented in Figure 8. During this period, several indicators were calculated: the average annual rainfall over the basin was approximately 25.8 km³/year, actual ET was 20.6 km³/year, and the average annual flow out of the basin was 1.5 km³/year. Overall, from 2003 to 2021, the basin recharged surface and groundwater storage at an average rate of 3.8 km³/year.

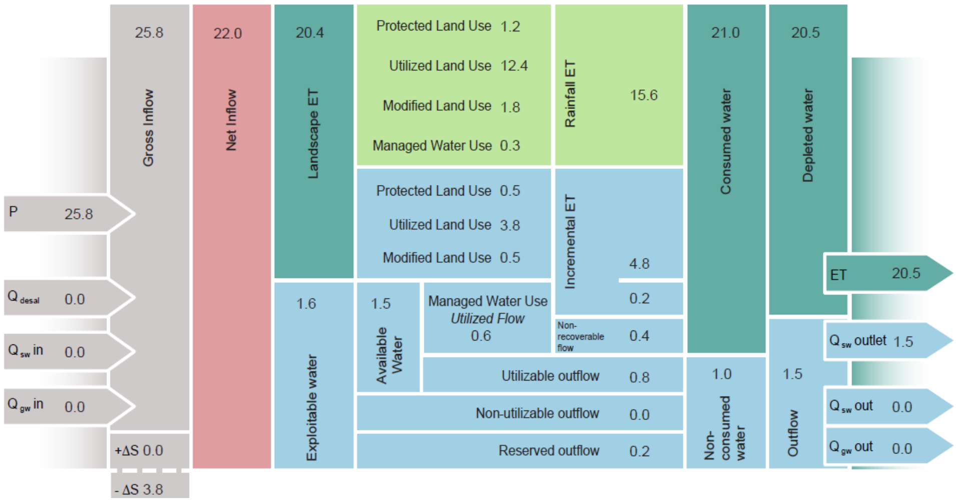


Figure 11:Sample WA output showing resource base sheet of long term (2003-2021) WA indicators for Maputo Basin.

The Maputo Basin has showed significant inter-annual variability in its water accounts over the years (Figure 12). Severe droughts in 2003, 2015, and 2018 significantly impacted water availability, with reduced rainfall and low utilizable outflows observed. On the other hand, wet conditions in 2009, 2013, and 2021 resulted in higher rainfall and increased water availability, particularly in 2021, which marked the highest outflow and utilizable outflow recorded in the basin during the period.

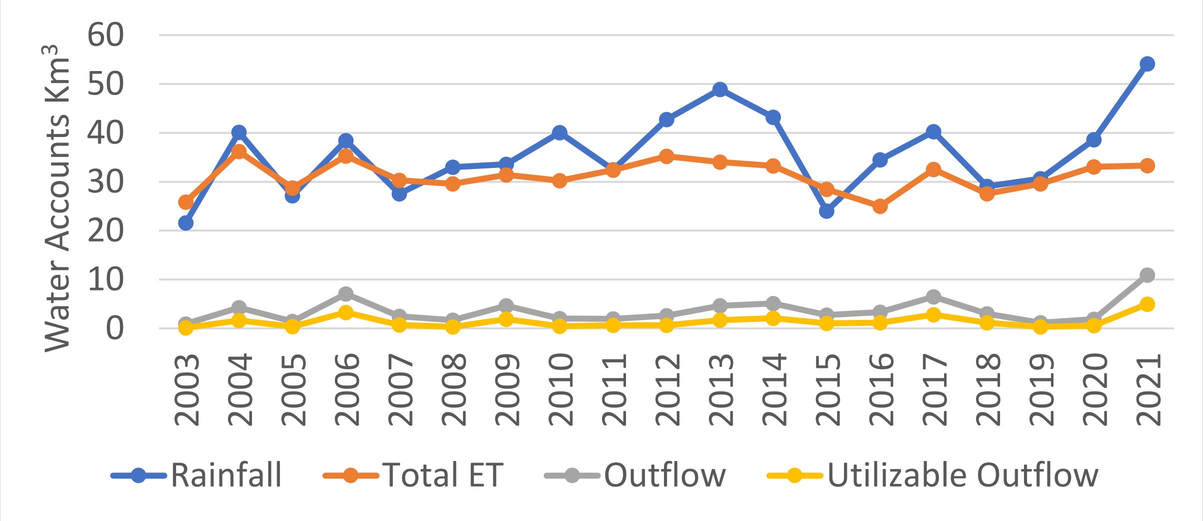


Figure 12:Inter- annual variability of water accounts-Maputo basin (2003-2021).

3.15 The Zambezi River Basin

The Zambezi River Basin located in Southern Africa is a transboundary basin shared by eight countries – Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe - that are dependent on their natural resources for their socio-economic development. The basin lies within the fourth-largest basin in Africa, covering 1.397 million Km^2 and is home to nearly 30 million people. Water plays a vital role in the livelihoods of people in the basin and in the promotion of economic growth, providing important environmental goods and services to the region and is essential to regional food security and hydropower production. Agriculture is the main economic activity in the basin and major water user, with an estimated 65-70% of the population living in the basin engaged in both, mall-scale rain-fed agriculture and commercial agriculture supported by irrigation. Hydropower is also a critical activity in the basin and an important water user, with the Lake Kariba and Lake Cahora Bassa the main reservoirs used for this purpose and holding a significant share of 24 % of the hydroelectricity generation contribution to the Southern African Power Pool.[8]

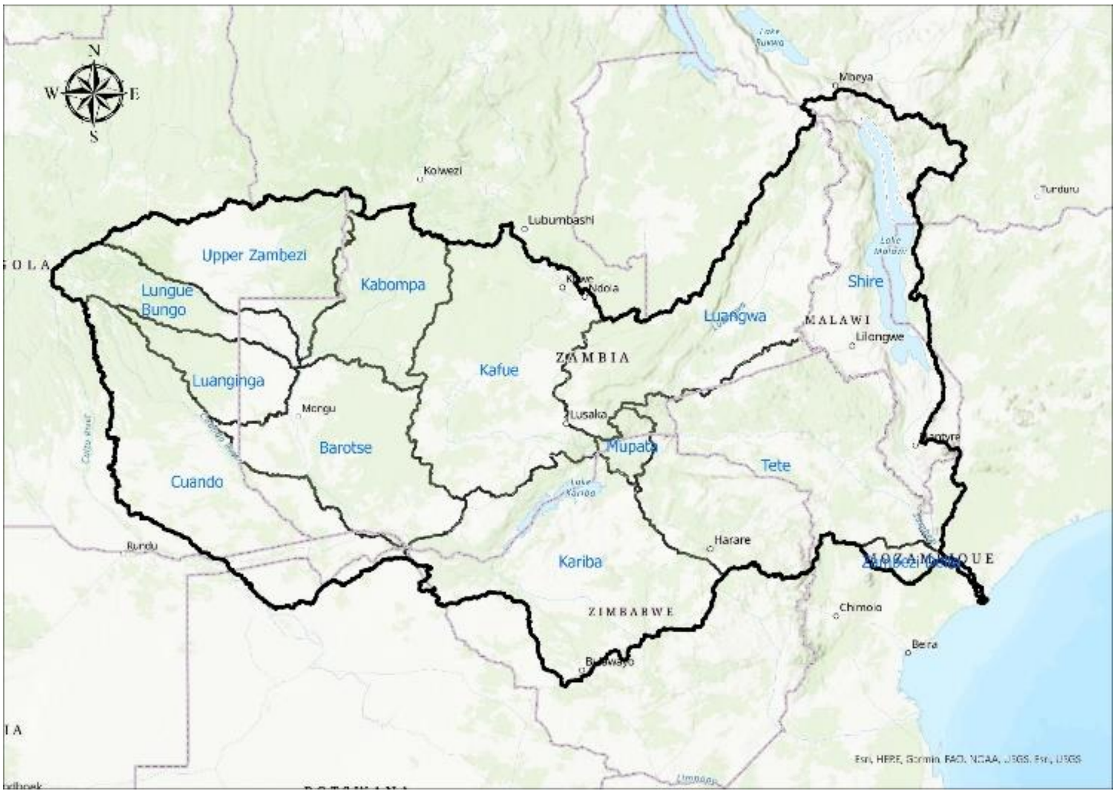


Figure 13. The Zambezi River Basin and its subbasins.

3.16 Summary WA Results for the Zambezi River Basin

The resource base sheet for the Zambezi River Basin, averaged from 2003 to 2023, is presented in Figure 14. During this period, several indicators were calculated: the average annual rainfall over the basin was approximately 1280.5 km³/year, actual ET was 1095.6 km³/year, and the average annual flow out of the basin was 69.0 km³/year. Overall, from 2003 to 2023, the basin recharged surface and groundwater storage at an average rate of 115.9 km³/year.

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[8] https://www.sciencedirect.com/science/article/pii/S2405844023104439#:~:text=The%20Zambezi%20River%20network%20cuts,Pool%20(SAPP)%5B46%5D.

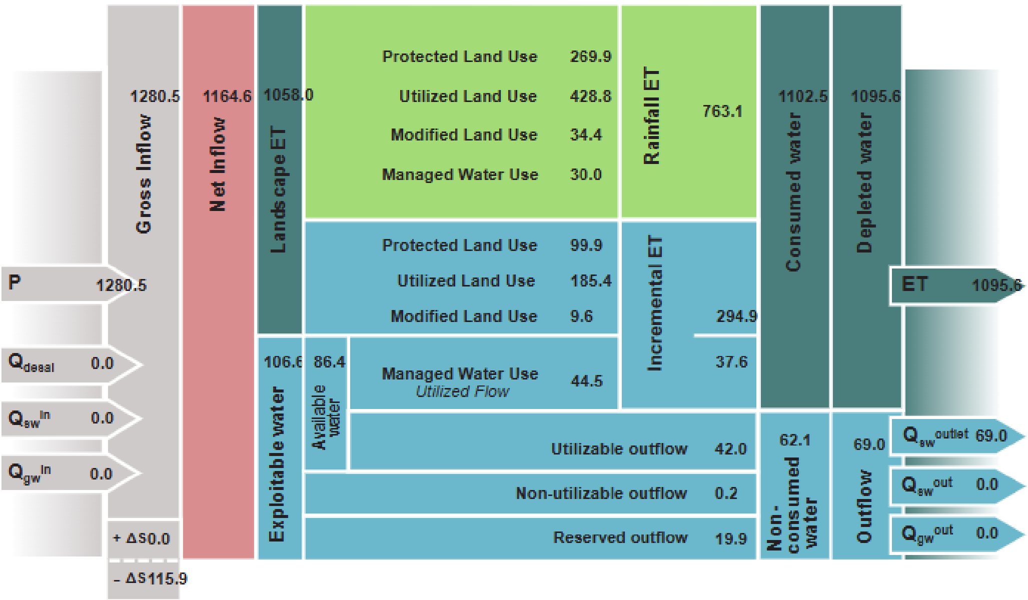


Figure 14: Sample WA output showing resource base sheet of long term (2003-2023) WA indicators for Zambezi Basin.

The Zambezi Basin had significant inter-annual variability in its water accounts over the years (Figure 15). Severe droughts in 2005, 2016, and 2023 significantly affected water availability, with reduced rainfall and extremely low utilizable outflows recorded, particularly in 2023, which marked the lowest utilizable outflow of the entire period. On the other hand, wet conditions in 2007, 2010, and 2022 were characterized by high rainfall and increased water availability. Highest rainfall was recorded in 2022, with an accompanying rise in actual evapotranspiration, despite a sharp decline in surface water outflows.

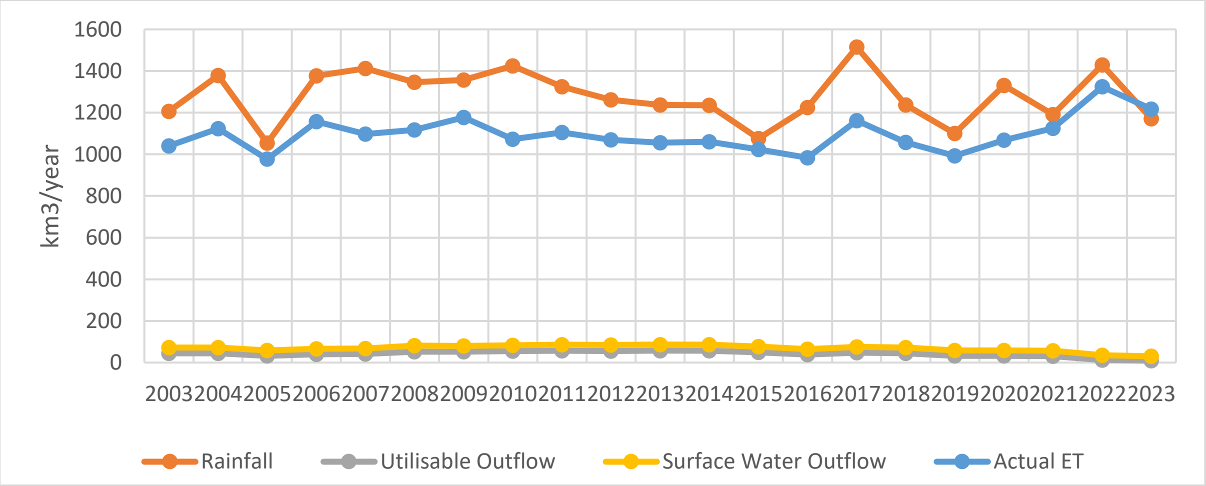


Figure 15: Inter- annual variability of water accounts-Zambezi basin (2003-2023).

4.0 Visualization of Water Accounting outputs

The dissemination of Water Accounting Plus (WA+) outputs is designed to engage stakeholders effectively and facilitate informed decision-making. WA+ outputs are presented in several formats to ensure accessibility and usability across diverse user groups:

- **Reports:** Comprehensive reports are developed to detail the findings of water accounting assessments, including in-depth analyses, data summaries, resource base sheets and technical insights. These reports provide a complete overview of water resources, usage patterns, and recommendations, supporting long-term planning and policy development.
- **Briefs:** Targeted briefs offer concise, high-level summaries of key water accounting results and insights. These are tailored for quick reference and are ideal for stakeholders who need actionable information in an accessible format, such as policymakers and management teams.
- **Interactive Dashboards:** Interactive dashboards serve as a dynamic tool for stakeholder engagement, allowing users to visualize water balance, availability, and usage indicators. This can be in form of story maps and web apps. These dashboards provide an interactive interface, enabling users to explore and analyze data specific to their interests, such as basin-level water insights, land usage, and monthly water balance changes. This format promotes active participation and supports adaptive water resource management by making data readily accessible and actionable for all stakeholders.

Various technical and non-technical water availability and scarcity indicators are produced using the SIWA+ framework. While SIWA+ can produce easy-to-understand sheets for summarizing water accounting indicators (resource base sheet, water use sheet etc.), they are difficult to share across multiple stakeholders in the region. Hence, IWMI has designed online water accounting dashboards as a new tool to disseminate and share water accounting information across multiple stakeholders. This is particularly useful for transboundary river basins where multiple countries share the water resources, and data sharing and transparency are significant bottlenecks for integrated water resources management.

4.1 Tableau Public Architecture

The Tableau-based Water Accounting Dashboard is built to support visualizing, analyzing, and managing water resources in various river basins. Tableau was chosen for the Water Accounting Dashboard because of its powerful data visualization capabilities, user-friendly interface, and ability to handle complex datasets effectively. Compared to other tools, Tableau allows for dynamic interaction, real-time data updates, and customization to support stakeholders in visualizing, analyzing, and managing water resources across various basins. The dashboard offers key insights into water balance, water availability, water indicators, and climate impact, aiding stakeholders in informed decision-making and sustainable resource management. It is made up of the following structure:

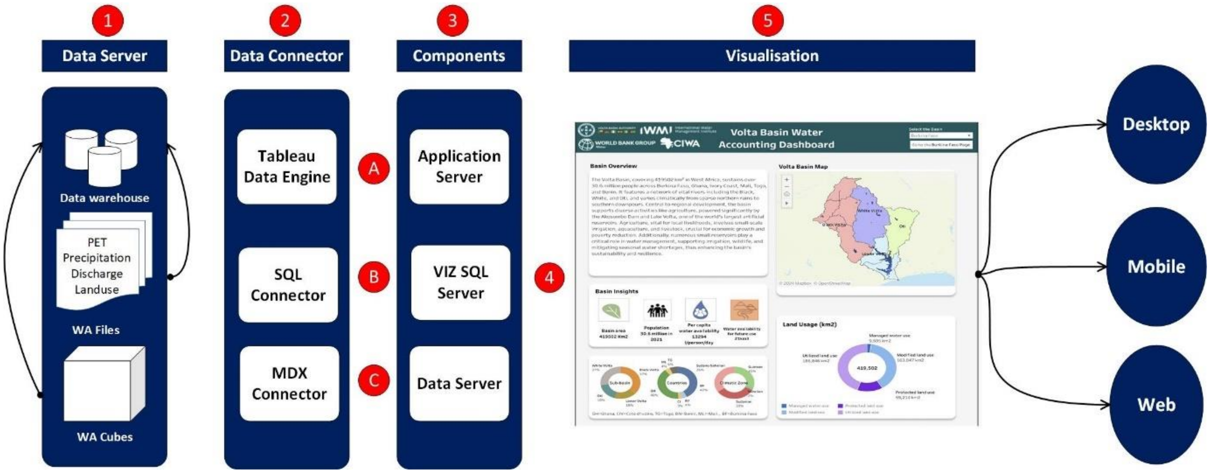


Figure 16 A: Tableau Architecture implemented for VBA

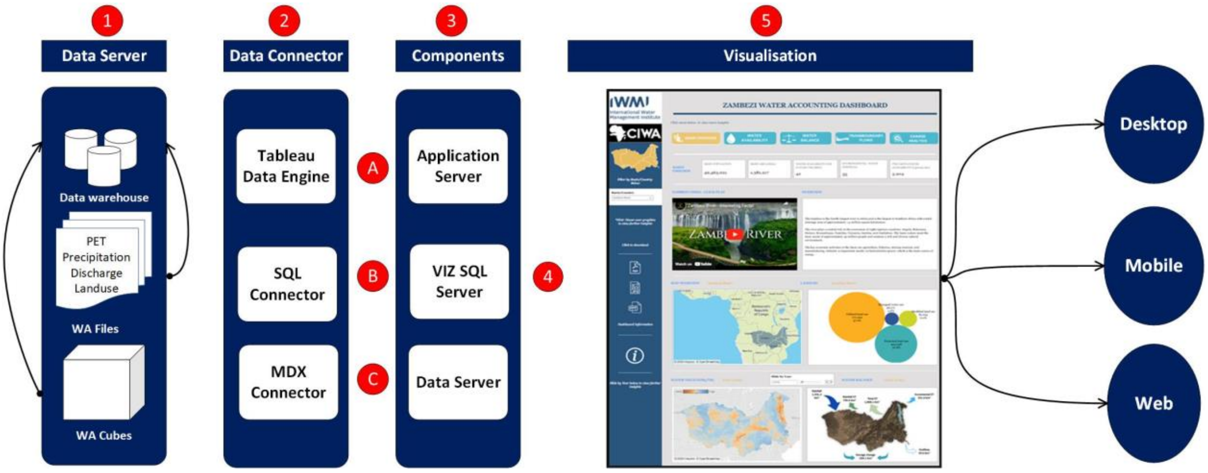


Figure 16 B. Tableau Architecture implemented in the Zambezi River basin.

1. **Software Used:**

- Tableau Desktop Public Edition: The Water Accounting dashboard is built on Tableau Public Edition, designed to work with multiple data sources and provide rich visualizations.

2. **Data Sources:**

- Hydrological models: Data for basin characteristics, water flows, and storage.
- Remote sensing data: Information on land use and rainfall.
- Population data: For calculating water availability per capita.
- Climate projections: Forecasts on future rainfall and its impact.

3. **Visualization Components:**

    - Maps: Show spatial patterns of rainfall and water availability.
    - Sankey Diagrams: Depict water flows within the basin, illustrating water balance.
    - Area Graphs: Display time-series trends in key indicators like rainfall, evapotranspiration (ET), and water availability.
    - Interactive Elements: Dropdown menus, filters, and clickable maps allowing dynamic exploration of data.

4. **Technical Specifications:**

- Operating Systems: Windows 10 or later, macOS Mojave or later.
- Processor: Intel Core i5 or AMD Ryzen 5 or higher.
- Memory: 8GB RAM recommended.
- Graphics: 1GB VRAM recommended.

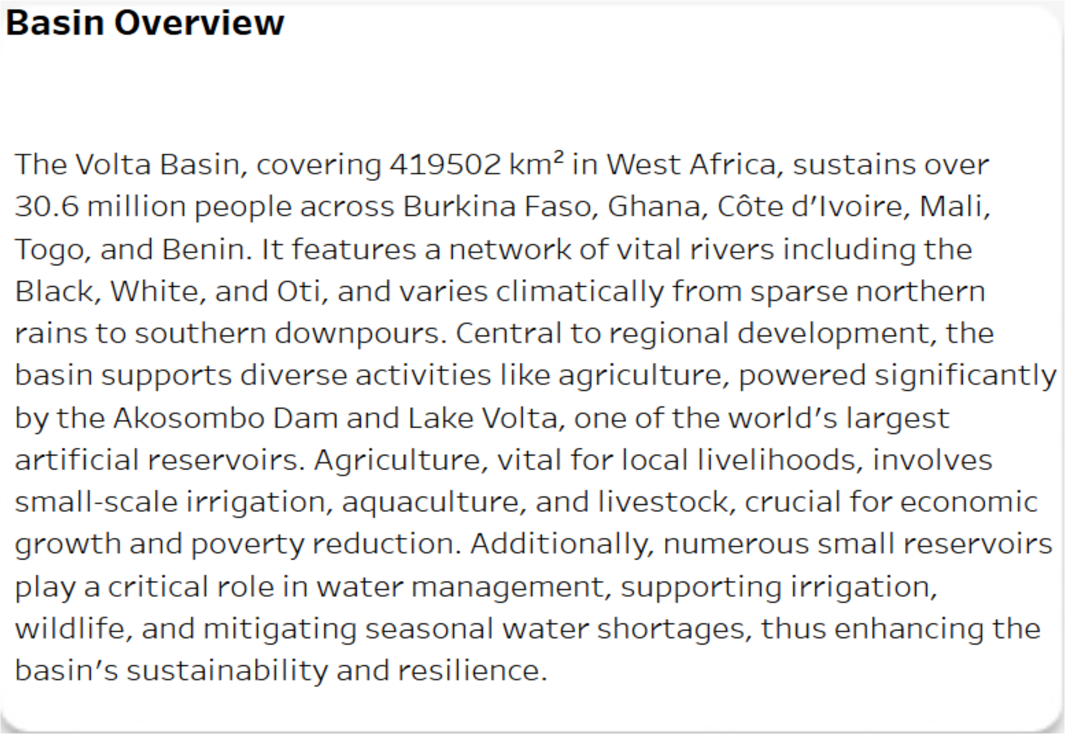
4.2 Developing Tableau based WA Dashboard for the RBOs (VBA, INMACOM, ZAMBEZI):

The Water Accounting (WA) Dashboards are a web-based tools designed to provide detailed, multi-year water accounts for the basins water resources. They offer insights into inflows, outflows, water usage patterns, and availability to support sustainable water resource management. Built using Tableau, the dashboard facilitates the visualization of complex water data, making it accessible to a range of stakeholders, including policymakers, scientists, and the general public.

Dashboard Key Features:

1. Basin Overview

The landing page of the dashboard provides the basin overview information. Several key baseline statistics on the river basin are provided on this page. The description of each section is provided here.

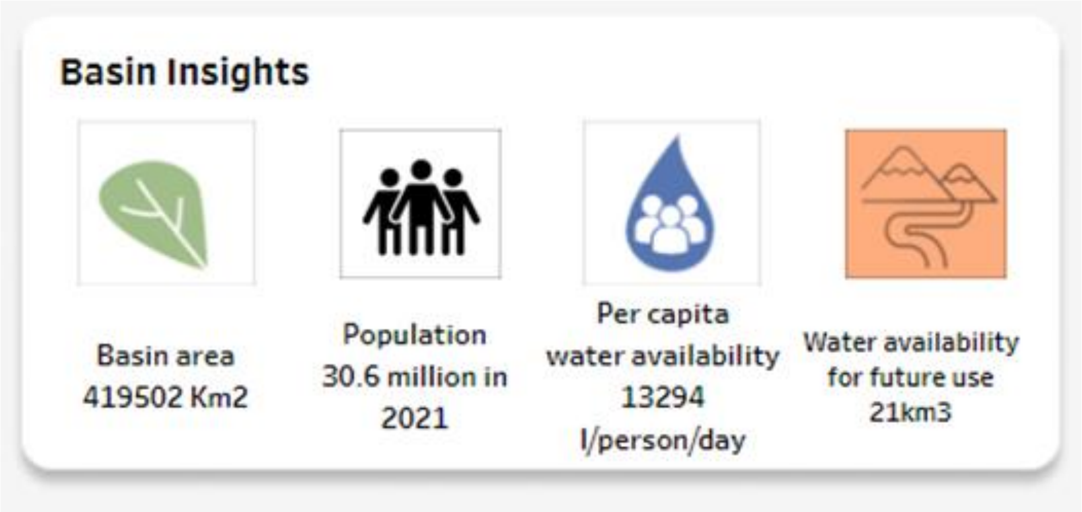


Basin Overview

The Volta Basin, covering 419502 km² in West Africa, sustains over 30.6 million people across Burkina Faso, Ghana, Côte d'Ivoire, Mali, Togo, and Benin. It features a network of vital rivers including the Black, White, and Oti, and varies climatically from sparse northern rains to southern downpours. Central to regional development, the basin supports diverse activities like agriculture, powered significantly by the Akosombo Dam and Lake Volta, one of the world's largest artificial reservoirs. Agriculture, vital for local livelihoods, involves small-scale irrigation, aquaculture, and livestock, crucial for economic growth and poverty reduction. Additionally, numerous small reservoirs play a critical role in water management, supporting irrigation, wildlife, and mitigating seasonal water shortages, thus enhancing the basin's sustainability and resilience.

Figure 17: The description of the basin provided on the basin overview page

- **Basin Description:** A brief synopsis of the dashboard and an account of the basin's hydrology, with a focus on hydrologic challenges.
- **Basin Insights:** Central section displaying basin insights like area, population, per-capita water availability, environmental water stress, and future water availability.



Basin Insights

Basin area
419502 Km2

Population
30.6 million in
2021

Per capita
water availability
13294
l/person/day

Water availability
for future use
21km3

Figure 18: The basic information on basin insights

- **Basin Map:** An interactive map allows users to zoom in/out, reset to full basin extent, and use additional features via a triangle icon.
- **Land Usage**: A double pie chart shows land use distribution:
  - *Utilized land:* Natural landscapes used without resource modification.
  - *Managed water:* Highly managed agricultural areas (e.g., irrigation).
  - *Modified land:* Modified landscapes for rainfed crops.
  - *Protected land:* Areas classified as protected (e.g., national parks).
  - The inner pie chart further details land use within these categories.
- Year Selection: Allows users to toggle between years, comparing water balance and yield changes over time.

2. Water Balance:

The water balance figure shows modeled estimates of key water balance terms. Each figure is specific to the year selected on the year selection tab. It includes annual precipitation received by the basin, total evapotranspiration (ET), and its two sources: Blue ET from blue water sources (e.g., surface water bodies and groundwater) and Rainfall ET, or Green ET, from soil moisture replenished by rainfall. The figure also provides information on basin outflow and changes in basin storage due to groundwater abstraction or recharge.

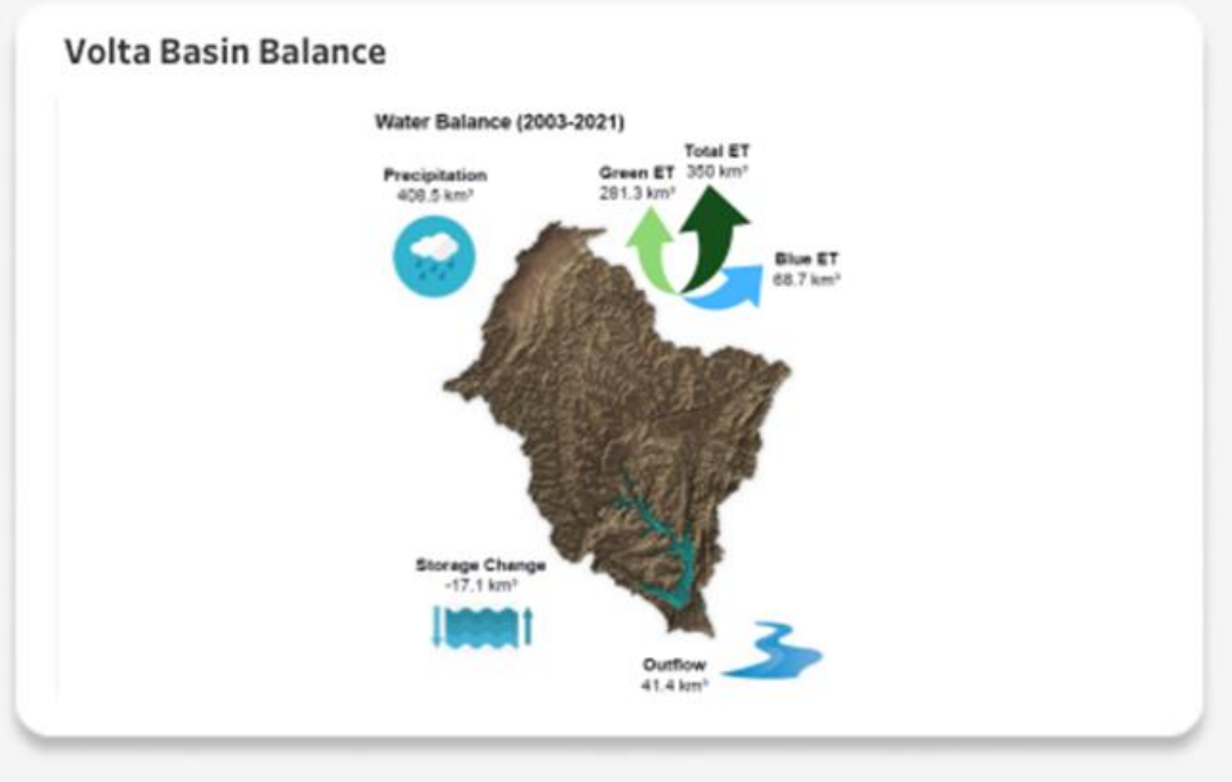


Figure 19: The water balance tab

3. Water Yield:

The map shows the water yield obtained from the water accounting analysis. The water yield is defined as water that is available after meeting landscape water requirement (landscape ET). This is the amount of water that can be exploitable for human needs. The map shows water yield for administrative regions within the basin. Some regions shows negative values, which indicate that at annual time scales there is not water available. Other regions show positive values which indicate that at annual time scale, water availability for human needs is not a problem. Such information is important to understand spatial variability of water availability within the basin. The blue areas are also called water towers of the basin are the regions that provide most water to the river and where future activities such as irrigation development or canals for diverting water can be constructed.

4. Water Availability

Information on water availability in a river basin is crucial for understanding various aspects of human, environmental, and economic well-being. Through this dashboard, water availability in a river basin is summarized using indicators of water availability for a) humans b) environment c) agriculture and d) other uses:

- **Water Availability Per Capita (m^3 per capita):** This indicator shows the amount of freshwater available for each person in a region, assessing a region's ability to meet population, economic, and environmental needs. This metric is presented on monthly and annual timescales, with annual values displayed in horizontal bar plots and monthly averages in vertical bar plots.
- **Water Availability for Further Use (MCM):** Highlights the volume of water remaining for further development after meeting all basin demands, such as natural evapotranspiration, rainfed agriculture, and domestic and industrial needs. This measure indicates the potential for future development projects.
- **Managed Evapotranspiration Fraction:** This fraction shows the part of ET that can be managed by adjusting land use, cultivation, and water withdrawals to support effective water conservation strategies.
- **Agricultural Evapotranspiration Fraction:** Represents the portion of ET from agriculture, focusing on water consumption in farming and supporting sustainable water management.
- **Irrigated Evapotranspiration Fraction:** Reflects the share of agricultural ET from irrigated agriculture, assessing water use specifically for irrigated crop production.
- **Basin Closure (%):** Calculates the proportion of water utilized within the basin relative to total available water. Higher values (closer to 100%) indicate near or complete usage of water resources in the basin, while lower values indicate additional water availability.
- **Climate Impact:** This tab analyzes the potential impact of climate change on rainfall. Three water drop containers represent different rainfall volume scenarios (8 km3/yr, 7 km3/yr, and 6 km3/yr) compared to the baseline. Four additional area graphs illustrate trends in ET, rainfall, outflow, and water availability (MCM) for the period 2000-2045 under these scenarios. Assess future water security challenges and inform adaptation strategies.

More information about the dashboard can be found on Annex 3.3.

5. Spatial Variation of WA Indicators

The spatial variation of WA indicator tab on the dashboard presents the key indicator parameters variables in Rainfall, ET, Water yield and its temporal change. A total of five parameters are presented on the dashboard – Rainfall, Blue ET, Rainfall ET, Total ET and water yield. The units are km3/year. The spatial variation of the basin's water accounts is presented as monthly maps. The maps display the monthly spatial variation of rainfall, Total evapotranspiration (ET), Rainfall(P), Blue ET, Green ET and water yield by selecting relevant parameters.

- **Rainfall ET:** Rainfall ET refers to crop or vegetation evapotranspiration (ET) comes from the water consumed by the vegetation from the root zone soil moisture and soil evaporation from the unsaturated soil surface.
- **Blue ET:** Blue ET comes from the water that is stored in the rivers, streams, surface-water bodies and groundwater resources.
- **Water Yield**: Water yield defined as difference between P and ET(P-ET)

6. Additional features on the dashboard:

There are several additional features available on the dashboard. A brief description and purpose of each of the icons located on the lower right corner are presented here.

- **Contact:** The contact icon is located on the lower right corner of the dashboard, and it would provide email information on whom to contact in case you have any questions on the dashboard.
- **About**: The about icon provides more info on the project.
- **Printing options**: The dashboard can be printed or saved using three options. The current view of the dashboard can be saved to the local computer in three different formats – PDF, JPG or PPT. Please use appropriate icon as per your need.

The RBOs Water Accounting dashboards can be accessed using the following links:

1. Volta basin
2. Incomati
3. Maputo

4. Zambezi

5.0 Summary of Capacity Building Workshops

5.1 VBA Co-Design Workshop

From May 7-10, 2024, IWMI in collaboration with the World Bank and the Volta Basin Authority conducted four days training for partners in Accra, Ghana on the Water Accounting dashboard developed for the VBA. In addition to the launch of the Water Accounting dashboard, within the framework of the Memorandum of Understanding between IWMI and the VBA, IWMI leveraged the workshop to engage VBA in discussions about the wealth of data and innovative tools developed under the 'Digital Innovations for Water Secure Africa' (DIWASA) initiative. DIWASA offers a suite of data products, tools, and methodologies that could be instrumental for VBA, presenting a unique opportunity for leverage cutting-edge technologies and methodologies. By tapping DIWASA's products, the VBA can enhance its management of water resources in the basin, thereby ensuring sustainable and equitable use for all basin countries.

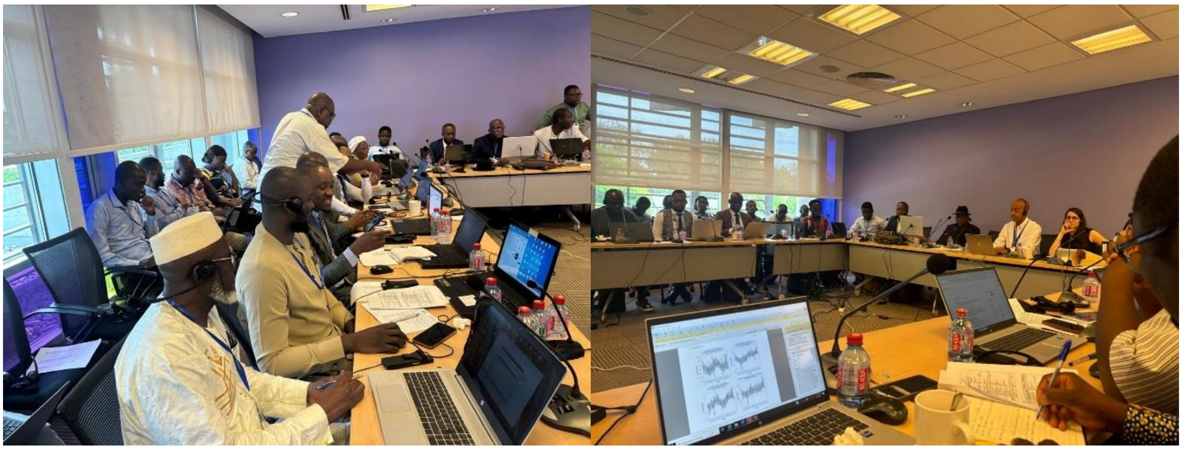


Figure 13. Participants during Day 1 of Joint Workshop on Developing Water Accounting Dashboard for the Volta Basin

The training materials were prepared, and conducted by representatives from IWMI, as well as several key note presentations by representatives from the World Bank and IWMI. The workshop aimed to provide participants with practical, hands-on training in water accounting, guiding them through the entire process from accessing satellite data to running the Water

Accounting (WA+) model and interpreting the results. The workshop activities included a series of sessions aimed at improving participants' understanding of water accounting and the use of the newly developed Water Accounting Dashboard for the Volta Basin. Over the four-day period, the workshop included:

1. Presentations:

These covered the background of the DIWASA project, fundamentals of water accounting, global water accounting experiences, and specific challenges within the Volta Basin.

2. Interactive Sessions:

Participants engaged in discussions on improving water management policies and integrating the Water Accounting Dashboard into the VBA’s strategy. These sessions focused on addressing challenges and refining dashboard functionalities based on feedback.

3. Hands-On Training:

Participants received practical training on using water accounting tools, downloading satellite data, and running the WA+ model. They explored the dashboard’s capabilities in visualizing water balances and accounting for water usage.

4. Stakeholder Engagement:

Participants co-designed use cases for applying the DIWASA tools to address specific water security challenges, identifying potential applications in their regions.

5.1.1 Dashboard interface, functionality and technical specifications: detailed walkthrough, Basic knowledge of Tableau

The Water Accounting Dashboard for the Volta Basin was officially unveiled. Participants were shown how to use it for assessing basin-wide water availability, water usage patterns, and climate impacts.

Figure 21. Participants during Day 2 of Joint Workshop on Developing Water Accounting Dashboard for the Volta Basin

5.1.2 Feedback on dashboard prototype

Key recommendations made by the groups for inclusion in the dashboard:

- **Seasonal time & scale reporting:** Implement features to generate reports that provide insights into water dynamics over different seasons and temporal scales.
- **Climate change integration:** Integrate considerations for climate change impacts into the dashboard to enhance resilience in water resource management practices.
- **Water quality monitoring:** Incorporate modules for monitoring water quality parameters to assess environmental health and human well-being accurately.
- **Water consumption/use tracking:** Include functionalities for tracking water consumption and usage across various sectors to support informed decision-making regarding resource allocation.
- **Short-term forecasting:** Develop capabilities for short-term forecasting of water-related variables to enable proactive responses to dynamic challenges.
- **Utilization of WA+ output:** Explore the use of WA+ output as input for the Volta Alarm system to enhance predictive capabilities and enable timely interventions in response to emerging water risks.

5.1.3 Dashboard integration to VBA website

Following the workshop, the dashboard was duly integrated into the VBA website where users are required to sign up to an account in order to access the dashboard.

5.1.4 Workshop reflections and conclusion

The 4-day workshop included a series of presentations, group discussions, exercises, group activities, and hands-on activities on running the water accounting model. Feedback from participants indicated improved of water accounting fundamentals. It can be concluded that the workshop successfully met its objectives of facilitating learning, sharing experiences, developing and designing the interactive dashboard with key stakeholders. Key reflections from the workshop and consultation process are summarized as follows:

- **Importance of Collective Action:** The emphasis on the necessity of collective action in water management was a recurring theme. Stakeholders underscored the critical role of collaboration among various entities, including IWMI, the World Bank, and the Volta Basin Authority, in achieving water security goals.
- **Diverse Skill Levels Among Participants:** The workshop highlighted the varying levels of understanding, skills, and experiences among participants, particularly in the use of remote sensing data and programming tools. This diversity necessitates tailored training and support to ensure all participants can effectively engage with the tools and concepts introduced.
- **Need for Additional Stakeholder Inclusion:** Participants noted the importance of including additional relevant stakeholders in the co-development process. This inclusion will ensure a more comprehensive approach to water management that integrates diverse perspectives and expertise.
- **Need for Additional Stakeholders:** Participants noted the importance of including additional relevant stakeholders in the co-creation process. This inclusion will ensure a more comprehensive approach to water management that integrates diverse perspectives and expertise.
- **Focus on Capacity Building:** Continuous capacity building, including training programs and internships, is necessary to increase knowledge transfer and develop local expertise in water resource management.

5.2 INMACOM Co-Design Workshop

The Incomati and Maputo Watercourse Commission (INMACOM) in collaboration with the International Water Management Institute (IWMI) and the World Bank, has developed an interactive Water Accounting Dashboard for the Incomati and Maputo river basins. This tool is developed to enhance stakeholder engagement and promote effective collaboration on water resources by providing clear and concise summaries of key water accounts for these basins, which are experiencing competition for water across various sectors. This dashboard offers evidence based information on the current state of water resources, which plays a vital role in making informed water management decisions. Following the development of a prototype of the dashboard, an online workshop was held on the 17th of October 2024 and an in-person workshop held on Friday, November 22, 2024 in Mbombela, South Africa. The online workshop aimed at bringing together key stakeholders to co-design key dashboard features, their functionality and to collect feedback from stakeholders for its finalization. While the in person workshop brought together stakeholders to launch the dashboard and to provide necessary training of stakeholders on its use and maintenance. The following is the summary proceedings of the workshops.

Online Learning Session

The first day introduced participants to water accounting approaches and tools. Following welcome remarks from representatives from IWMI, INMACOM and World Bank, sessions focused on:

Water Accounting Assessments:

Participants were provided with an insightful overview of water accounting procedures and their application in the Incomati Basin. The session began with a definition of water accounting, emphasizing its significance and clarifying its distinction from water balance concepts. A brief history of water accounting was presented, followed by an introduction to the Water Accounting Plus (WA+) framework, which incorporates remote sensing as a core element. Attendees were guided through the WA+ framework, with explanations on its inputs, outputs, and the critical questions it can address, such as quantifying and reporting the status of water resources in a basin and evaluating the potential impacts of planned interventions. The SIWA+ framework was also discussed, highlighting its role in comprehensive water management.

HydroInformatics and New Technologies:

Participants were introduced to innovative work on transforming hydroinformatics by reimagining data, analytics, and knowledge for INMACOM. The session highlighted challenges due to varying perspectives in hydrology and underscored the importance of technology in creating a unified view. Transboundary water challenges were discussed, classified into issues around information, institutions, and investments. A new wave of technology was introduced, categorized into “disrupting” data, production, and stakeholder value chains, encouraging the adoption of advanced tools like online analysis-ready data services, open data APIs, and cloud analytics to enhance water management.

The presentation covered emerging technologies, including artificial intelligence (AI), outlining both its benefits and risks and stressing its responsible use in water management. Specific AI tools available for water resource management were introduced, with participants encouraged to explore them. The World Bank’s "Livable Planet Observatory" was presented as an initiative to integrate diverse data sources and improve accessibility. Lastly, the concept of "e-packaging" was explained as a method for effectively disseminating and visualizing complex data results.

Prototype Dashboard Unveiling:

The dashboard prototype for Water Accounting was showcased, highlighting its functionality in visualizing water balance and usage indicators for the Incomati and Maputo basins. An interactive demonstration of the dashboard was provided, showing its user-friendly operation. Key indicators within the dashboard were then detailed, covering features such as basin overview, basin insights, land usage, interactive basin maps, water availability, water balance, monthly water balance, and change analysis. The basin overview feature was described as offering baseline information on the current state of water resources in the Incomati River Basin, enabling users to quickly grasp essential water metrics. The workshop concluded with remarks and outlined next steps, focusing on the collaborative design and feedback process.

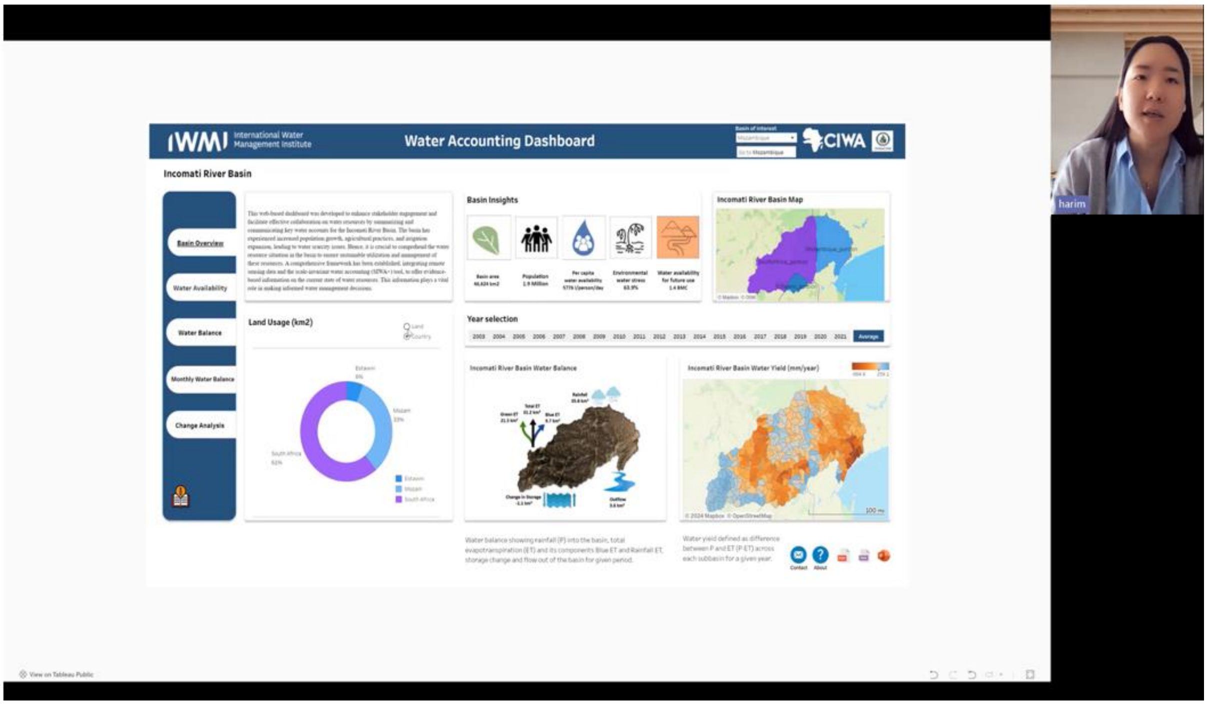


Figure 2214: Water Accounting Dashboard unveiling by Harim, the dashboard developer during the Online Learning session of Joint Workshop on capacity building of the use of remote sensing data and water accounting for Incomati and Maputo Watercourse Commission (INMACOM).

In person practice Session

The in-person workshop held on Friday, November 22, 2024 in Mbombela, South Africa brought together 14 participants from 5 organizations across 3 countries, including the Incomati and Maputo Watercourse Commission (INMACOM), the department of Water and Sanitation South Africa, Joint River Basin Authority and Incomati-Usuthu Catchment Management Agency.

Workshop Organization

The workshop followed a structured format, incorporating various elements to ensure comprehensive engagement and participation, including presentations, introduction to visualization tools, Interactive Sessions, group discussions and hands-on training**.** The training materials were prepared, and conducted by Dr. Mansoor Leh, Researcher and Dr Kirubel Gebreyesus, Researcher.

Introduction Session

The workshop began with welcome remarks delivered by Mr. Buyani Fakudze from INMACOM, who extended greetings to all participants and facilitated introductions around the room. It was acknowledged that participants from Mozambique were unable to attend due to current on-going security issues. However, the collective purpose of the meeting was emphasized: the development of the Water Accounting tool for INMACOM to support informed decision-making. Mr Buyani highlighted the importance of having robust tools, such as the Water Accounting Dashboard to enhance water resource management and mitigate potential conflicts. The Executive Secretary of INMACOM Mr. Edward Mswane expressed gratitude to the attendees for their participation and encouraged them to remain focused throughout the workshop. Dr. Mansoor Leh welcomed participants on behalf of IWMI. He noted that although the colleagues from the World Bank were unable to attend due to conflicting schedules, they sent their heartfelt apologies and wished all participants a successful deliberation.

Overview of Technical Sessions

The workshop was structured into two sessions, each designed to maximize engagement and learning. The morning session focused on the technical aspects, providing hands-on training and in-depth exploration of the Water Accounting scripts, generation of output data for the water accounting dashboard. The afternoon session shifted towards discussions on the dashboard, fostering collaboration among participants through open dialogue, group discussions, and feedback sessions. This ensured a balanced approach, combining technical expertise with stakeholder insights and recommendations.

The first session introduced participants to the key aspects of the water accounting assessment for the Incomati basin. An overview of the SIWA+ framework was provided, focusing on its reliance on remote sensing-based products as key inputs.

Figure 23: Participants during the first session of the Water Accounting training.

The session provided participants with an in-depth understanding of SIWA+ input data requirements, including the importance and need for bias-correction of remote sensing data with observed datasets where possible, and the significance of discharge data within the framework. Participants also learned about how the VegET hydrological model was used for simulating river discharge for continental Africa as well as how it is was validated using in-situ based river discharge mostly from the GRDC website. The validation of the eight remote sensing (RS) rainfall products used in the Incomati basin and their performance was explained, leading to the conclusion of ARC and RFE as the best-performing products, capturing both wet and dry rainfall years.

WA Visualizations: IWMI Geoportal, Dashboards

The morning session concluded with an introduction to visualization of WA output data led by Dr. Mansoor. Illustrations of visualization of WA+ results included IWMI Geoportal (https://iwmi.africageoportal.com/) which provides insights at various scales (river basin, country, and regional levels) of various water accounting assessments undertaken by IWMI. Other forms avenues of WA output dissemination including the dashboards, DEA Africa portal were also highlighted.

Key Questions and comments during the morning session

- Following the presentations, a number participants were interested to know whether groundwater was incorporated into the Water Accounting framework. It was acknowledged that groundwater is one of the limitations of the current model. It is not fully accounted for, as the model does not include lateral flow. However, efforts are being made to address this by integrating SWAT-gflow framework in the model for the future.
- Participants were also interested in comparing the performance of the model with other studies conducted in the basin.
- The participants noted that the visualizations of the WA+ outputs were a significant strength of the framework, they are great and serve as excellent tools for communication.
- For the Incomati Basin, there is a need for a finer resolution simulation because previous studies have shown that coarse resolution rainfall data does not capture the peak rainfall accurately, leading to incorrect results compared to measurements taken on the ground.

Figure 24: Participants and presenters working through the running of the WA+ model.

5.2.1 Dashboard interface, functionality and technical specifications: detailed walkthrough, Basic knowledge of Tableau

The session on the dashboard interface, functionality, and technical specifications was led by Harim, the dashboard developer who presented online. She provided participants with a detailed walkthrough of the Incomati and Maputo basin Water Accounting dashboard, demonstrating its features and interactivity. Participants were guided through key functionalities, including how to view the country portions of the basin water accounts, view basin overview statistics, and access various water accounting indicators across different years. Key visual tools such as pie charts, heat maps, and their utility in understanding water resource dynamics illustrated. The interactive Sankey diagram and its role in illustrating water accounts within the basins was illustrated.

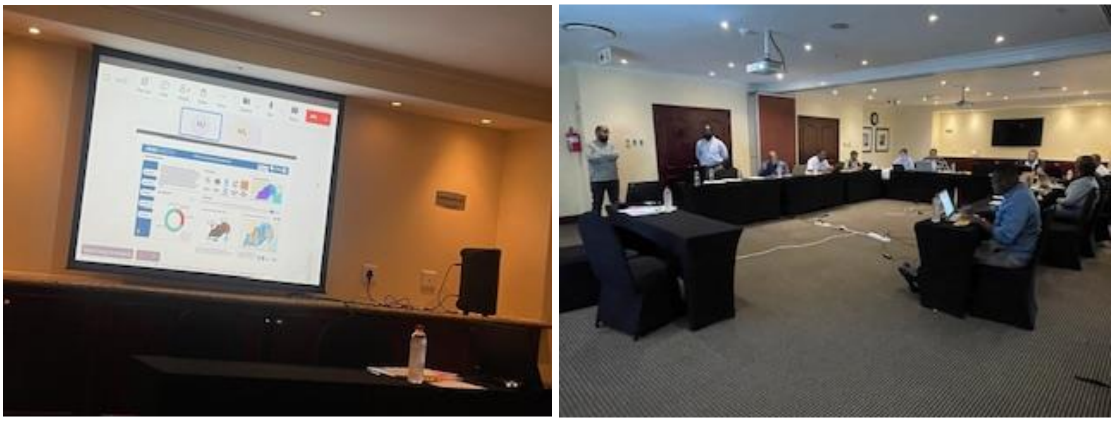


Figure 25: Dashboard interface, functionality, and technical specifications session.

In addition to the dashboard demonstration, participants were given a basic introduction to Tableau, the platform underlying the dashboard. Participants learned how to input data, create visualizations, and customize outputs gaining an understanding of how datasets are integrated into the system. To ensure continued exploration, participants were provided with a link to access Tableau, enabling them to practice and apply the skills demonstrated during the session. Following the dashboard presentation, was a discussion on various aspects of the dashboard.

Key Questions and comments during the afternoon session

The key questions during the afternoon session included the frequency of updating the dashboard, level of customization. Also, there a discussion regarding level of validation of the WA tool at the local level and with locally used PITMAN model.

5.2.2 Feedback on dashboard prototype

A discussion on participant feedback which had been collected online was facilitated by Dr. Kirubel Gebreyesus. This approach allowed participants to share their thoughts, suggestions, and concerns in real-time, fostering active engagement and enabling the collection of valuable insights for improving the dashboard. Key stakeholder comments are summarized below.

Figure 26: Dashboard feedback discussion session

Key recommendations made by the for inclusion in the dashboard:

- **Resolution and temporal scale of input data:** Generate water accounts at higher resolution (100m) to provide information where coarse resolution rainfall data may not be adequate. Also possibly provide data at seasonal or daily time scales.
- **Groundwater component:** Integrate groundwater modeling components into the dashboard.
- **Short-term forecasting:** Develop capabilities for short-term forecasting of water-related variables to enable proactive responses to dynamic challenges.
- **Validation at local scale:** Explore the potential to validate WA+ outputs at a local scale.

5.2.3 Dashboard integration to INMACOM website

The discussion on integrating the dashboard into the INMACOM website was led by Mr Buyani Fakudze the data manager at INMACOM. The session began by explaining the rationale behind the need for a dashboard. He highlighted the next steps towards integration to the INMACOM website as further engagement with stakeholders. This will include demonstrations and assessments how the dashboard can complement their activities, noting that some may face challenges in adopting the dashboard due to various reasons, including a lack of immediate need. Mr Buyani emphasized that the goal is to ensure the dashboard brings long-lasting value to stakeholders and that, as an open-source tool, it is designed for sustainability and long-term use. He reiterated the importance of not developing something that would eventually become obsolete.

5.2.4 Workshop reflections and conclusion

The 1-day training program included a series of presentations, group discussions, exercises, group activities, hands-on training on running the water accounting model. It was clear the participants had a better appreciation of the WA+ model and dashboard after the introductory workshop. It can be concluded that the workshop successfully met its objectives of facilitating learning, sharing experiences on the interactive dashboard with key stakeholders. Key reflections from the workshop are summarized as follows:

- **WA+ Dashboard as a tool for water resources communication:** Participants particularly praised the tool's visualization capabilities and expressed a desire for more interaction to explore its capacities.
- **Longer stakeholder engagements and deliberation: Participants** noted the short period of engagement on the project, felt the training sessions were too short and would have benefited from being longer sessions to be more familiar with the tool

- **Focus on Capacity Building:** Continuous capacity building, including training programs and internships, is necessary to increase knowledge transfer and develop local expertise. Further it was suggested to involve local master's and PhD students in studying the dashboard's applicability at a local scale.

Annex 3.1. Water Accounting input datasets for the Volta, Incomati and Maputo, and Zamcom basins.

Data type	Data	Units	Volta	Incomati & Maputo	Zambezi	References
dynamic data	Precipitation	mm	CHIRPS v2	ARC v2	CHIRPS v2, Zambia Met. Depart., SASSCAL	Funk et al., 2015;Herman et al., 1997
dynamic data	Actual ET	mm	SSEBop v5	SSEBop v5	SSEBop v5	Senay et al., 2020
dynamic data	Reference ET	mm	GLEAM v3.6a	GLEAM v3.6a	GLEAM v3.6a	Martens et al., 2017
dynamic data	Leaf area index (LAI)	m^2/ m^2	MOD15A2H	MOD15A2H	MOD15A2H	Myneni et al., 2015
static data	Saturated soil moisture	m^3/m^3	Hihydrosoils v2.0	Hihydrosoils v2.0	Hihydrosoils v2.0	Simons et al., 2020
dynamic data	Net primary production (NPP)	$kg\ m^{-2}\ yr^{-1}$	MOD17A3HGF.061	MOD17A3HGF.061	MOD17A3HGF.061	Running and Zhao, 2021
dynamic data	Gross primary production (GPP)	$kg\ m^{-2}\ yr^{-1}$	MOD17A2HGF.061	MOD17A2HGF.061	MOD17A2HGF.061	Running and Zhao, 2021
dynamic data	Net dry matter (NDM)	kg/ha	Derived from GPP and NPP	Derived from GPP and NPP	Derived from GPP and NPP	-
dynamic data	Landcover	-	CCI LC V2	CCI LC V2	CCI LC V2	ESA CCI, 2015
Static data	Digital elevation map (DEM)	m	Hydrosheds (30s)	Hydrosheds (30s)	Hydrosheds (30s)	Lehner et al., 2008

Static data	Irrigated areas	%	Global map of irrigated areas (GMIA)	Global map of irrigated areas (GMIA)	Global map of irrigated areas (GMIA)	Siebert et al., 2013
Static data	Reserved flow	-	Environmental water requirement	Environmental water requirement	Environmental water requirement	Smakhtin et al., 2009
Static data	Grey water footprint	-	Water pollution levels (WPL)	Water pollution levels (WPL)	Water pollution levels (WPL)	Liu et al., 2012
dynamic data	Population	pop/ha	WorldPop - 2015 (adjusted)	WorldPop - 2015 (adjusted)	WorldPop - 2015 (adjusted)	Lloyd et al., 2019
Static data	The world database on protected areas	Shape file	WDPA,2021	WDPA,2021	WDPA,2021	WDPA (2022)
Static data	The global reservoir and dam database	Shape file	GRanDv1 -NASA	GRanDv1 -NASA	GRanDv1 -NASA	Lehner et al. (2011),
dynamic data	Discharge	m3/s		Modeled Veg-ET Discharge data	Modeled Veg-ET Discharge data, Measured station discharge	Akpoti et al., 2024, ZAMCOM

Annex 3.2. Description of water accounting indicators and their equations

No	Flux/Indicators	Description	Equation
1	*P* advection	Precipitation received in the basin, aggregated over the hydrologic year	$\sum_{i=1}^{12} P$
2	Basin inflow (interbasin transfer)	Surface water or groundwater diverted into the basin	Q_{in}^{sw} and Q_{in}^{gw} (Measured estimates)
3	Gross Inflow, *GI*	Total inflow from all sources	$P + Q_{in}^{sw} + Q_{in}^{gw}$
4	Change in the soil moisture, ΔSM	See equation 2.	See equation 2.
5	Net Inflow, *NI*	The gross inflow plus the change in soil moisture	$GI \pm \Delta SM$
6	ET rainfall, ET_{rain}	ETa that occurs from effective precipitation and canopy interception, summarized for all land cover classes (1 to n classes).	$\sum_{i=1}^{n} ET_{rain}$
7	ET incremental, ET_{incr}	ETa that occurs from other sources except effective precipitation and interception. Includes ET from irrigation water, groundwater abstraction, open water sources, summarized for all land cover classes (1 to n classes).	$\sum_{i=1}^{n} ET_{incr}$
8	Landscape ET, ETa_{land}	ETa from natural landscapes (protected, utilized and modified land	$ET_{rain} + ET_{incr}$

		use classes); not due to water management.	
9	Consumed water, C_{water}	Total ETa that occurs from all landscapes over all months	$\sum_{i=1}^{12} ET_a$
10	Utilized flow, $Uzed_{flow}$	ETa from managed water use (irrigated crops, managed reservoirs).	ET_{incr} from the managed water use class
11	Exploitable water, EX_{water}	The exploitable water is the amount of water that can potentially be used within the basin	$NI - ET_{landscape}$
12	Available water, AW	The water that is left after meeting ET and reserve flow requirements	$GI - ETa_{land} - Reserve\ Flows$
13	Utilizable outflow, $Uzble_{flow}$	The water that can be reallocated for further uses after accounting for reserved flows and utilized flows.	$EX_{water} - ER_{flow} - Uzed_{flow}$
14	Qsw outlet	The river outflow at the outlet of the basin	Q_{outlet}^{sw}
15	Basin outflow (interbasin transfer)	Surface water or groundwater diverted to areas outside the basin	Q_{out}^{sw} and Q_{out}^{gw}
16	Non-consumed water, NC_{water}	Total outflow	$Q_{outlet}^{sw} + Q_{out}^{sw} + Q_{out}^{gw}$

Annex 3.3. Dashboard user manual for the Volta Basin - English

Water Accounting (WA) Dashboard
A User Manual
August, 2024

1.What is a WA dashboard?

The water accounting dashboard provides detailed multi-year water accounts of a basin’s water resources including inflows, outflows, water use patterns and availability, to establish baseline conditions. It can also compare baseline and future water accounts (where available), to provide stakeholders with an understanding of the current and potential future water resources status.

The platform leverages advanced data visualization tools to offer user-friendly access to complex information, empowering stakeholders to understand the dynamics between various water-balance parameters. In addition, the dashboard was designed to ensure that it caters to stakeholders of diverse backgrounds and expertise, from policymakers to scientists. Stakeholder feedback was incorporated to enrich the platform's accessibility and user experience to enable active participation and engagement.

This web-based dashboard represents one of the tools that could be used in promoting effective stakeholder deliberation of water balance information for sustainable water resource management.

2.Why do we need a WA dashboard?

Water resource management is an essential global challenge, necessitating a comprehensive and inclusive approach to address the diverse needs of the stakeholders involved. Stakeholder deliberation is crucial in fostering cooperation and informed decision-making for sustainable water management. However, lack of hydrometeorological observations often limits our understanding on the complex interlinkages between competing demands for water in the basin or a country. To overcome the challenges of water data scarcity in managing water resources, the International Water Management Institute is generating reliable and systematic analysis ready water data products on water use, demand, water availability and scarcity using water accounting plus (WA+) framework. The water accounting plus (WA+) approach (Karimi et al., 2013) derives basin scale water availability and scarcity indicators using earth observation data products and limited in situ observations. The WA+ framework is an open-source python programming-based model that uses a collection of remote sensing data products and in situ data to quantify water accounting indicators such as a) water yield, b) irrigation/rainfed water use, c) productive/unproductive water use, and other water availability indicators at river basin scale. Scale Invariant Water accounting plus (SIWA+) is a modified version of WA+ where the water accounting indicators can be generated for any given boundary (catchment, or a country or a county).

The suite of water data generated by water accounting studies provides several new insights into water availability and scarcity indicators at continental scale. The availability of open source codes enables repeatable and rapid water accounting assessments without much effort. IWMI's WA dashboard is a web-based dashboard built using Tableau technology to enhance stakeholder engagement and facilitate effective deliberation by summarizing and communicating the key water accounts basin.

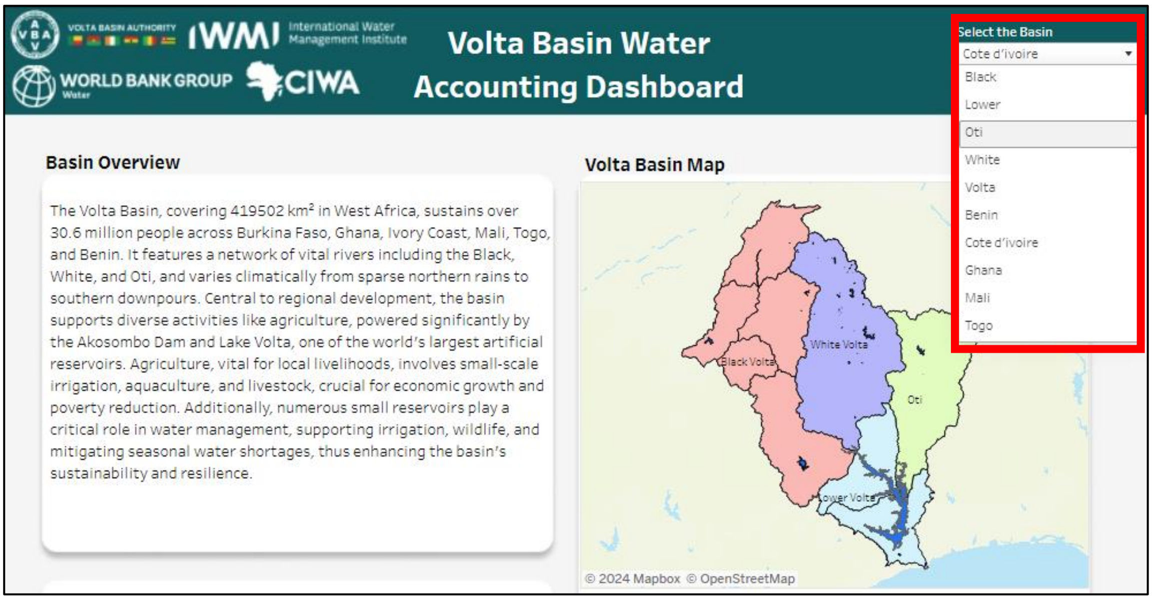
3.Key Elements of the WA Dashboard

There are five key elements in a WA dashboard:

i) Basin overview
ii) Water availability
iii) Water balance
iv) Spatial variation of WA indicators
v) WA indicators.

Selecting the basin

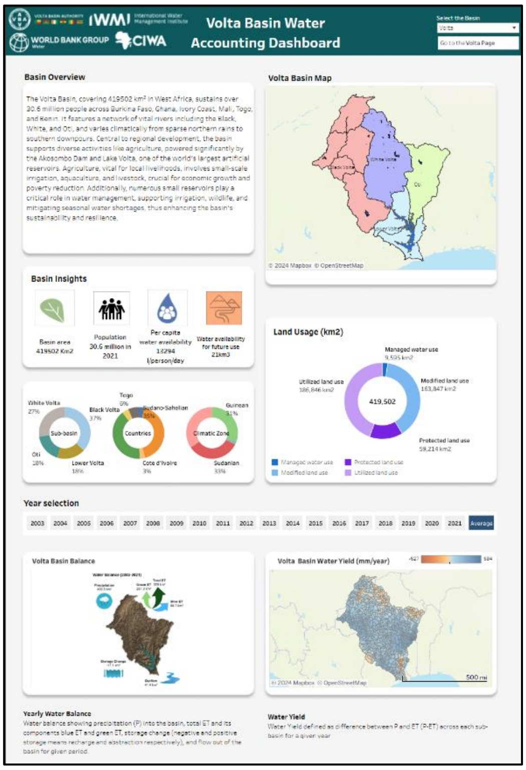
In dashboard top right corner, select the basin needed and click on GO TO THE PAGE



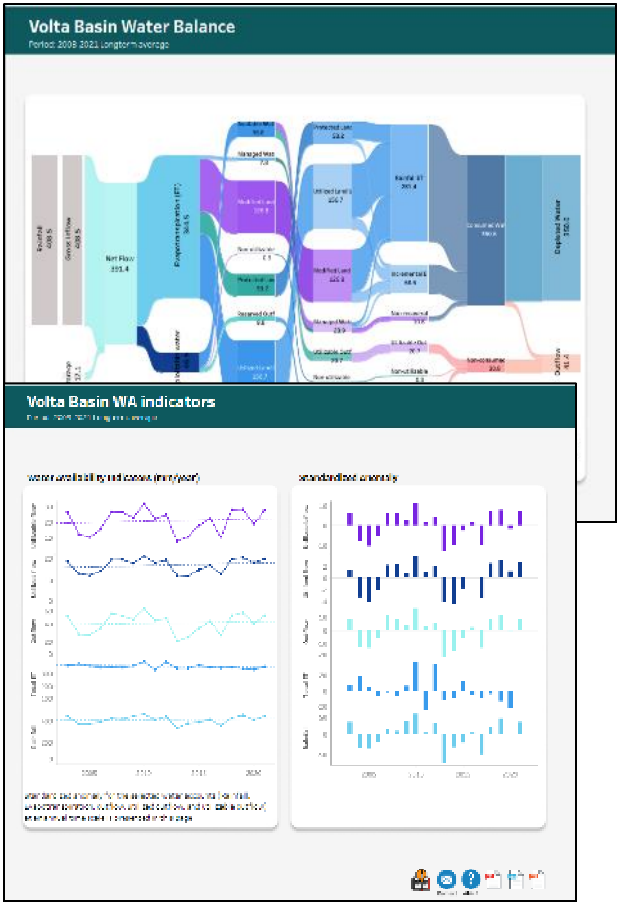
Basin Overview

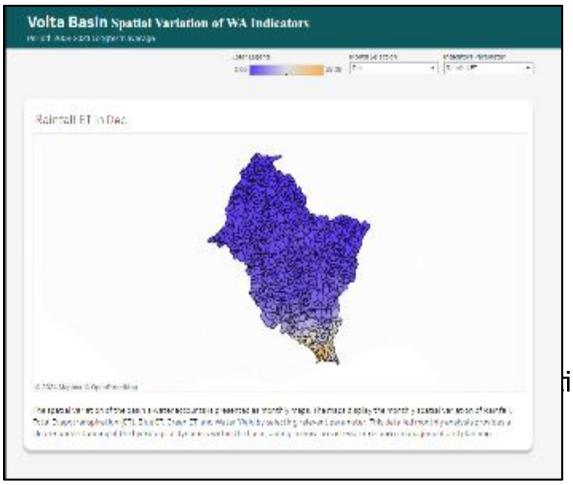
The Volta Basin, covering 419502 km² in West Africa, sustains over 30.6 million people across Burkina Faso, Ghana, Ivory Coast, Mali, Togo, and Benin. It features a network of vital rivers including the Black, White, and Oti, and varies climatically from sparse northern rains to southern downpours. Central to regional development, the basin supports diverse activities like agriculture, powered significantly by the Akosombo Dam and Lake Volta, one of the world's largest artificial reservoirs. Agriculture, vital for local livelihoods, involves small-scale irrigation, aquaculture, and livestock, crucial for economic growth and poverty reduction. Additionally, numerous small reservoirs play a critical role in water management, supporting irrigation, wildlife, and mitigating seasonal water shortages, thus enhancing the basin's sustainability and resilience.

Volta Basin



After selecting the basin. Use Scroll and navigate the page to see other sections





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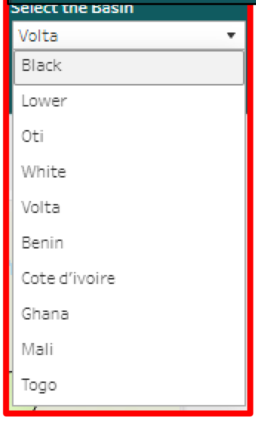
Same can be done by selecting the Country as follows:

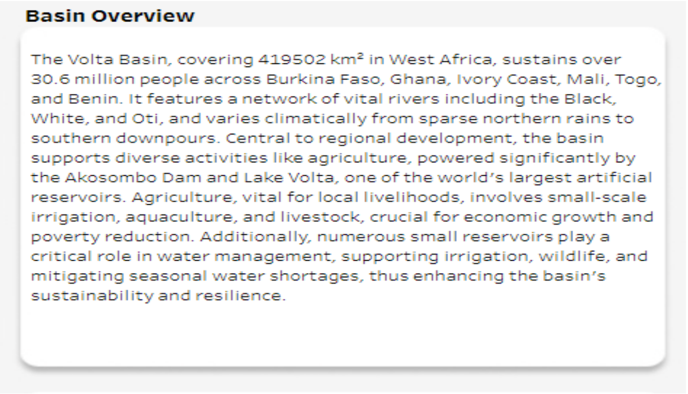


The description of each element and the contents of water accounts displayed under each element are presented in detailed here.

3.1 Basin Overview

The landing page of the dashboard provides the basin overview information. Several key baseline statistics on the river basin are provided on this page. The description of each section is provided here.

Basin description: The basin overview page provides a brief synopsis of the dashboard. A basin description is provided to give a brief account of the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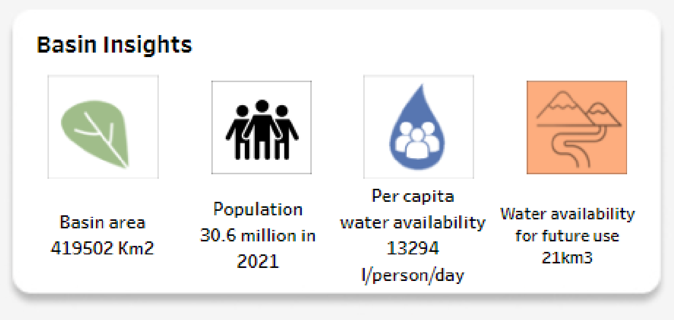
basin hydrology and highlights important hydrologic challenges in the basin.

Figure 2. The description of the basin provided on the basin overview page

Basin Insights: The middle central portion of the basin overview page provides basic information on basin insights such as basin area, population, per-capita water availability, environmental water stress and water availability for future use.



Basin Insights

Basin area 419502 Km2

Population 30.6 million in 2021

Per capita water availability 13294 l/person/day

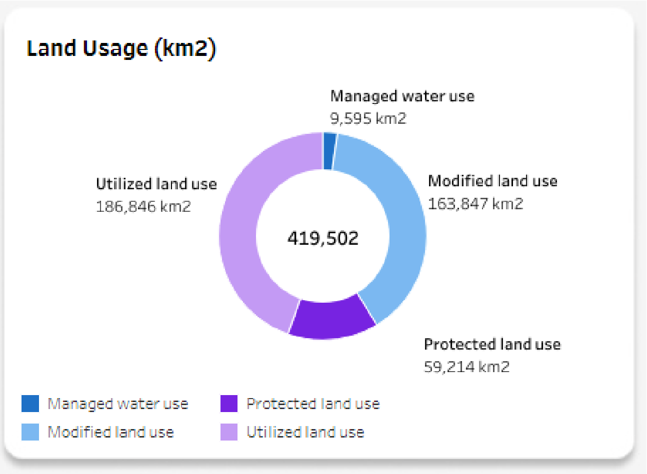
Water availability for future use 21km3

Figure 3. The basic information on basin insights

Basin Map: Here users can see an interactive map of the river basin. The users can zoom in and out of the basin area overlaid on the world map using the + and – symbols. The home icon on the map will reset the map to the full extent of the basin. The triangle icon offers additional features for interacting with the map.

Figure 4. Interactive map of the basin

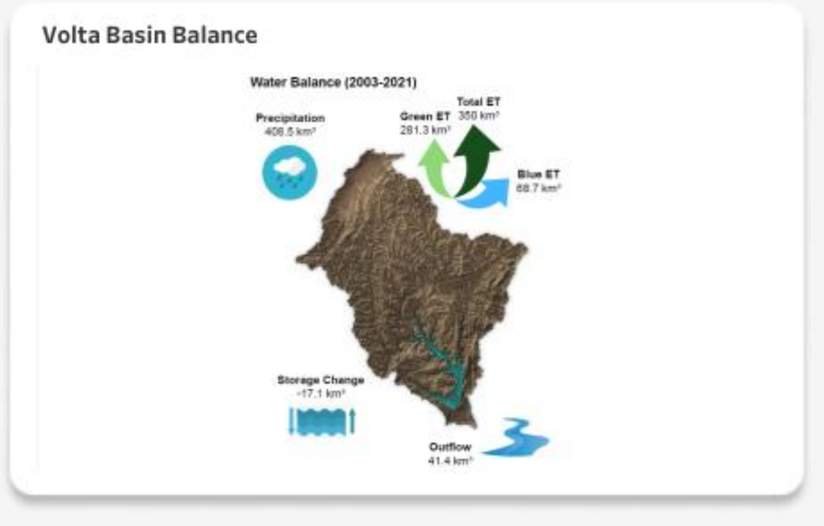
Land usage: The distribution of land use classes across the basin are provided in a double pie chart. In the outer pie chart, different landcover classes are reclassified into four broad classes of land use for water accounting (LUWA) classes. 1) The Utilized land represents natural landscapes that are utilized in their natural forms, without modifying or altering water and land resources. For example, humans utilize forests, grasslands, and shrub lands for grazing. 2) The Managed water class represents areas that are managed for agriculture where water is highly managed, such as irrigation. 3) The Modified land represents area where land is modified for human use. For example, the natural landscapes are cleared/modified to grow crops under rainfed conditions. 4) Protected land use defines the area that is classified as protected such as national parks or other preserved areas.



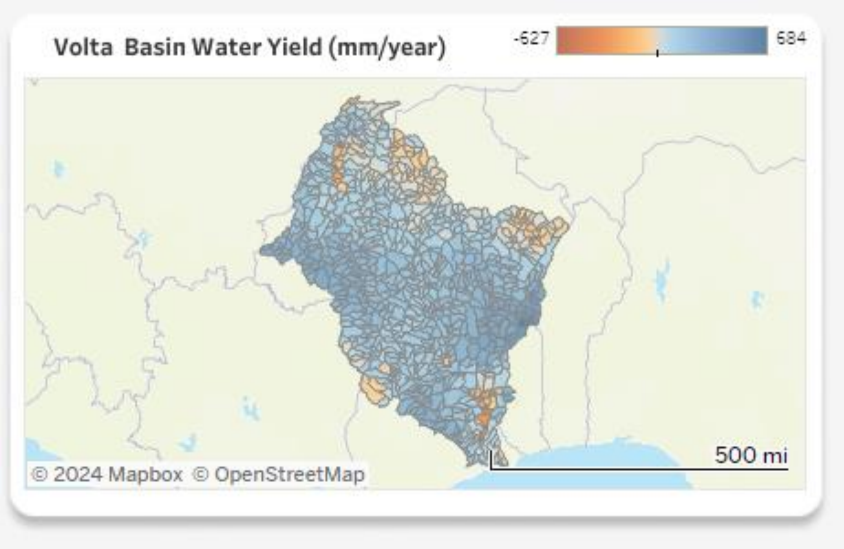
The inner pie chart shows the distribution of various classes that are classified/grouped into the board four categories.

Year Selection: The year selection tab helps users access overview of water balance and basin water yield information. The users can click and toggle between years to compare how water balance can changes over time.

Water Balance: The water balance figure shows modeled estimates of key water balance terms. Each figure is specific to the year selected on the year selection tab. The dark blue colored downward arrow represents the total volumetric annual precipitation (P, in km3) received in the basin. The light green colored upward arrow represents total volumetric evapotranspiration (TotalET, in km3). The lighter blue upward arrow represents BlueET (Blue ET, in km3), a portion of total ET, occurring from the blue water sources (surface water bodies, river, lakes or shallow groundwater aquifers). The small dark green upward arrow represents, Rainfall ET or Green ET (in km3), a portion of total ET occurring from the green water sources (soil moisture replenished by the rainfall). The sum of Blue ET and Ranifall ET is equal to the total ET. The empty blue colored arrow represents basin outflow (in km3) and the storage change denotes the changes in the basin storage due to either groundwater abstraction (+ve value) or groundwater recharge (-ve value).



Water Yield: The map shows the water yield obtained from the water accounting analysis. The water yield is defined as water that is available after meeting landscape water requirement (landscape ET). This is the amount of water that can be exploitable for human needs. The map shows water yield for administrative regions within the basin. Some regions shows negative values (shades of red), which indicate that at annual time scales there is not water available. Other regions show positive values (shades of blue) which indicate that at annual time scale, water availability for human needs is not a problem. Such information is important to understand spatial variability of water availability within the basin. The blue areas are also called water towers of the basin are the regions that provide most water to the river and where future activities such as irrigation development or canals for diverting water can be constructed



3.2 Water Availability

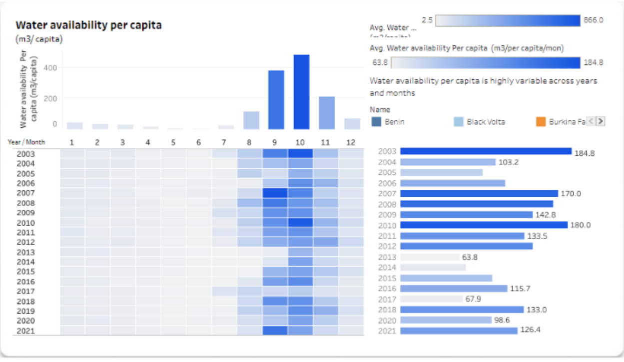
Information on water availability in a river basin is crucial for understanding various aspects of human, environmental, and economic well-being. Through this dashboard, water availability in a river basin is summarized using indicators of water availability for a) humans b) environment c) agriculture and d) other uses.

Water Availability Per Capita (m3/per capita): Water availability per capita refers to the amount of freshwater resources available for each person in a specific region or country. It is typically measured in cubic meters (m^3) per person per year and is an important indicator of a region's or country's ability to meet the water needs of its population while also supporting economic and environmental demands. Calculating water availability per capita involves dividing the total annual freshwater resources of a region or country by its population. Within water accounting, we derive water availability per capita as

$$\text{Water Availability Per Capita} = \frac{available\ water}{Population}$$

The water availability per capita is estimated is presented at monthly and annual timescales from 2009 to 2018.

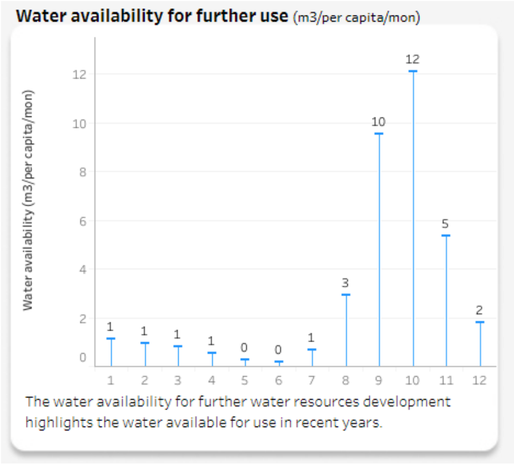
The annual total per capita water availability is presented to the right side as horizontal bar plots. The monthly average per capita water availability is presented on the top as the vertical bar plots.



Water availability per capita is highly variable across years and months

Water Availability for further use (MCM)

The water available for further water resources development highlights the water scarcity in the basin. The estimates presented in the figure quantifies the amount of water available after meeting all the basin demands of nature via landscape evapotranspiration, rainfed agriculture, domestic and industrial demand and irrigated water use. This is the volume of water that can be used for planning any basin developmental activities such as additional diversion for domestic and industrial water use, additional irrigation development etc.



The water availability for further water resources development highlights the water available for use in recent years.

Managed Evapotranspiration Fraction

The ET processes in a basin that could be manipulated by land use, cultivation practices and water withdrawals. This allows for more effective water management and conservation strategies in agricultural and land management practices

$$\text{Managed ET Fraction} = \frac{ET\ Managed}{ET}$$

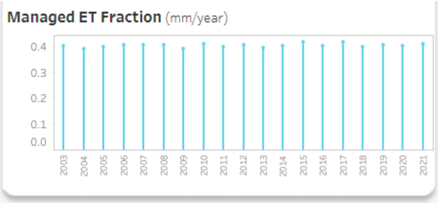
Agricultural Evapotranspiration Fraction

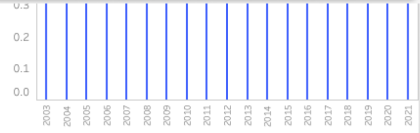
The part of ET that is attributed to agriculture production. The Agricultural ET Fraction highlights the proportion of evapotranspiration specifically from agricultural activities, emphasizing the water consumption in farming. This helps in planning sustainable water management strategies.

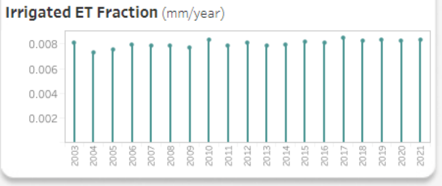
$$\text{Agricultural ET Fraction} = \frac{Agricultureal\ ET}{ET}$$

Irrigated Evapotranspiration Fraction

The irrigated ET fraction describes the portion of agricultural ET that is attributed to irrigated agriculture, emphasizing the importance of irrigation in water use for crop production. By calculating this







fraction, it quantifies the water used for irrigated agricultural ET relative to the total water used in agricultural ET.

$$\text{Irrigated Evapotranspiration Fraction} = \frac{Irrigated\ agricultureal\ ET}{Agricultural\ ET}$$

Basin closure (%)

The basin closure is calculated as total amount of water available that is utilized within a basin.

$$Basin\ closure = \frac{utilized}{available\ water}$$

Basin Closure (%) from 2010 to 2020

The basin closure is calculated as total amount of available water that is utilised within a basin. The graphs show the Volta Basin approached closure in several years.

Any basin with estimates closer to 100% indicate basin closure – indicating most to all water availability in the basin is currently consumed with in the basin. A smaller value indicates that water is available in the basin.

3.3 Water Balance

The Water balance, also known as the hydrologic balance or water budget, is a fundamental concept in hydrology. It refers to the equilibrium or accounting of water inputs, outputs, and storage within a defined area, such as a watershed, catchment, or region. The water balance equation helps quantify the movement and distribution of water in various forms through the Earth's hydrological cycle.

Within the water accounting framework, water balance of a river basin is quantified and presented using a number of hydrologic variables. Unlike most hydrologic studies where the water balance is mostly represented by the key hydrologic variables such as Precipitation, evapotranspiration, discharge and change in storage, the water accounting framework derives a variety of hydrologic parameters. A full list of water balance indicators quantified in the water accounting framework are presented in Table 1.

The figure below shows basin input parameters on the left side and basin output parameters on the right side. The WA+ framework tracks both the flow and consumption (depletion) that occur within the basin as water moves from the inlet to the outlet of the basin. The depletion accounting is used to estimate how much of water us consumed over different landscapes. This is summarized under four broad categories of land cover/land use – Protected-conservation areas with minimal changes in land and/or water management, Utilized- are areas with limited human influence and can include forest, natural pastures, savannahs and deserts, Modified- areas that are significantly modified by human activities usually for rainfed agriculture and Managed water use- are land use classes that are significantly modified for agriculture and include water purposefully withdrawn from the surface or groundwater sources for use The flow accounting derives a bunch of parameters such as exploitable water, available water, managed water use, utilizable flows, non-utilizable outflows, reserved outflows, and non-consumed water.

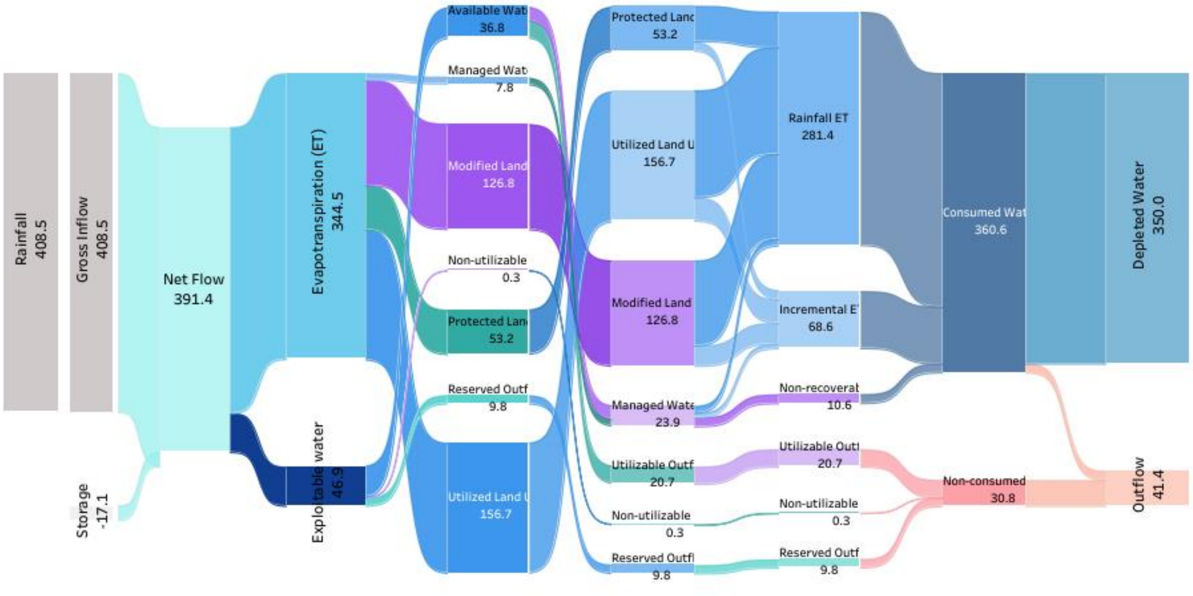


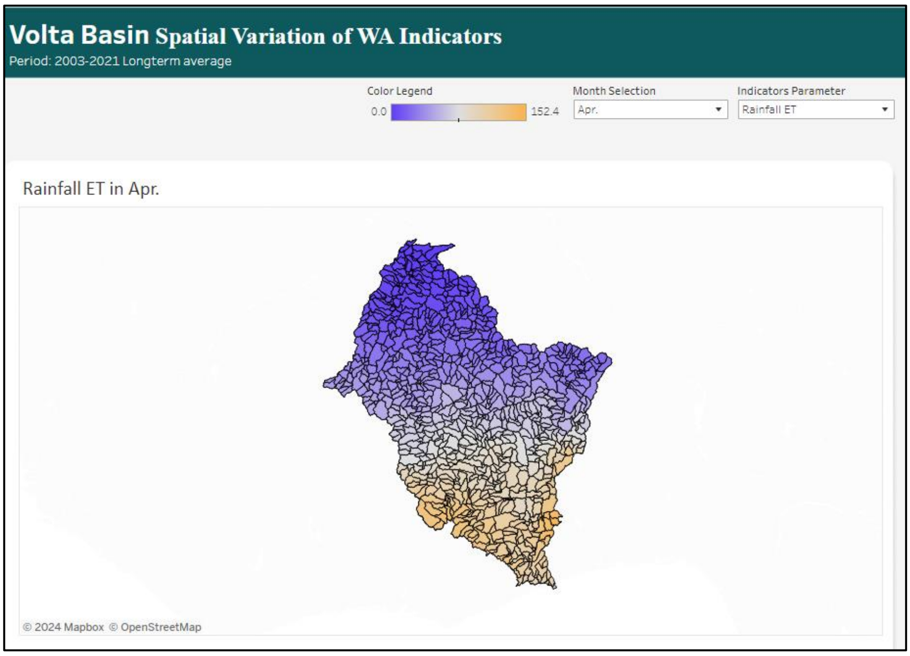
Table 1. List of hydrological variables and indicators quantified in the water accounting framework.

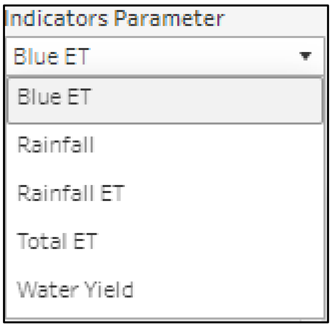
No	Flux/Indicators	Description	Equation
1	*P* advection	Precipitation received in the basin, aggregated over the hydrologic year	$\sum_{i=1}^{12} P$
2	Basin inflow (interbasin transfer)	Surface water or groundwater diverted into the basin	Q_{in}^{sw} and Q_{in}^{gw} (Measured estimates)
3	Gross Inflow, *GI*	Total inflow from all sources	$P + Q_{in}^{sw} + Q_{in}^{gw}$
4	Change in the soil moisture, ΔSM	See equation 2.	See equation 2.
5	Net Inflow, *NI*	The gross inflow plus the change in soil moisture	$GI \pm \Delta SM$
6	ET rainfall, ET_{rain}	ETa that occurs from effective precipitation and canopy interception, summarized for all land cover classes (1 to n classes).	$\sum_{i=1}^{n} ET_{rain}$
7	ET incremental, ET_{incr}	ETa that occurs from other sources except effective precipitation and interception. Includes ET from irrigation water, groundwater abstraction, open water sources,	$\sum_{i=1}^{n} ET_{incr}$

		summarized for all land cover classes (1 to n classes).	
8	Landscape ET, ETa_{land}	ETa from natural landscapes (protected, utilized and modified land use classes); not due to water management.	$ET_{rain} + ET_{incr}$
9	Consumed water, C_{water}	Total ETa that occurs from all landscapes over all months	$\sum_{i=1}^{12} ET_a$
10	Utilized flow, $Uzed_{flow}$	ETa from managed water use (irrigated crops, managed reservoirs).	ET_{incr} from the managed water use class
11	Exploitable water, EX_{water}	The exploitable water is the amount of water that can potentially be used within the basin	$NI - ET_{landscape}$
12	Available water, AW	The water that is left after meeting ET and reserve flow requirements	$GI - ETa_{land} - Reserve\ Flows$
13	Utilizable outflow, $Uzble_{flow}$	The water that can be reallocated for further uses after accounting for reserved flows and utilized flows.	$EX_{water} - ER_{flow} - Uzed_{flow}$
14	Qsw outlet	The river outflow at the outlet of the basin	Q_{outlet}^{sw}
15	Basin outflow (interbasin transfer)	Surface water or groundwater diverted to areas outside the basin	Q_{out}^{sw} and Q_{out}^{gw}
16	Non-consumed water, NC_{water}	Total outflow	$Q_{outlet}^{sw} + Q_{out}^{sw} + Q_{out}^{gw}$

3.4 Spatial Variation of WA Indicators

The spatial variation of WA indicator tab on the dashboard presents the key indicator parameters variables in Rainfall, ET, Water yield and its temporal change. A total of five parameters are presented on the dashboard – Rainfall, Blue ET, Rainfall ET, Total ET and water yield. The units are km3/year


Volta Basin Spatial Variation of WA Indicators
Period: 2003-2021 Longterm average
Color Legend 0.0 152.4
Month Selection: Apr.
Indicators Parameter: Rainfall ET
Rainfall ET in Apr.
© 2024 Mapbox © OpenStreetMap


Indicators Parameter: Blue ET

The spatial variation of the basin’s water accounts is presented as monthly maps. The maps display the monthly spatial variation of rainfall, Total evapotranspiration (ET), Rainfall(P), Blue ET, Green ET and water yield by selecting relevant parameters.

Rainfall ET

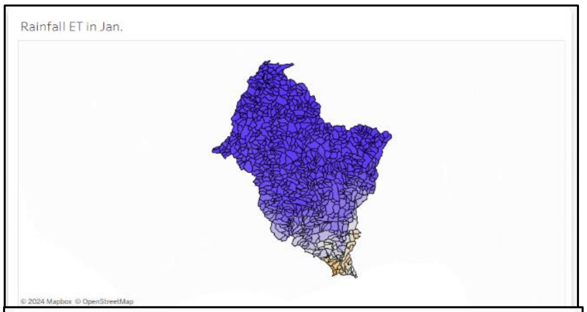
Rainfall ET refers to crop or vegetation evapotranspiration (ET) comes from the water consumed by the vegetation from the root zone soil moisture and soil evaporation from the unsaturated soil surface.

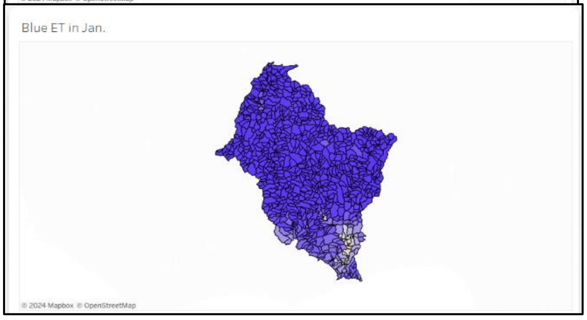
Blue ET

Blue ET comes from the water that is stored in the rivers, streams, surface-water bodies and groundwater resources.

Water Yield

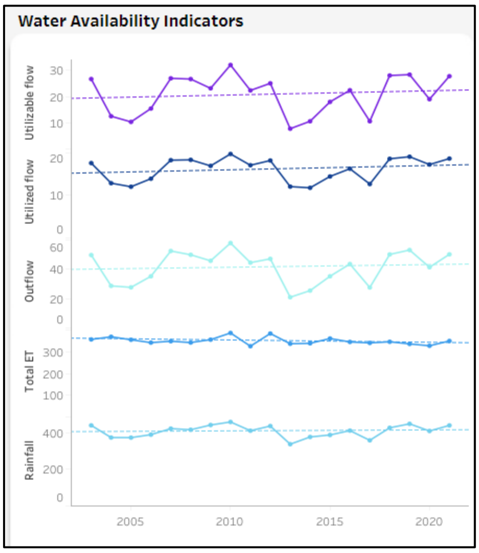
Water yield defined as difference between P and ET(P-ET)

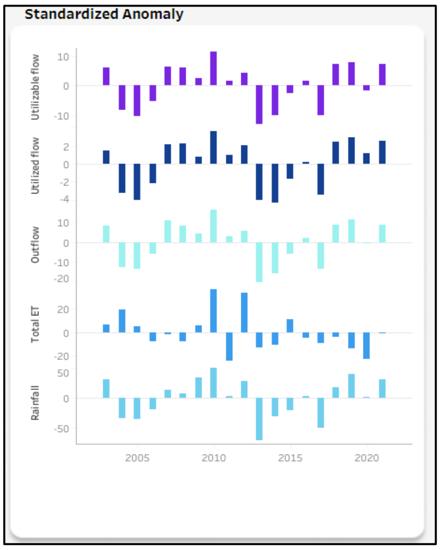

Rainfall ET in Jan.
© 2024 Mapbox © OpenStreetMap


Blue ET in Jan.
© 2024 Mapbox © OpenStreetMap

3.5 WA Indicators

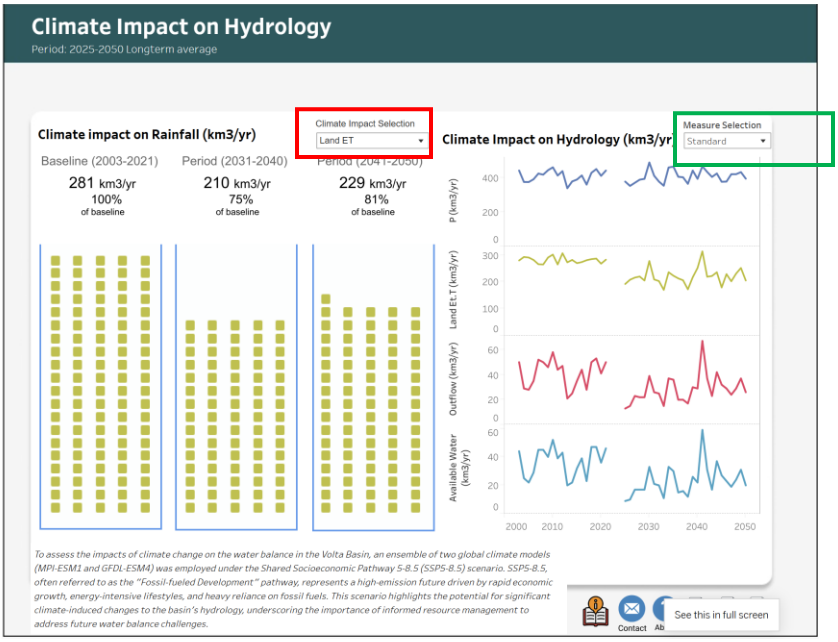
Long-term changes in hydrology refer to significant and persistent alteration in the water cycle and the distribution of water resources (both temporal and spatial) over extended periods of time. On the dashboard, we present to charts. On the left side, we present long-term changes in hydrology with a focus on demonstrating increasing or declining trend in the parameter and on the right side, we present insights in to quantifying the change for 2003 -2021.





3.6 Climate Impact on Hydrology

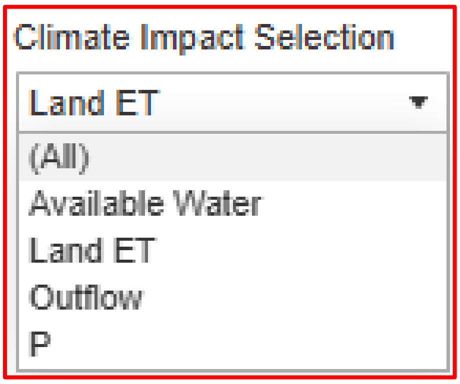
The "Climate Impact on Hydrology" tab provides a detailed overview of the long-term impacts of climate change on hydrological variables, focusing on key metrics such as rainfall, Land evapotranspiration, Outflow, and available water. This tool is designed to analyze and compare historical baseline data (2003–2021) with future projections for the period 2031-2040 and 2041-2050.

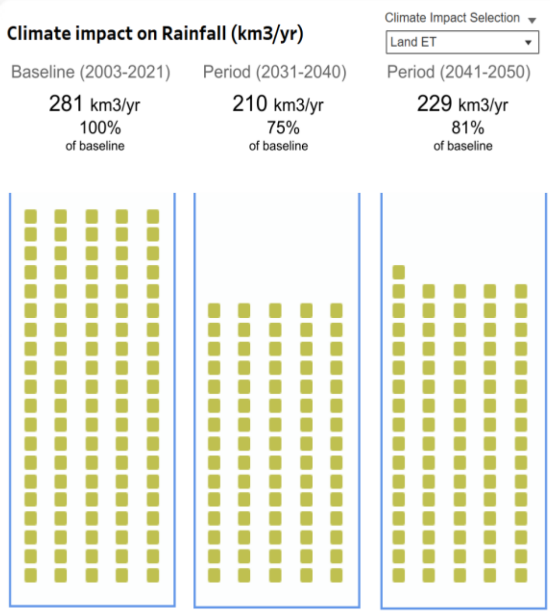


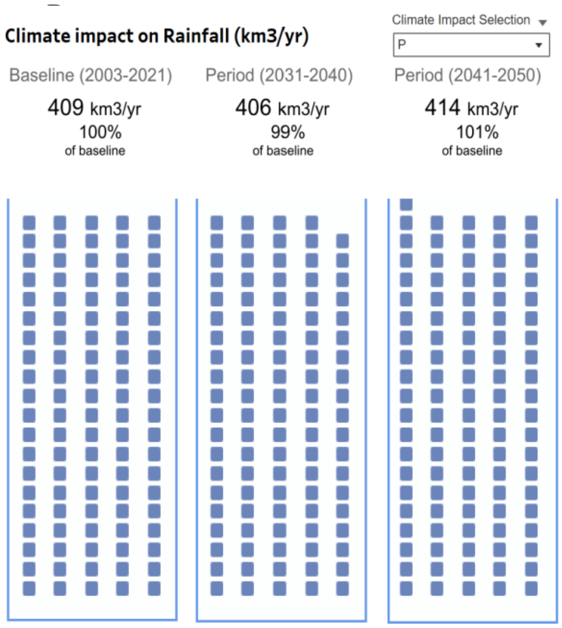
To assess the impacts of climate change on the water balance in the Volta Basin, an ensemble of two global climate models (MPI-ESM1 and GFDL-ESM4) was employed under the Shared Socioeconomic Pathway 5-8.5 (SSP5-8.5) scenario. SSP5-8.5, often referred to as the "Fossil-fueled Development" pathway, represents a high-emission future driven by rapid economic growth, energy-intensive lifestyles, and heavy reliance on fossil fuels. This scenario highlights the potential for significant climate-induced changes to the basin's hydrology, underscoring the importance of informed resource management to address future water balance challenges.

Dropdown menu for climate selection that allows users to choose key hydrological variables, displayed across three distinct periods

1. **Baseline Period (2003–2021):** Depicts historical average values for reference.
2. **Period 2031-2040**: Projects levels and their percentage relative to the baseline, representing short-term climate changes
3. **Period 2041-2050**: Shows mid-century projections, indicating long-term trends







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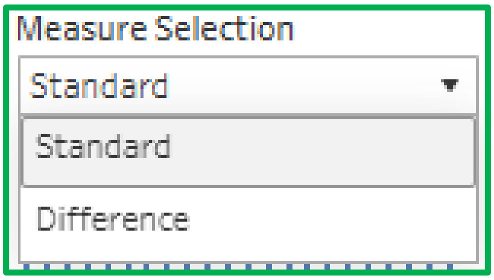
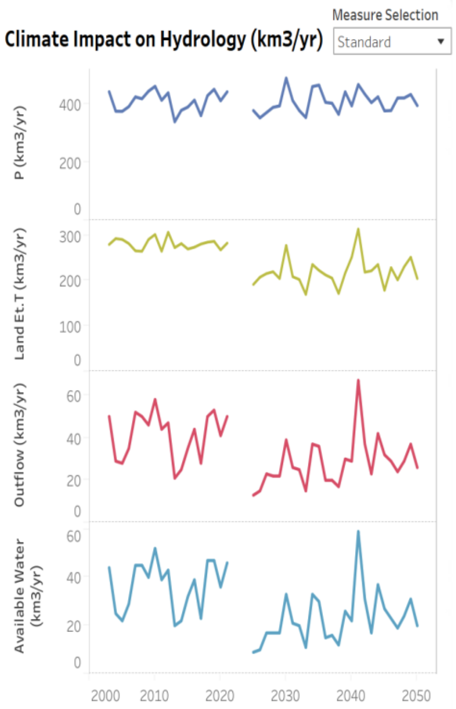
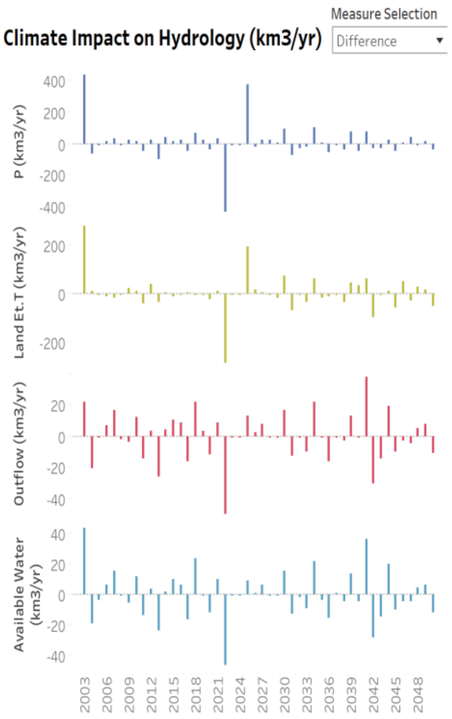


Standard



Difference



Additional features on the dashboard:

There are several additional features available on the dashboard. A brief description and purpose of each of the icons located on the lower right corner are presented here.

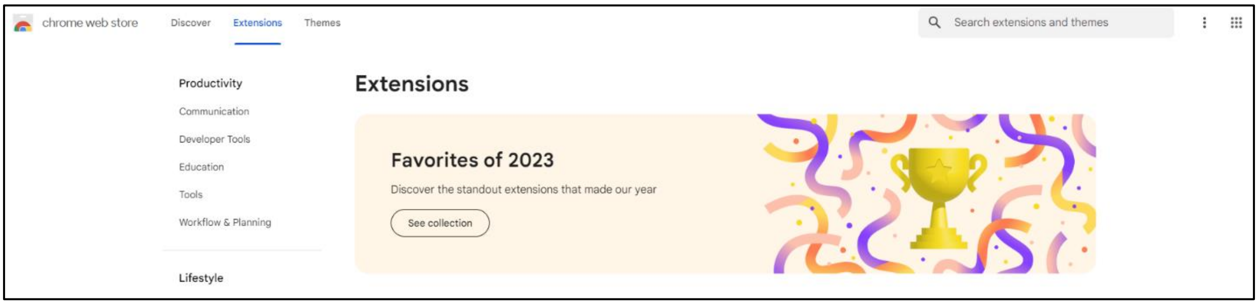
✉ Contact ? About PDF JPG PPT

Contact: The contact icon is located on the lower right corner of the dashboard and it would provide email information on whom to contact in case you have any questions on the dashboard.
About: The about icon provides more info on the project.
Printing options: The dashboard can be printed or saved using three options. The current view of the dashboard can be saved to the local computer in three different formats – PDF, JPG or PPT. Please use appropriate icon as per your need.

4.Installing Google translate plugin

1.**Go to link using Google Chrome web Browser**: https://chromewebstore.google.com/

This opens the Chrome web store

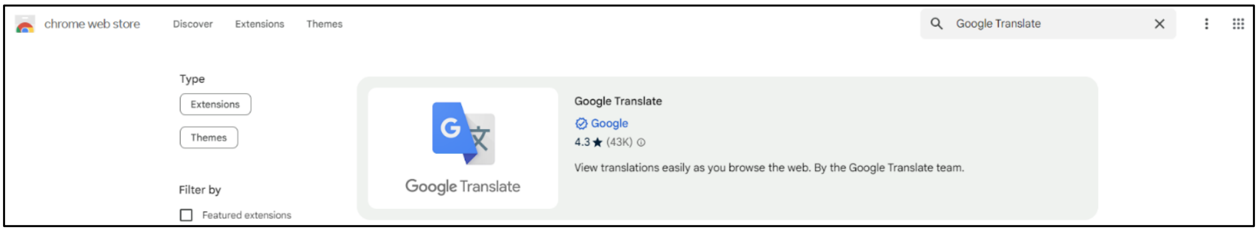


Discover the standout extensions that made our year

2. **Search for Google Translate**

In the search bar at the top right, type "Google Translate”, and press Enter

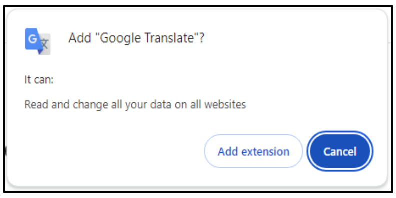
Next, Click top of the icon



View translations easily as you browse the web. By the Google Translate team.

3. **Add Extension to Chrome**

Click on the "Add to Chrome" button



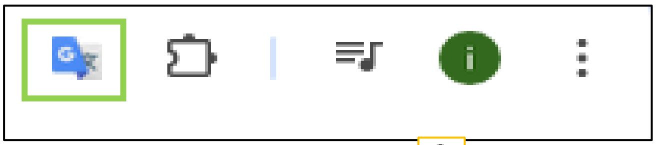
Add "Google Translate"?

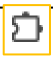
It can:

Read and change all your data on all websites

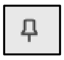
A pop-up will appear; click "Add extension" to confirm. Now Google Translate added to the chrome

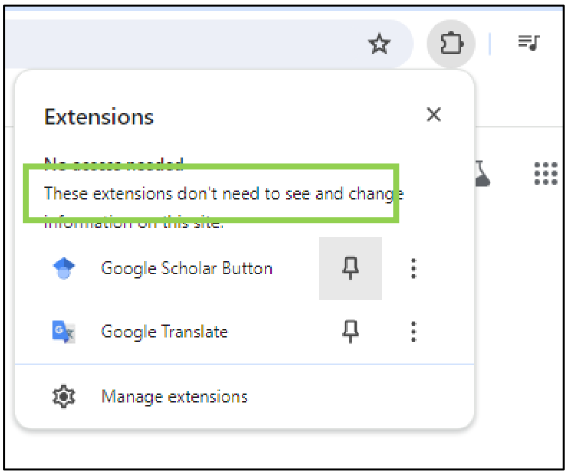
Extension will add Automatically to extension bar on chrome.





If not Click the extension icon

Click pin icon 



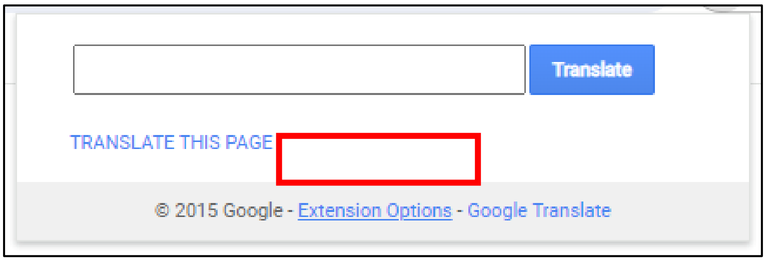
Extensions

No access needed

These extensions don't need to see and change information on this site.

4.Change the language

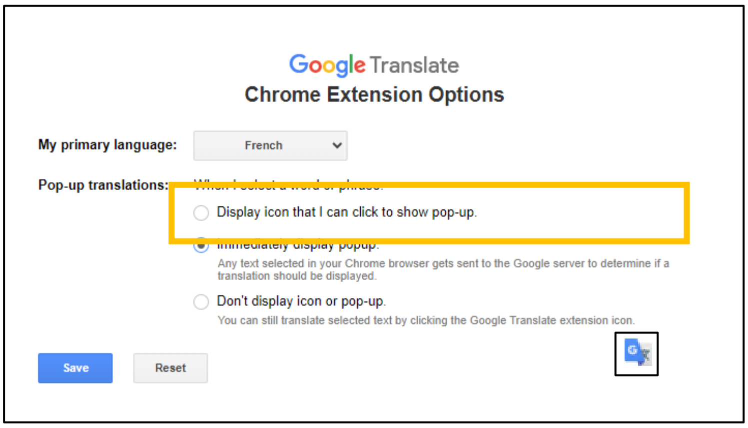
Click on Google translate icon and go to **Extension Option**.



© 2015 Google - Extension Options - Google Translate

Select **My Primary language as French** and click Save.

Select “**Immediately Display popup**”: this popup translated text immediately when select.



Google Translate

Chrome Extension Options

My primary language: French

Pop-up translations: When I select a word or phrase:

○ Display icon that I can click to show pop-up.

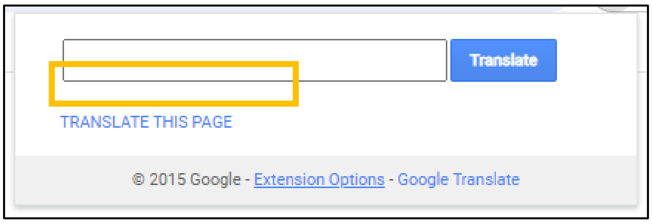
● Immediately display popup.

Any text selected in your Chrome browser gets sent to the Google server to determine if a translation should be displayed.

○ Don't display icon or pop-up.

You can still translate selected text by clicking the Google Translate extension icon.

Go to desired web page and select text or click on translate icon and click “TRANSLATE THIS PAGE”



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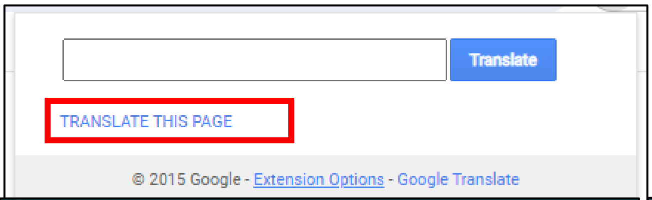
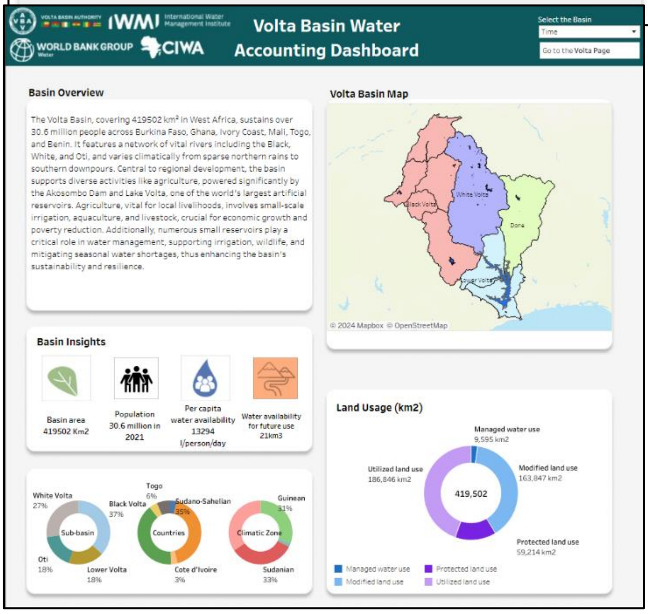
Example:

1.Open the web Page : https://public.tableau.com/views/Voltabasinvertical/Merged?%3AshowVizHome=no&%3Aembed=true#1

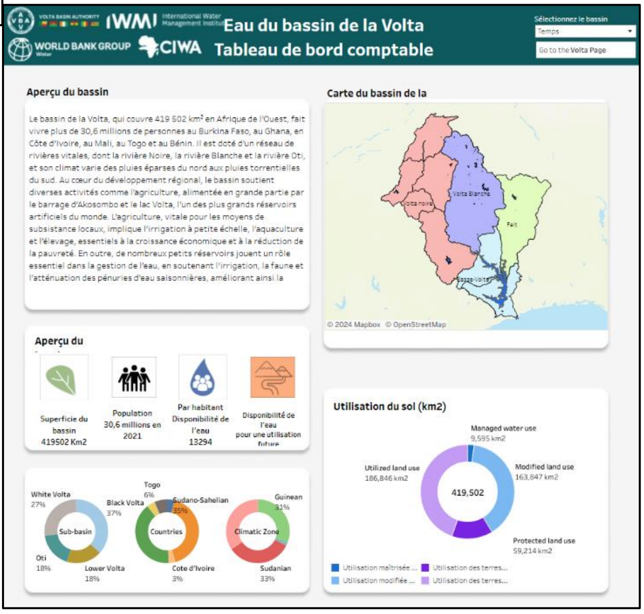
Click on the translate icon and click on

Next click on “TRANSLATE THIS PAGE”. Then page will translate





The Volta Basin, covering 419502 km² in West Africa, sustains over 30.6 million people across Burkina Faso, Ghana, Ivory Coast, Mali, Togo, and Benin. It features a network of vital rivers including the Black, White, and Oti, and varies climatically from sparse northern rains to southern downpours. Central to regional development, the basin supports diverse activities like agriculture, powered significantly by the Akosombo Dam and Lake Volta, one of the world's largest artificial reservoirs. Agriculture, vital for local livelihoods, involves small-scale irrigation, aquaculture, and livestock, crucial for economic growth and poverty reduction. Additionally, numerous small reservoirs play a critical role in water management, supporting irrigation, wildlife, and mitigating seasonal water shortages, thus enhancing the basin's sustainability and resilience.



Le bassin de la Volta, qui couvre 419 502 km² en Afrique de l'Ouest, fait vivre plus de 30,6 millions de personnes au Burkina Faso, au Ghana, en Côte d'Ivoire, au Mali, au Togo et au Bénin. Il est doté d'un réseau de rivières vitales, dont la rivière Noire, la rivière Blanche et la rivière Oti, et son climat varie des pluies éparses du nord aux pluies torrentielles du sud. Au cœur du développement régional, le bassin soutient diverses activités comme l'agriculture, alimentée en grande partie par le barrage d'Akosombo et le lac Volta, l'un des plus grands réservoirs artificiels du monde. L'agriculture, vitale pour les moyens de subsistance locaux, implique l'irrigation à petite échelle, l'aquaculture et l'élevage, essentiels à la croissance économique et à la réduction de la pauvreté. En outre, de nombreux petits réservoirs jouent un rôle essentiel dans la gestion de l'eau, en soutenant l'irrigation, la faune et l'atténuation des pénuries d'eau saisonnières, améliorant ainsi la

Version française du manuel d'utilisation
Tableau de bord de la Comptabilité de l'Eau (WA)

Annex 3.4. Dashboard user manual - French

Tableau de bord de la Comptabilité de l'Eau (WA)
Manuel d'utilisation

1.Qu'est-ce qu'un tableau de bord WA ?

Le tableau de bord de la comptabilité de l'eau fournit des comptes pluriannuels détaillés des ressources en eau d'un bassin, y compris les apports et les débits, les habitudes d'utilisation de l'eau et la disponibilité, afin d'établir les conditions de référence. Il peut également comparer les comptes de référence et futurs de l'eau (le cas échéant), afin de fournir aux parties prenantes une compréhension de l'état actuel et futur potentiel des ressources en eau.

La plateforme s'appuie sur des outils avancés de visualisation des données pour offrir un accès convivial à des informations complexes, permettant aux parties prenantes de comprendre la dynamique entre divers paramètres de bilan hydrique. En outre, le tableau de bord a été conçu pour s'assurer qu'il s'adresse aux parties prenantes d'horizons et d'expertises diverses, des décideurs politiques aux scientifiques. Les commentaires des parties prenantes ont été intégrés afin d'enrichir l'accessibilité de la plateforme et l'expérience utilisateur afin de permettre une participation et un engagement actifs.

Ce tableau de bord en ligne représente l'un des outils qui pourraient être utilisés pour promouvoir une délibération efficace des parties prenantes sur les informations sur le bilan hydrique pour une gestion durable des ressources en eau.

2.Pourquoi avons-nous besoin d'un tableau de bord WA ?

La gestion des ressources en eau est un défi mondial essentiel, qui nécessite une approche globale et inclusive pour répondre aux divers besoins des parties prenantes concernées. Les délibérations des parties prenantes sont cruciales pour favoriser la coopération et la prise de décisions éclairées pour une gestion durable de l'eau. Cependant, le manque d'observations hydrométéorologiques limite souvent notre compréhension des interconnexions complexes entre les demandes d'eau concurrentes dans le bassin ou dans un pays. Pour surmonter les défis de la rareté des données sur l'eau dans la gestion des ressources en eau, l'Institut international de gestion de l'eau génère des produits de données sur l'utilisation de l'eau, la demande, la disponibilité et la rareté de l'eau en utilisant le cadre de la comptabilité de l'eau plus (WA+). L'approche de la comptabilité de l'eau plus (WA+) (Karimi et al., 2013) permet d'obtenir des indicateurs de disponibilité et de rareté de l'eau à l'échelle du bassin à l'aide de produits de données d'observation de la Terre et d'observations in situ limitées. Le cadre WA+ est un modèle open source basé sur la programmation python qui utilise une collection de produits de données de télédétection et de données in situ pour quantifier les indicateurs de comptabilité de l'eau tels que a) l'apport en eau, b) l'utilisation de l'eau d'irrigation/pluviale, c) l'utilisation productive ou improductive de l'eau et d'autres indicateurs de disponibilité de l'eau à l'échelle du bassin fluvial. La comptabilité continentale de l'eau plus (CWA+) est une version modifiée de WA+ où les indicateurs de comptabilité de l'eau peuvent être générés pour n'importe quelle frontière donnée (bassin versant, pays ou comté).

L'ensemble des données sur l'eau générées par les études de comptabilité de l'eau fournit plusieurs nouvelles informations sur les indicateurs de disponibilité et de rareté de l'eau à l'échelle continentale. La disponibilité de codes open source permet des évaluations comptables reproductibles et rapides de l'eau sans trop d'efforts. Le tableau de bord WA de l'IWMI est un tableau de bord Web construit à l'aide de la technologie Tableau pour améliorer l'engagement des parties prenantes et faciliter une délibération efficace en résumant et en communiquant les principaux comptes de l'eau du bassin.

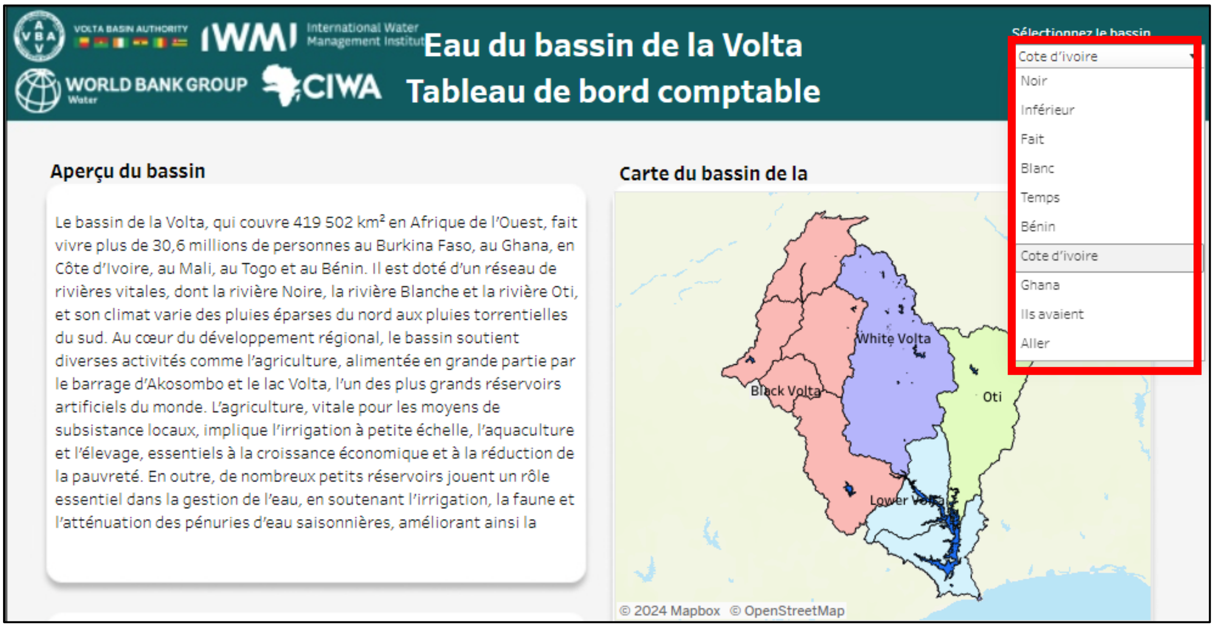
3.Éléments clés du tableau de bord WA

Il y a cinq éléments clés dans ce tableau de bord WA :

i) Vue d'ensemble du bassin
ii) Disponibilité de l'eau
iii) Bilan hydrique
iv) Variation spatiale des indicateurs WA
v) Indicateurs WA.

Sélection du bassin

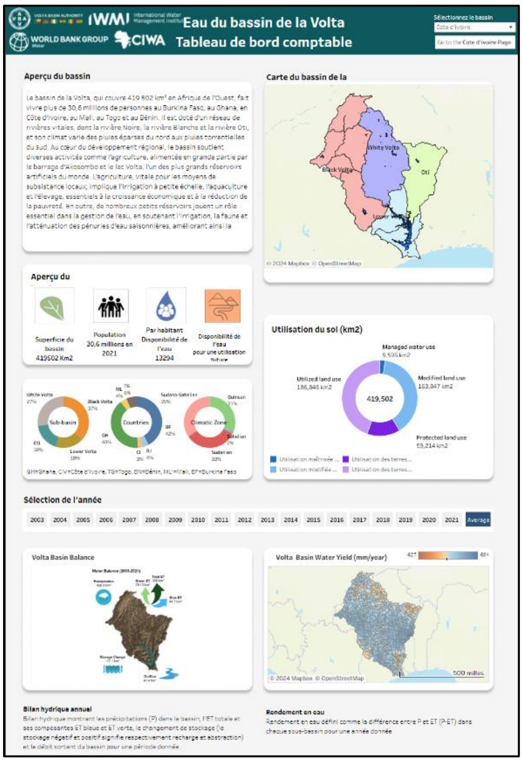
Dans le coin supérieur droit du tableau de bord, sélectionnez le bassin souhaité et cliquez sur ALLER À LA PAGE

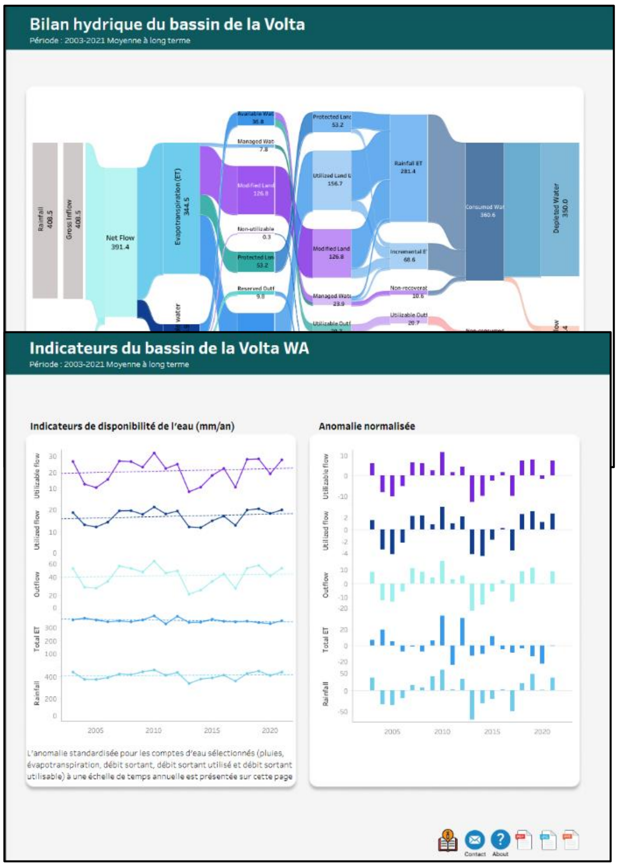


Le bassin de la Volta, qui couvre 419 502 km² en Afrique de l'Ouest, fait vivre plus de 30,6 millions de personnes au Burkina Faso, au Ghana, en Côte d'Ivoire, au Mali, au Togo et au Bénin. Il est doté d'un réseau de rivières vitales, dont la rivière Noire, la rivière Blanche et la rivière Oti, et son climat varie des pluies éparses du nord aux pluies torrentielles du sud. Au cœur du développement régional, le bassin soutient diverses activités comme l'agriculture, alimentée en grande partie par le barrage d'Akosombo et le lac Volta, l'un des plus grands réservoirs artificiels du monde. L'agriculture, vitale pour les moyens de subsistance locaux, implique l'irrigation à petite échelle, l'aquaculture et l'élevage, essentiels à la croissance économique et à la réduction de la pauvreté. En outre, de nombreux petits réservoirs jouent un rôle essentiel dans la gestion de l'eau, en soutenant l'irrigation, la faune et l'atténuation des pénuries d'eau saisonnières, améliorant ainsi la

Bassin de la Volta

Après avoir sélectionné le bassin. Utilisez l'option Faire défiler et naviguer dans la page pour voir d'autres sections

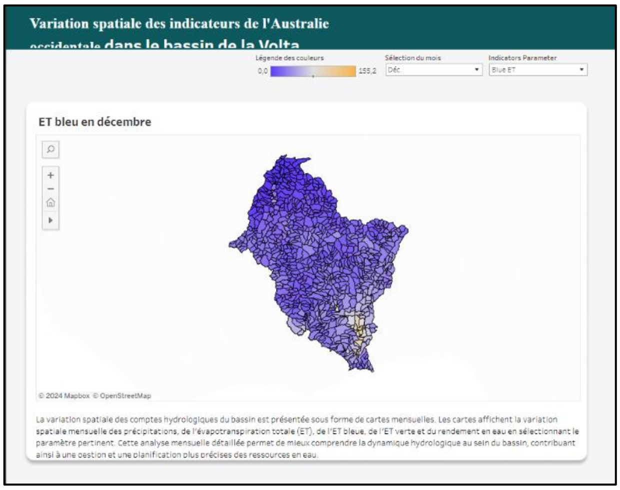




L'anomalie standardisée pour les comptes d'eau sélectionnés (pluies, évapotranspiration, débit sortant, débit sortant utilisé et débit sortant utilisable) à une échelle de temps annuelle est présentée sur cette page

Disponibilité de l'eau dans le bassin de la Volta

La disponibilité de l'eau par habitant varie fortement selon les années et les mois

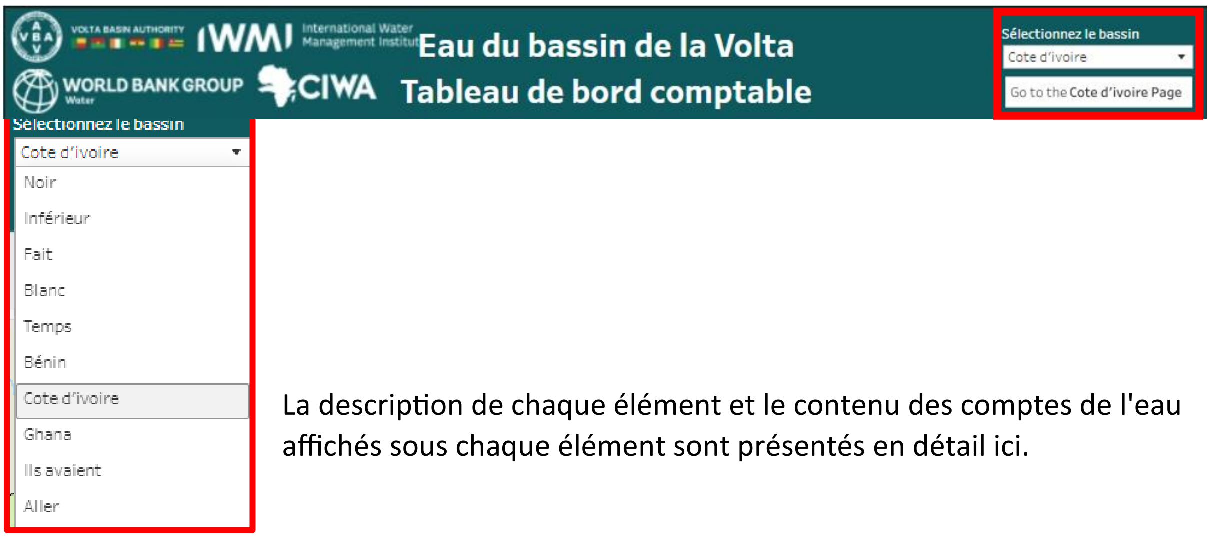


Variation spatiale des indicateurs de l'Australie occidentale dans le bassin de la Volta

La variation spatiale des comptes hydrologiques du bassin est présentée sous forme de cartes mensuelles. Les cartes affichent la variation spatiale mensuelle des précipitations, de l'évapotranspiration totale (ET), de l'ET bleue, de l'ET verte et du rendement en eau en sélectionnant le paramètre pertinent. Cette analyse mensuelle détaillée permet de mieux comprendre la dynamique hydrologique au sein du bassin, contribuant ainsi à une gestion et une planification plus précises des ressources en eau.

Graphique 1. Illustration du tableau de bord de la comptabilité de l'eau pour le bassin de la Volta.

La même chose peut être faite en sélectionnant le pays comme suit :



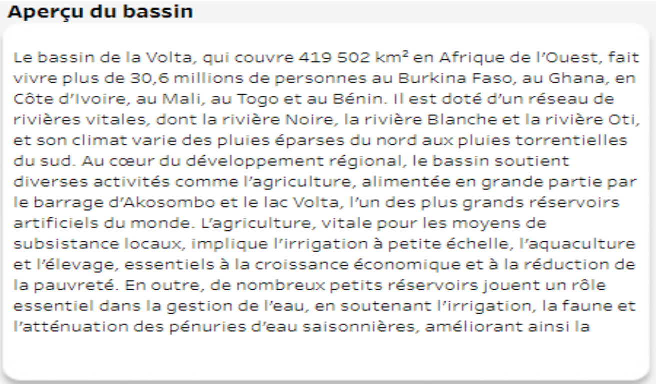
Eau du bassin de la Volta
Tableau de bord comptable

La description de chaque élément et le contenu des comptes de l'eau affichés sous chaque élément sont présentés en détail ici.

3.1 Vue d'ensemble du bassin

La page d'accueil du tableau de bord fournit des informations sur la vue d'ensemble du bassin. Cette page contient plusieurs statistiques de référence clés sur le bassin fluvial. La description de chaque section est fournie ici.

Description du bassin : la page d'aperçu du bassin fournit un bref résumé du tableau de bord. Une description du bassin est fournie pour donner un bref aperçu de l'hydrologie du bassin et met en évidence les défis hydrologiques importants dans le bassin.



Aperçu du bassin

Le bassin de la Volta, qui couvre 419 502 km² en Afrique de l'Ouest, fait vivre plus de 30,6 millions de personnes au Burkina Faso, au Ghana, en Côte d'Ivoire, au Mali, au Togo et au Bénin. Il est doté d'un réseau de rivières vitales, dont la rivière Noire, la rivière Blanche et la rivière Oti, et son climat varie des pluies éparses du nord aux pluies torrentielles du sud. Au cœur du développement régional, le bassin soutient diverses activités comme l'agriculture, alimentée en grande partie par le barrage d'Akosombo et le lac Volta, l'un des plus grands réservoirs artificiels du monde. L'agriculture, vitale pour les moyens de subsistance locaux, implique l'irrigation à petite échelle, l'aquaculture et l'élevage, essentiels à la croissance économique et à la réduction de la pauvreté. En outre, de nombreux petits réservoirs jouent un rôle essentiel dans la gestion de l'eau, en soutenant l'irrigation, la faune et l'atténuation des pénuries d'eau saisonnières, améliorant ainsi la

Graphique 2. La description du bassin fournie sur la page d'aperçu du bassin

Aperçu du bassin : La partie centrale centrale de la page d'aperçu du bassin fournit des renseignements de base sur le bassin, comme la superficie du bassin, la population, la disponibilité de l'eau par habitant, le stress hydrique environnemental et la disponibilité de l'eau pour une utilisation future.

Aperçu du

Superficie du bassin 419502 Km2

Population 30,6 millions en 2021

Par habitant Disponibilité de l'eau 13294

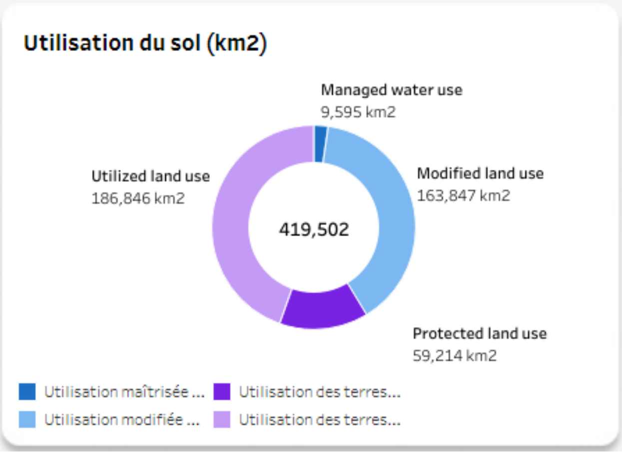
Disponibilité de l'eau pour une utilisation future

Graphique 3. Les informations de base sur les informations sur les bassins

Carte du bassin : Ici, les utilisateurs peuvent voir une carte interactive du bassin fluvial. Les utilisateurs peuvent zoomer et dézoomer sur la zone du bassin superposée sur la carte du monde à l'aide des symboles + et -. L'icône d'accueil sur la carte réinitialisera la carte à l'ensemble du bassin. L'icône du triangle offre des fonctionnalités supplémentaires pour interagir avec la carte.

Graphique 4. Carte interactive du bassin

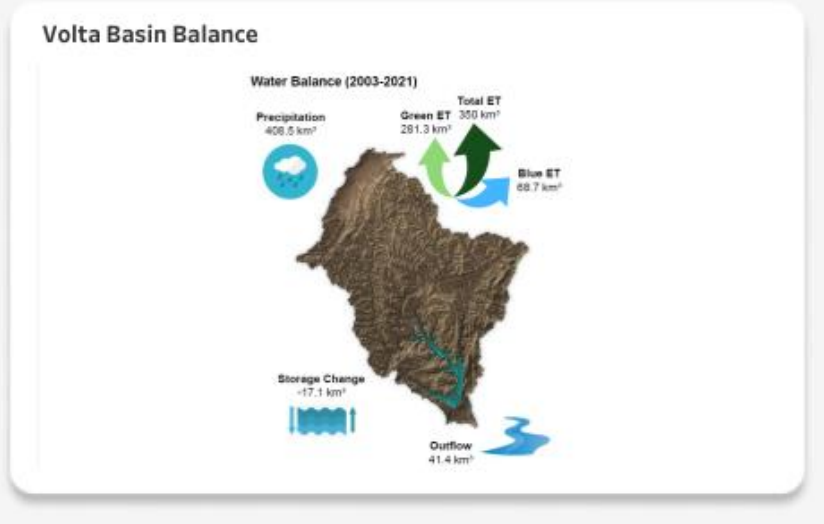
Utilisation des terres : La répartition des catégories d'utilisation des terres dans l'ensemble du bassin est présentée dans un graphique à deux secteurs. Dans le diagramme circulaire externe, différentes classes d'occupation du sol sont reclassées en quatre grandes classes de classes de comptabilisation de l'utilisation des terres pour l'eau (LUWA). 1) Les terres utilisées représentent des paysages naturels qui sont utilisés dans leurs formes naturelles, sans modifier ni altérer les ressources en eau et en terres. Par exemple, les humains utilisent les forêts, les prairies et les arbustes pour le pâturage. 2) La catégorie des eaux gérées représente les zones gérées pour l'agriculture où l'eau est fortement gérée, comme l'irrigation. 3) Les terres modifiées représentent la zone où les terres sont modifiées pour l'utilisation humaine. Par exemple, les paysages naturels sont défrichés/modifiés pour faire pousser des cultures dans des conditions pluviales. 4) L'utilisation des terres protégées définit la zone classée comme protégée, comme les parcs nationaux ou d'autres zones préservées.



Le graphique circulaire interne montre la distribution des différentes classes qui sont classées/regroupées dans le tableau en quatre catégories.

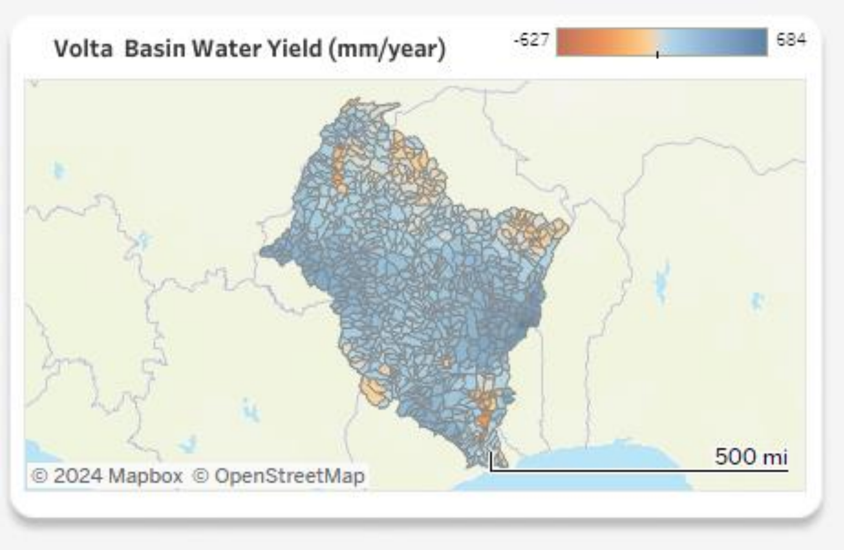
Sélection de l'année : L'onglet de sélection de l'année permet aux utilisateurs d'accéder à une vue d'ensemble du bilan hydrique et de l'apport en eau du bassin. Les utilisateurs peuvent cliquer et basculer entre les années pour comparer comment le bilan hydrique peut changer au fil du temps.

Bilan hydrique : La figure du bilan hydrique montre des estimations modélisées des principaux termes du bilan hydrique. Chaque chiffre est spécifique à l'année sélectionnée dans l'onglet de sélection de l'année. La flèche vers le bas de couleur bleu foncé représente les précipitations annuelles volumétriques totales (P, en km3) reçues dans le bassin. La flèche vers le haut de couleur vert clair représente l'évapotranspiration volumétrique totale (TotalET, en km3). La flèche bleu plus clair vers le haut représente l'ET bleu (ET bleu, en km3), une partie de l'ET total, provenant



des sources d'eau bleues (plans d'eau de surface, rivières, lacs ou aquifères souterrains peu profonds). La petite flèche vert foncé vers le haut représente, Précipitations ET ou ET vertes (en km3), une partie de l'ET totale provenant des sources d'eau vertes (humidité du sol reconstituée par les précipitations). La somme de Blue ET et et de Ranifall est égale à l'ET total. La flèche bleue vide représente l'écoulement sortant du bassin (en km3) et la modification du stockage indique les modifications du stockage du bassin dues soit à la prétude des eaux souterraines (+valeur ve), soit à la recharge des eaux souterraines (valeur -ve).

Apport en eau : La carte montre le rendement en eau obtenu à partir de l'analyse comptable de l'eau. L'apport en eau est défini comme l'eau disponible après avoir satisfait aux besoins en eau du paysage (ET). Il s'agit de la quantité d'eau qui peut être exploitable pour les besoins humains. La carte montre l'apport en eau pour les régions administratives du bassin. Certaines régions affichent des valeurs négatives (nuances de rouge), ce qui indique qu'à l'échelle de temps annuelle, il n'y a pas d'eau disponible. D'autres régions affichent des valeurs positives (nuances de bleu) qui indiquent qu'à l'échelle de temps annuelle, la disponibilité de l'eau pour les besoins humains n'est pas un problème. Ces informations sont importantes pour comprendre la variabilité spatiale de la disponibilité de l'eau dans le bassin. Les zones bleues sont également appelées châteaux d'eau du bassin sont les régions qui fournissent le plus d'eau à la rivière et où des activités futures telles que le développement de l'irrigation ou des canaux de détournement de l'eau peuvent être construites



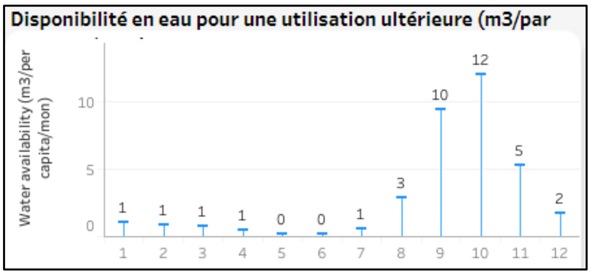
3.2 Disponibilité de l'eau

L'information sur la disponibilité de l'eau dans un bassin fluvial est cruciale pour comprendre divers aspects du bien-être humain, environnemental et économique. À travers ce tableau de bord, la disponibilité en eau dans un bassin fluvial est résumée à l'aide d'indicateurs de disponibilité de l'eau pour a) les humains b) l'environnement c) l'agriculture et d) d) d'autres utilisations.

- Disponibilité en eau par habitant (m3/par habitant) : La disponibilité en eau par habitant fait référence à la quantité de ressources en eau douce disponibles pour chaque personne dans une région ou un pays spécifique. Il est généralement mesuré en mètres cubes (m³) par personne et par an et constitue un indicateur important de la capacité d'une région ou d'un pays à répondre aux besoins en eau de sa population tout en répondant aux demandes économiques et environnementales. Le calcul de la disponibilité en eau par habitant consiste à diviser les ressources annuelles totales en eau douce d'une région ou d'un pays par sa population. Dans la comptabilité de l'eau, nous déduisons la disponibilité de l'eau par habitant comme suit :

-
    - Disponibilité en eau par habitant = $\frac{available\ water}{Population}$
    -
- Les disponibilités en eau par habitant sont estimées sur des échelles de temps mensuelles et annuelles de 2009 à 2018.
-
- La disponibilité totale annuelle en eau par habitant est présentée sur le côté droit sous forme de diagrammes à barres horizontales. La disponibilité mensuelle moyenne en eau par habitant est présentée en haut sous forme de diagrammes à barres verticales.
    -
    -

- *Disponibilité de l'eau pour une utilisation ultérieure (MCM)*
-
- L'eau disponible pour le développement des ressources en eau met en évidence la rareté de l'eau dans le bassin. Les estimations présentées dans la figure quantifient la quantité d'eau disponible après avoir répondu à toutes les demandes du bassin de la nature via l'évapotranspiration du paysage, l'agriculture pluviale, la demande domestique et industrielle et l'utilisation de l'eau irriguée. Il s'agit du volume d'eau qui peut être utilisé pour planifier toute activité de développement du bassin, telle que la dérivation supplémentaire pour l'utilisation de l'eau domestique et industrielle, le développement de l'irrigation, etc.

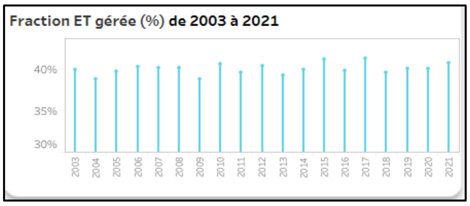


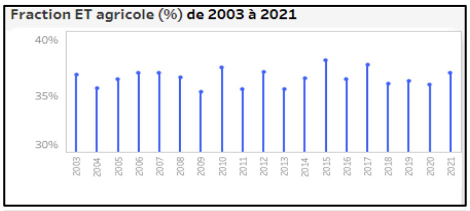
Fraction d'évapotranspiration gérée

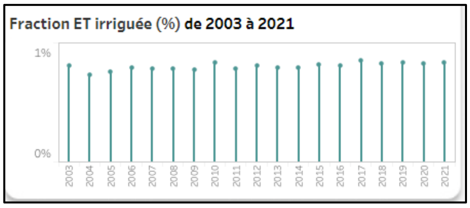
\Les processus ET dans un bassin qui pourrait être manipulé par l'utilisation des terres, les pratiques culturales et les prélèvements d'eau. Cela permet d'adopter des stratégies de gestion et de conservation de l'eau plus efficaces dans les pratiques agricoles et de gestion des terres

$$\text{Managed ET Fraction} = \frac{ET\ Managed}{ET}$$

Fraction d'évapotranspiration agricole







La part de l'ET qui est attribuée à la production agricole. La fraction ET agricole met en évidence la proportion d'évapotranspiration provenant spécifiquement des activités agricoles, en mettant l'accent sur la consommation d'eau dans l'agriculture. Cela aide à planifier des stratégies de gestion durable de l'eau.

$$\text{Agricultural ET Fraction} = \frac{Agricultureal\ ET}{ET}$$

Fraction d'évapotranspiration irriguée

La fraction ET irriguée décrit la part de l'ET agricole attribuée à l'agriculture irriguée, en mettant l'accent sur l'importance de l'irrigation dans l'utilisation de l'eau pour la production agricole. En calculant cette fraction, on quantifie l'eau utilisée pour les ET agricoles irriguées par rapport à l'eau totale utilisée pour les ET agricoles.

$$\text{Irrigated Evapotranspiration Fraction} = \frac{Irrigated\ agricultureal\ ET}{Agricultural\ ET}$$

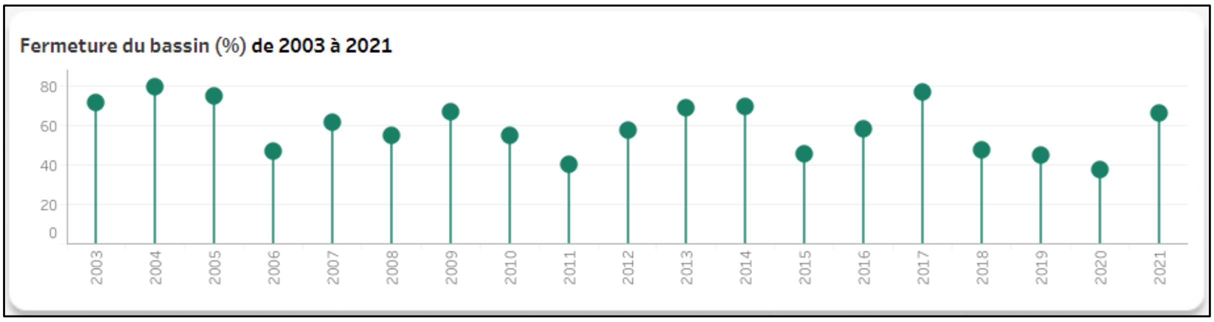
Fermeture du bassin (%)

La fermeture du bassin est calculée en fonction de la quantité totale d'eau disponible qui est utilisée dans un bassin. $Basin\ closure = \frac{utilized}{available\ water}$

Tout bassin dont les estimations sont plus proches de 100 % indique une fermeture du bassin, ce qui indique que la plus grande partie de la disponibilité de l'eau dans le bassin est actuellement consommée dans le bassin. Une valeur plus petite indique que de l'eau est disponible dans le bassin.

3.3 Bilan hydrique

Le bilan hydrique, également appelé bilan hydrologique ou bilan hydrique, est un concept fondamental en hydrologie. Il s'agit de l'équilibre ou de la comptabilisation des entrées, des sorties et du stockage de l'eau dans une zone définie, telle qu'un bassin versant, un bassin versant ou une région. L'équation du bilan hydrique aide à quantifier le mouvement et la distribution de l'eau sous diverses formes au cours du cycle hydrologique de la Terre.



Dans le cadre de la comptabilité de l'eau, le bilan hydrique d'un bassin hydrographique est quantifié et présenté à l'aide d'un certain nombre de variables hydrologiques.

Contrairement à la plupart des études hydrologiques où le bilan hydrique est principalement représenté par les variables hydrologiques clés telles que les précipitations, l'évapotranspiration, le débit et la variation du stockage, le cadre de comptabilisation de l'eau dérive une variété de paramètres hydrologiques. Une liste complète des indicateurs du bilan hydrique quantifiés dans le cadre de comptabilisation de l'eau est présentée dans le tableau 1.

La figure ci-dessous montre les paramètres d'entrée du bassin sur le côté gauche et les paramètres de sortie du bassin sur le côté droit. Le cadre WA+ suit à la fois le débit et la consommation (épuisement) qui se produisent dans le bassin lorsque l'eau se déplace de l'entrée à la sortie du bassin. La comptabilité de l'épuisement est utilisée pour estimer la quantité d'eau que nous avons consommée dans différents paysages. Ceci est résumé en quatre grandes catégories de couverture terrestre/utilisation des terres : Protégées - zones de conservation avec des changements minimes dans la gestion des terres et/ou de l'eau, Utilisées - sont des zones où l'influence humaine est limitée et peuvent inclure des forêts, des pâturages naturels, des savanes et des déserts, Modifiées - zones qui sont considérablement modifiées par les activités humaines, généralement pour l'agriculture pluviale et Utilisation gérée de l'eau - sont des classes d'utilisation des terres qui sont considérablement modifiées pour l'agriculture et incluent l'eau à dessein. prélevé des sources d'eau de surface ou souterraines pour être utilisé La comptabilité des débits dérive un ensemble de paramètres tels que l'eau exploitable, l'eau disponible, l'utilisation gérée de l'eau, les débits utilisables, les débits sortants non utilisables, les débits sortants réservés et l'eau non consommée.

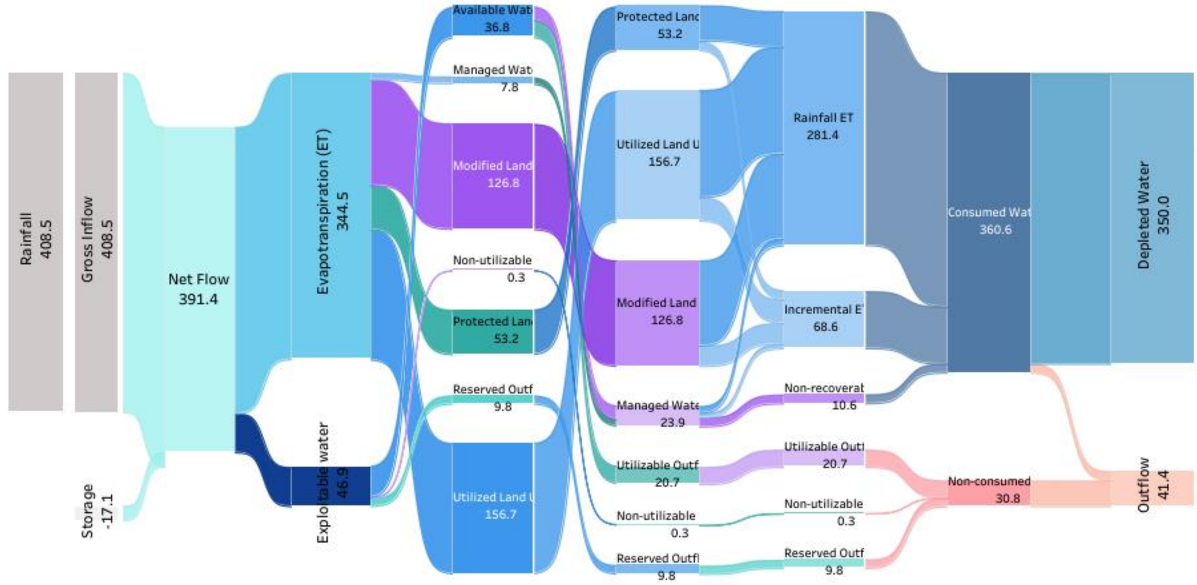


Tableau 1. Liste des variables et indicateurs hydrologiques quantifiés dans le cadre de la comptabilité de l'eau.

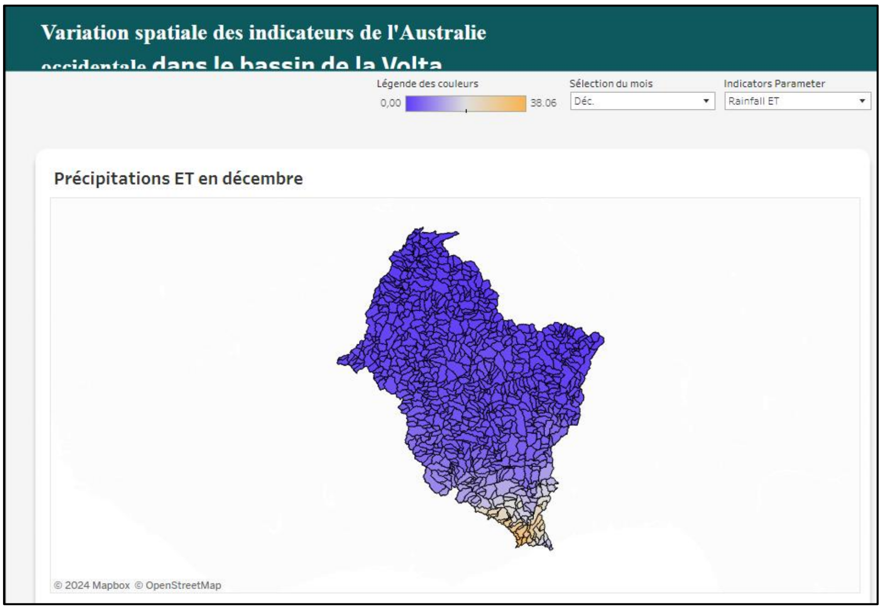
Non	Flux/Indicateurs	Description	Équation
1	*Advection P*	Précipitations reçues dans le bassin, agrégées sur l'année hydrologique	$\sum_{i=1}^{12} P$
2	Entrée de bassin (transfert interbassin)	Eau de surface ou eau souterraine détournée dans le bassin	Q_{in}^{sw} et (Estimations mesurées)Q_{in}^{gw}
3	Entrées brutes, *IG*	Entrées totales de toutes les sources	$P + Q_{in}^{sw} + Q_{in}^{gw}$

4	Variation de l'humidité du sol, ΔSM	Voir l'équation 2.	Voir l'équation 2.
5	Afflux net, *NI*	L'apport brut plus la variation de l'humidité du sol	$GI \pm \Delta SM$
6	ET rainfall, *ETrain*	ETa qui se produit à partir des précipitations efficaces et de l'interception du couvert forestier, résumée pour toutes les classes de couverture terrestre (classes 1 à n).	$\sum_{i=1}^{n} ET_{rain}$
7	ET incrémentiel, *ETincr*	ETa qui se produit à partir d'autres sources, à l'exception des précipitations efficaces et de l'interception. Comprend les extraterrestres provenant de l'eau d'irrigation, des prélèvements d'eau souterraine, des sources d'eau libres, résumés pour toutes les classes de couverture terrestre (classes 1 à n).	$\sum_{i=1}^{n} ET_{incr}$
8	Paysage ET, pays ETa	ETa des paysages naturels (classes d'utilisation des terres protégées, utilisées et modifiées) ; non en raison de la gestion de l'eau.	$ET_{rain} + ET_{incr}$
9	Eau consommée, *Cwater*	ETa totale qui se produit dans tous les paysages sur tous les mois	$\sum_{i=1}^{12} ET_{a}$
10	Débit utilisé, *Uzedflow*	ETa de l'utilisation gérée de l'eau (cultures irriguées, réservoirs gérés).	ET_{incr} de la catégorie d'utilisation gérée de l'eau
11	Eau exploitable, *EXwater*	L'eau exploitable est la quantité d'eau qui peut potentiellement être utilisée dans le bassin	$NI - ET_{landscape}$
12	Eau disponible, *AW*	L'eau qui reste après avoir satisfait aux exigences en matière d'ET et de débit de réserve	$GI - ETa_{land} - Reserve\ Flows$
13	Écoulement utilisable, *Uzbleflow*	L'eau qui peut être réaffectée à d'autres utilisations après avoir pris en compte les débits réservés et les débits utilisés.	$EX_{water} - ER_{flow} - Uzed_{flow}$
14	Prise Qsw	L'écoulement de la rivière à la sortie du bassin	Q_{outlet}^{sw}
15	Débit sortant du bassin (transfert entre bassins)	Eau de surface ou eau souterraine détournée vers des zones situées à l'extérieur du bassin	Q_{out}^{sw} et Q_{out}^{gw}

16	Eau non consommée, *NCwater*	Sortie totale	$Q^{sw}_{outlet} + Q^{sw}_{out} + Q^{gw}_{out}$

3.4 Variation spatiale des indicateurs d'AO

L'onglet Variation spatiale de l'indicateur WA sur le tableau de bord présente les variables des paramètres clés de l'indicateur en Précipitations, ET, Apport en eau et son changement temporel. Au total, cinq paramètres sont présentés sur le tableau de bord : Précipitations, ET bleu, Précipitations ET, ET total et apport en eau. Les unités sont en km3/an

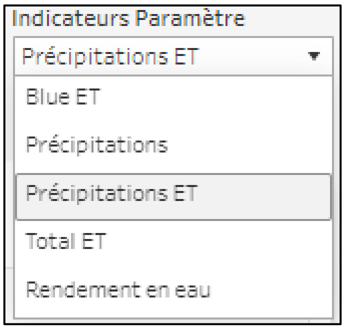

Variation spatiale des indicateurs de l'Australie occidentale dans le bassin de la Volta

Légende des couleurs 0,00 38.06

Sélection du mois: Déc.

Indicators Parameter: Rainfall ET

Précipitations ET en décembre


Indicateurs Paramètre: Précipitations ET

La variation spatiale des comptes de l'eau du bassin est présentée sous forme de cartes mensuelles. Les cartes affichent la variation spatiale mensuelle des précipitations, de l'évapotranspiration totale (ET), des précipitations (P), de l'ET bleu, de l'ET vert et de l'apport en eau en sélectionnant les paramètres pertinents.

Précipitations ET

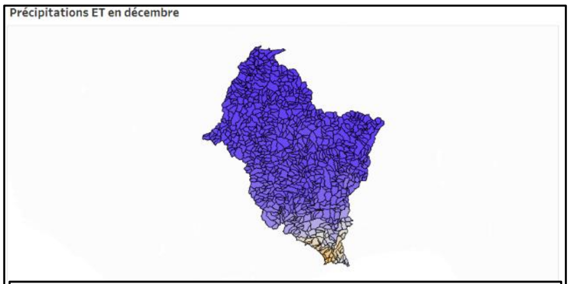
L'évapotranspiration des cultures ou de la végétation (ET) provient de l'eau consommée par la végétation de la zone racinaire, de l'humidité du sol et de l'évaporation du sol de la surface du sol non saturée.

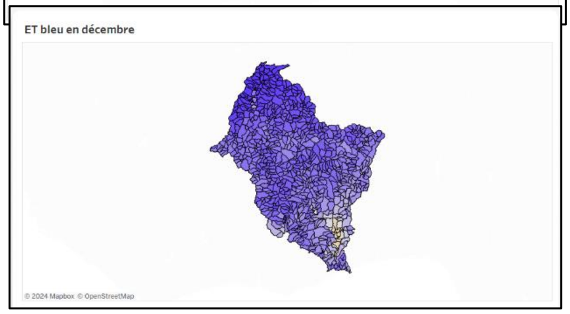
Bleu ET

L'ET bleu provient de l'eau stockée dans les rivières, les ruisseaux, les plans d'eau de surface et les ressources en eaux souterraines.

Rendement en eau

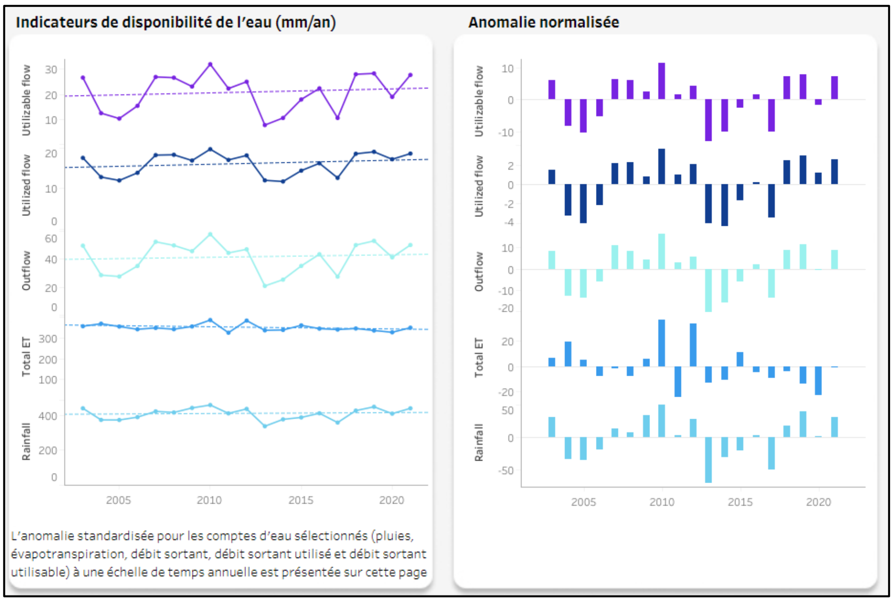
L'apport en eau est défini comme la différence entre P et ET(P-ET)


Précipitations ET en décembre


ET bleu en décembre

3.5 Indicateurs WA

Les changements hydrologiques à long terme font référence à une altération importante et persistante du cycle de l'eau et de la distribution des ressources en eau (à la fois temporelles et spatiales) sur de longues périodes. Sur le tableau de bord, nous présentons des graphiques. Sur le côté gauche, nous présentons les changements à long terme de l'hydrologie en mettant l'accent sur la démonstration de la tendance à la hausse ou à la baisse du paramètre et sur le côté droit, nous présentons des informations sur la quantification du changement pour 2003-2021.



L'anomalie standardisée pour les comptes d'eau sélectionnés (pluies, évapotranspiration, débit sortant, débit sortant utilisé et débit sortant utilisable) à une échelle de temps annuelle est présentée sur cette page

Fonctionnalités supplémentaires sur le tableau de bord :

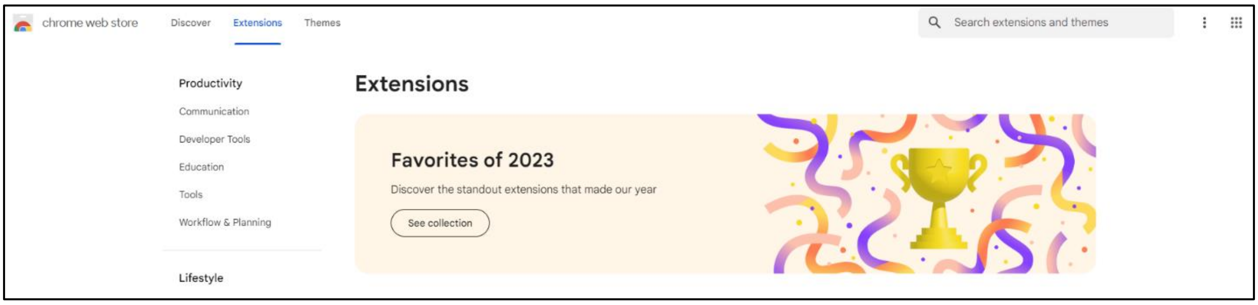
Plusieurs fonctionnalités supplémentaires sont disponibles sur le tableau de bord. Une brève description et l'objectif de chacune des icônes situées dans le coin inférieur droit sont présentés ici.

✉ Contact ? About PDF JPG PPT

Contact : L'icône de contact est située dans le coin inférieur droit du tableau de bord et fournit des informations par e-mail sur les personnes à contacter si vous avez des questions sur le tableau de bord.
À propos : l'icône à propos fournit plus d'informations sur le projet.
Options d'impression : Le tableau de bord peut être imprimé ou enregistré à l'aide de trois options. La vue actuelle du tableau de bord peut être enregistrée sur l'ordinateur local dans trois formats différents : PDF, JPG ou PPT. Veuillez utiliser l'icône appropriée selon vos besoins.

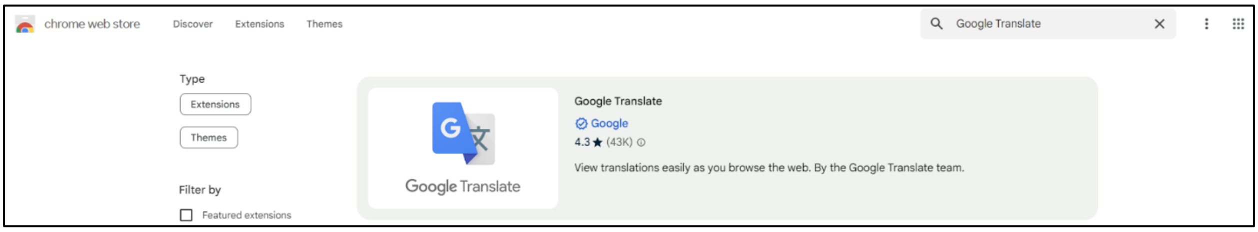
4. Installation du plugin Google translate

1.Allez **au lien à l'aide du navigateur Web Google Chrome** :
https://chromewebstore.google.com/
Le Chrome Web Store s'ouvre



Discover the standout extensions that made our year

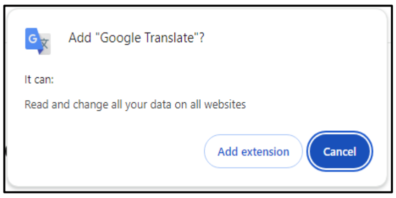
2. **Rechercher Google Translate**
Dans la barre de recherche en haut à droite, tapez « Google Translate », puis appuyez sur Entrée
Ensuite, cliquez sur le haut de l'icône



Google Translate

View translations easily as you browse the web. By the Google Translate team.

3. **Ajouter une extension à Chrome**
Cliquez sur le bouton « Ajouter à Chrome »

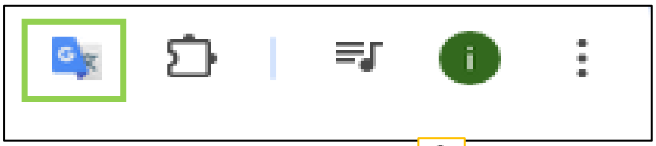

Add "Google Translate"?

It can:

Read and change all your data on all websites

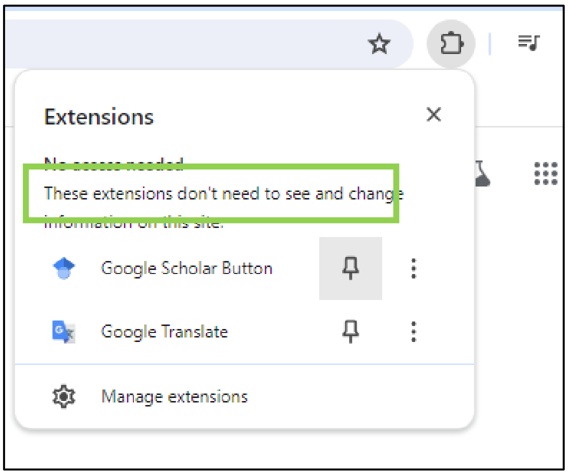
Une fenêtre contextuelle apparaîtra ; cliquez sur « Ajouter une extension » pour confirmer. Maintenant, Google Translate a été ajouté au chrome

L'extension ajoutera automatiquement à la barre d'extension sur Chrome.



Si ce n'est pas le cas, cliquez sur l'icône de l'extension

Cliquez sur l'icône d'épingle



Extensions

No access needed

These extensions don't need to see and change information on this site.

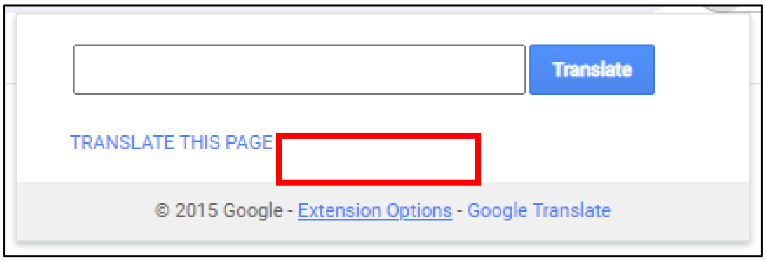
Google Scholar Button

Google Translate

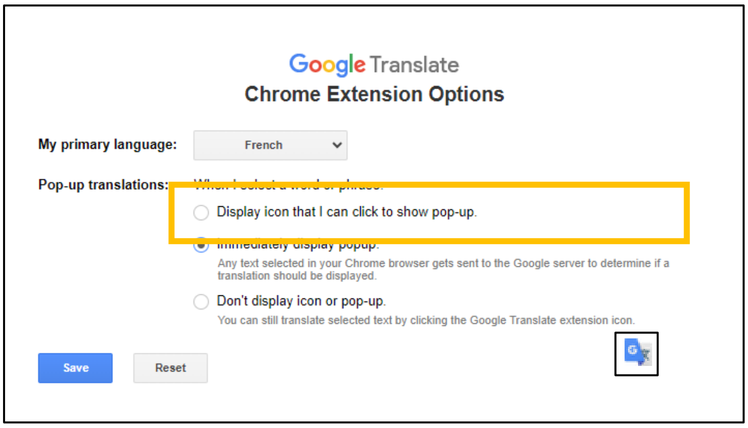
Manage extensions

4. Changer la langue

Cliquez sur l'icône Google translate et accédez à l' **option d'extension**.



Sélectionnez **Ma langue principale comme le français** et cliquez sur Enregistrer.
Sélectionnez « **Afficher immédiatement la fenêtre contextuelle** » : cette fenêtre contextuelle traduit le texte immédiatement lors de sa sélection.



Google Translate
Chrome Extension Options

My primary language: French

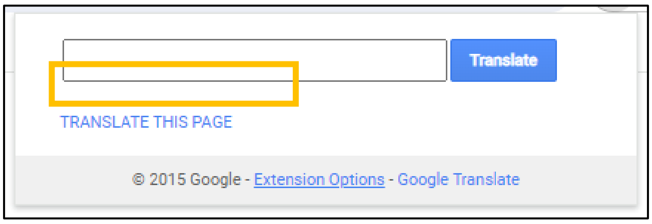
Pop-up translations: When I select a word or phrase:

○ Display icon that I can click to show pop-up.

● Immediately display popup.
Any text selected in your Chrome browser gets sent to the Google server to determine if a translation should be displayed.

○ Don't display icon or pop-up.
You can still translate selected text by clicking the Google Translate extension icon.

Allez à la page Web souhaitée et sélectionnez le texte ou cliquez sur l'icône de traduction et cliquez sur « TRADUIRE CETTE PAGE »

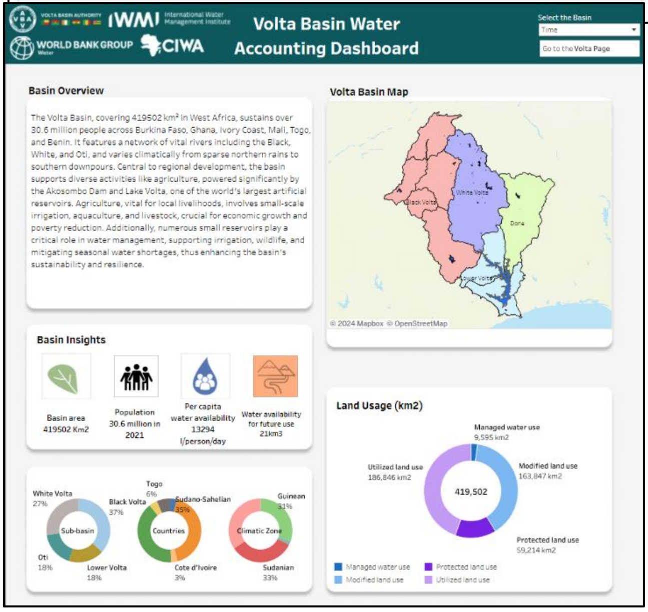


Exemple:

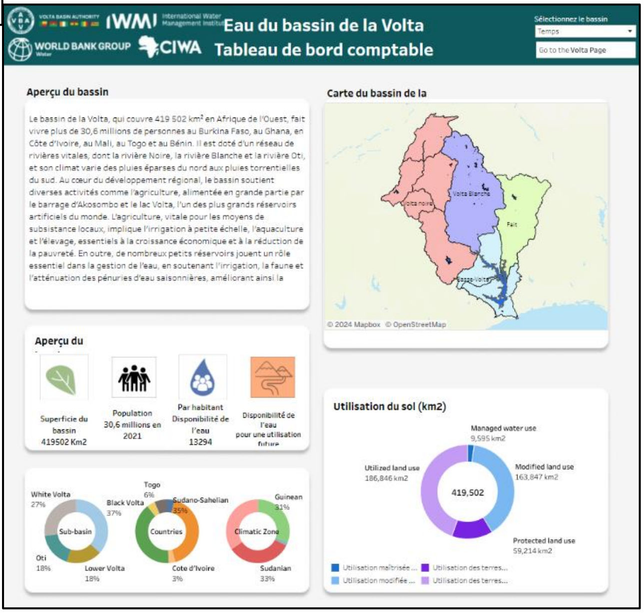
1.Ouvrez la page web : https://public.tableau.com/views/Voltabasinvertical/Merged?%3AshowVizHome=no&%3Aembed=true#1

Cliquez sur l'icône de traduction et cliquez sur

Cliquez ensuite sur « TRADUIRE CETTE PAGE ». Ensuite, la page se traduira



The Volta Basin, covering 419502 km² in West Africa, sustains over 30.6 million people across Burkina Faso, Ghana, Ivory Coast, Mali, Togo, and Benin. It features a network of vital rivers including the Black, White, and Oti, and varies climatically from sparse northern rains to southern downpours. Central to regional development, the basin supports diverse activities like agriculture, powered significantly by the Akosombo Dam and Lake Volta, one of the world's largest artificial reservoirs. Agriculture, vital for local livelihoods, involves small-scale irrigation, aquaculture, and livestock, crucial for economic growth and poverty reduction. Additionally, numerous small reservoirs play a critical role in water management, supporting irrigation, wildlife, and mitigating seasonal water shortages, thus enhancing the basin's sustainability and resilience.



Le bassin de la Volta, qui couvre 419 502 km² en Afrique de l'Ouest, fait vivre plus de 30,6 millions de personnes au Burkina Faso, au Ghana, en Côte d'Ivoire, au Mali, au Togo et au Bénin. Il est doté d'un réseau de rivières vitales, dont la rivière Noire, la rivière Blanche et la rivière Oti, et son climat varie des pluies éparses du nord aux pluies torrentielles du sud. Au cœur du développement régional, le bassin soutient diverses activités comme l'agriculture, alimentée en grande partie par le barrage d'Akosombo et le lac Volta, l'un des plus grands réservoirs artificiels du monde. L'agriculture, vitale pour les moyens de subsistance locaux, implique l'irrigation à petite échelle, l'aquaculture et l'élevage, essentiels à la croissance économique et à la réduction de la pauvreté. En outre, de nombreux petits réservoirs jouent un rôle essentiel dans la gestion de l'eau, en soutenant l'irrigation, la faune et l'atténuation des pénuries d'eau saisonnières, améliorant ainsi la

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