



Water Management: Insights from Two Distinct Sub-Saharan Africa

Awol Kedir Jewaro^{1*}, M. Yunus Pamukoglu², Martina Zelenakova³

¹Suleyman Demirel University, Graduate School of Natural and Applied Sciences, Department of Water Management, Türkiye

²Suleyman Demirel University, Faculty of Engineering and Natural Sciences, Department of Environmental Engineering, Türkiye

³Technical University of Košice, Faculty of Civil Engineering, Department of Environmental Engineering, Slovakia

*e-mail: d2040186051@ogr.sdu.edu.tr

Abstract

Water management seeks the optimal solutions to the challenges posed by society's demand for food security, energy production, socioeconomic advancement, and sound ecosystems. In the 21st century, the complexities of natural disasters and human-induced factors impede the ability to address water security issues. Sub-Saharan Africa is at a critical juncture where it must implement substantial reforms in the planning and management of its water systems to enhance the sustainability of its water resources. Yet, the region faces numerous water-related issues due to complex natural disasters and human factors such as urbanization and population growth, particularly in countries like Ethiopia and Mauritania. This paper delves into the availability, sustainability, management, and governance of water in these two regions of Horn Africa (Ethiopia) and Western Africa (Mauritania). It also highlights the practices involved in planning, managing, and utilizing water systems and services in these areas. Therefore, this paper provides a foundation for further research and the development of sustainable water resources management in the region.

Keywords: sub-Saharan Africa; water resources; water security; climate change; sustainability

1 Introduction

Water is a fundamental element of life, and it represents a shared legacy with diverse functions, applications, and roles [1,2]. It is also limited in quantity, susceptible to pollution, and subject to the impacts of climate fluctuations, thereby casting doubt on its future accessibility. Similarly, the whole life on planet Earth relies on water systems to sustain food security, energy generation, socioeconomic development, and sound ecosystems. Furthermore, these resources are considered as central to natural environment sustainability and ecological ecosystem evolution.

Globally, the prosperity of communities relies significantly on effectively utilizing water as a valuable resource [3]. The availability and management of these resources significantly influence a nation's prosperity and the well-being of its society. However, with recent rapid industrialization and rapid population increases, the availability and sustainable management of this precious natural resource compromised [4]. On the other hand, concerns about whether there is adequate quantity and quality of water resources to meet societal needs have increasingly become uncertain in recent decades. Especially, with the challenges posed by climate change, complex natural disasters, anthropogenic factors (Figure 5), and the rising demand for this resource have hindered efforts to address water issues [3].

This situation is particularly notable in Sub-Saharan African (SSA) countries [5] such as Ethiopia and Mauritania. The combination of rapid population growth and unplanned urbanization in SSA, coupled with high climate variability, underscores the critical importance of addressing water challenges [6]. The region is notably deficient in access to water supply and sanitation, as highlighted by [7]. Consequently, issues such as increased water pollution, depletion of water resources, ecosystem degradation, and socioeconomic and environmental factors pose significant threats to the region's progress toward water security.

In recent years, complex natural disasters (Figure 5) such as drought, flood, hurricane, have been witnessed on all continents, affecting vast regions the world [8,9]. Among them, Sub-Saharan Africa has recently witnessed exhausting challenges like water scarcity and drought. The region has experienced the worst impacts of climate change, resulting in a significant decline in an annual total precipitation, water scarcity, drought and in some other places flood in the last two decades. This is becoming more severe particularly in western and horn of Africa including Mauritania and Ethiopia.

Water security entails the sustainable and consistent availability of sufficient and acceptable quality water to meet the needs of both human populations and ecosystems, while mitigating potential risks [10]. It involves ensuring the long-term protection of water resources to support current and future generations. Water scarcity arises from an imbalance between water supply and demand in a given geographical area. This issue is particularly pressing in developing countries, especially in Sub-Saharan Africa (SSA), where rapid population growth and climate change are exacerbating water stress. According to [11], under current climate conditions, approximately 50% of the global population in around 50 countries, including those in SSA, could face water stress or scarcity within the next 20 years.

In response to the various water-related challenges facing humanity, the United Nations General Assembly (UNGA) established the Sustainable Development Goals (SDGs) in 2015, with SDG 6—ensuring the availability and sustainable management of water and sanitation for all—as a primary objective [12]. Among responses to such challenges, this paper highlights availability, sustainability, policies and regulations, management and governance of water resources in the two SSA regions. Consequently, in a rapidly changing world, the management of water resources in the Sub-Saharan Africa regions of Ethiopia and Mauritania must prioritize addressing key challenges to achieve SDG and sustainable water resource management in particular.

There are only a few studies that address more than one region of Africa so far as ascertained from the literature. Similarly, there is no exhaustive study covering the two SSA regions. Therefore, this paper aims to address some of these gaps. Thus, here the paper contributes to the sharing of experience emphasizing water availability, management, and governance in two distinct SSA regions, presenting the case of Ethiopia, and Mauritania and finally proffering substantial remarks. It is hoped that these lessons will shed light on water resources management and help the two countries and other sub-Saharan Africa to ensure sustainable water management and SDGs particularly goal 6 (Clean Water and Sanitation) and goal 13 (Climate Action).

The two study regions constitute the sub-Saharan Africa in eastern and western Africa where the paper highlights main challenges. The challenges of water management vary from region to region [13,14], but the nature of prospective solutions to water-related challenges remains the same for different regions, including the two regions (Ethiopia horn of Africa and Western region Mauritania). Therefore, this paper addresses availability, sustainability, challenges, governance and management of water resources in the two regions. In these contexts, this paper makes a novel contribution to the literature on availability, dimensions, regulations, governance and management of water resources in two regions. The lessons learned from the paper include:

- Exploring up to date approaches for sustainable planning and management of water resources to achieve sustainable use of water resources in the two regions
- Addressing the two regions water issues, policies and regulation mechanisms to improve water sustainable planning and demonstrate how one country could learn from the experiences of the other
- Demonstrate lessons learned and put out a comprehensive, consistent, forward-looking on water resources management in Ethiopia, Mauritania, and the rest of SSA regions

2 Materials and Methods

For this article, a comprehensive literature review has been conducted to encompass Water Management: Insights from Two Distinct Sub-Saharan Africa. Sub-Saharan regions, including densely populated countries like Ethiopia and arid desert climate countries such as Mauritania, are striving to find sustainable solutions to water-related issues. This paper's content is based on an extensive literature review that consolidates key research findings on water resources management in Sub-Saharan Africa.

With a focus on Ethiopia, representing one of the most populous countries in Sub-Saharan Africa characterized by highland and sub-tropical regions with relatively abundant water resources, and Mauritania, which exemplifies the water scarcity issues faced by arid and semi-arid regions in Sub-Saharan Africa, providing insights into water management practices in water-scarce environment. Thus, the paper facilitates discussions aimed at improving water management and governance for sustainable development, illustrating how one country can learn from the experiences of the other.

The study was designed to be exploratory, involving content analysis and analyzing data from legislative, administrative and hydrographic areas. Initially, the study focused on two Sub-Saharan regions representing extreme scenarios: non-arid Ethiopia and arid Mauritania, both

affected by complex natural disasters and human factors. The primary data sources were mainly obtained from official agencies in both countries, supplemented by other sources. The data on water resource availability and status in these regions were sourced from the AQUASTAT database, an information system managed by the Food and Agriculture Organization (FAO). The results are presented in tables and figures to illustrate the findings.

The Federal Democratic Republic of Ethiopia, situated in the Horn of Africa (Figure 1), has a population exceeding 125 million [15]. It shares borders with Eritrea and Djibouti to the north, Somalia to the east, Kenya and Somalia to the south, and Sudan and South Sudan to the west. Ethiopia spans an area of 1,127 km², with a water area of 7,444 km² and varying altitudes from 4,550m (Ras Dejan Mountain) to 125m (Dalol Depression) below sea level [16].

Mauritania is a country located in the west of the African continent (Figure 1). The country borders with Western Sahara, Morocco, and the Saharan Democratic Arab Republic, Algeria, Mali and Senegal and bounded on the west by the Atlantic Ocean. Mauritania having a population exceeding 5 million is a water-poor country located partly within the Sahara Desert, receiving very little rainfall [17]. Only the coastal regions of the country receive significant seasonal rainfall. Despite being a water poor nation, in 2000, the country was also one of the world's largest water consumers, with more than 5000 m³ per capita (Figure 3). The total available freshwater resources (surface and groundwaters) were estimated at about 11.5 billion m³ and the total withdrawal water for domestic, agricultural, and industrial purposes (Figure 2) is estimated as 1.7 billion m³ [18].

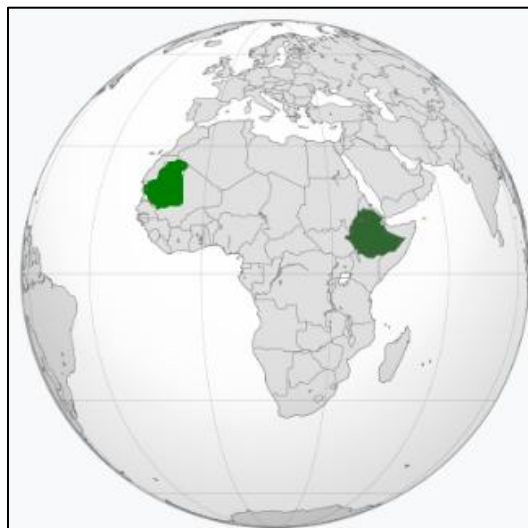


Figure 1. The geo-referenced map of the two regions (Ethiopia and Mauritania) showing its location on the globe in the Eastern and Western of Africa, indicated in Green

3 Results and discussions

3.1 Availability, sustainability, management and governance of water resources in the two regions

The intricacy of water as a multidimensional strategic resource has been widely debated in many parts of the world [19]. The sustainable management of water resources has thus become a core topic of debate stemming from complex natural disasters and human induced factors, the two regions experiencing enormous challenges in water security. Water availability pertains to the physical quantity of water that is accessible for use in a given region or system. It is influenced by factors such as climate, precipitation, surface water flows, groundwater reserves, and seasonal variations [20]. While water may be physically available in some areas, its usability can be constrained by factors like pollution, salinity, inaccessibility, salinity, inaccessibility, poor infrastructure and unsustainable management.

The global water availability is finite, and Africa, being one of the most populous and driest continents, faces particular challenges in this regard [21]. Africa is the second driest continent in the world after Australia, and the most populous continent in the world after Asia [22,23]. The continental annual average water availability per capita is 4,008 m³/person /year, very low below the global average of 6,498 m³ [24]. The continent represents only 9 percent of global freshwater resources, whereas 15 percent of the global population.

In SSA, the lack of access to potable drinking water, a prevalent issue. According to Nkiaka et al.,[7] who assessed SSA using the Water–Energy–Food (WEF) Nexus Index tool, indicates suboptimal performance, with countries in the West African sub-region of Mauritania performing worst. Across SSA, 69 percent of the population lacks adequate sanitation and hygiene facilities, and 40 percent are without access to clean water and the availability of improved sanitation facilities stands at about 18% [25]. For example, in Ethiopia, approximately half of its population has no access to safe drinking water services, while only 14% having access to safely managed drinking water [23]. Conversely, relatively with its smaller population Mauritania boasts a higher level of access to basic drinking water services at about 78%, with 65% of the population having improved sanitation facilities and 87% having access to improved drinking water sources [26,27].

Moreover, both the availability and distribution of water vary significantly across the continent [28], thus leading to economic imbalances, poor governance, and institutional failures. Some regions have an abundance of water while others struggle with severe shortages. For example, in areas such as Sub-Saharan Africa, specifically in arid and semi-arid region of Mauritania and some areas of Ethiopia chronic water shortages are prevalent. As opposed to East and Northwestern areas, the central African region and southern parts relatively possess ample waters.

Ethiopia naturally possesses abundant water resources that could meet domestic needs, provided sufficient financial resources are allocated for water resources development [29]. Owing to its geographical location and favorable climate, the country gets relatively high rainfall. However, more than 80% of the country's water resources are found only in the four major basins which contain no more than one third of the country's population [16, 29]. Furthermore, in recent

years, there has been a significant decrease in precipitation, making the country likely to face challenges in achieving water and food security due to the dramatic effects of climate change. Geographically Mauritania is located in one of the regions mostly affected by complex disasters in sub-Saharan Africa. Natural calamities such as climate change, temperature increase and rainfall variability accelerating depletion of water resources in the region [30]. The sum of total renewable groundwater and renewable surface water resources (both internal and external) is estimated as 11.4 billion m³ per year [31,32].

With a total annual water withdrawal of nearly 6 billion cubic meters (BCM), Ethiopia faces moderate to high water stress, projected to increase by 2040 to 0.55, indicating high water stress due to population growth and climate change impacts [11, 18]. Similarly, Mauritania classified as a water-scarce country, with a water stress index of 0.85 [33, 34] indicating very high-water stress projected to remain high, necessitating urgent use of innovative water technologies alongside traditional water management practices, provides a balanced approach to addressing water scarcity. Therefore, improved water use efficiency such as smart irrigation system and investment in infrastructure are essential to address water issues and enhance sustainable development.

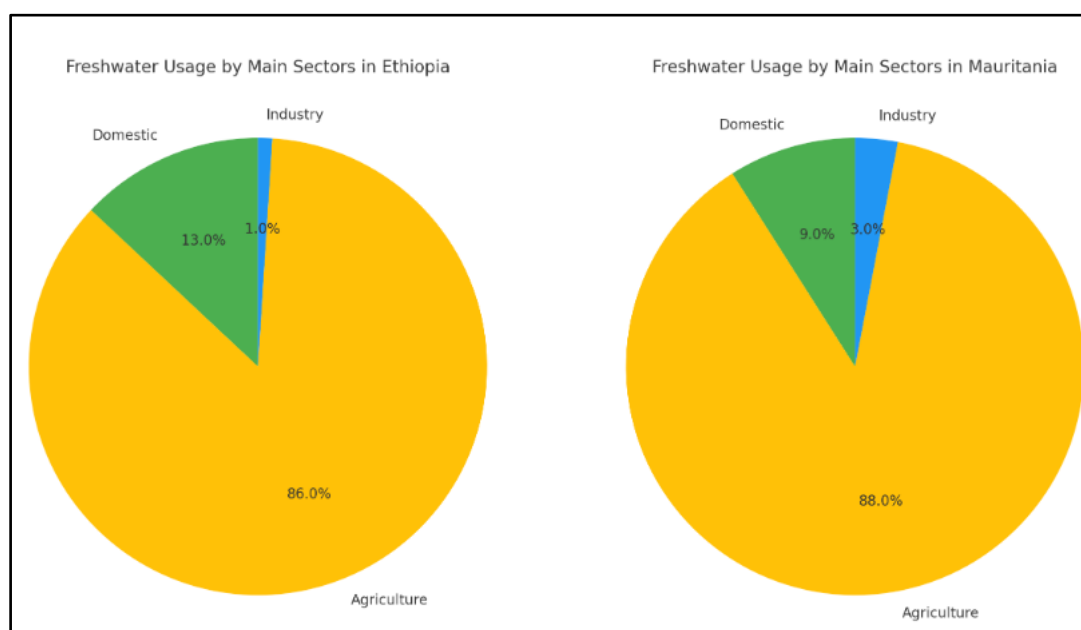


Figure 2. The two countries' freshwater allocation for domestic, agriculture and industry [23,33]

The above figure illustrates that the agricultural sector is the largest water consumer in both countries. In both regions, more than 85% of the water allocation is used for agricultural purposes, which is notably above the global average of 70%. Likewise, the following figure 3 reveals concise water resources per capita in the two regions.

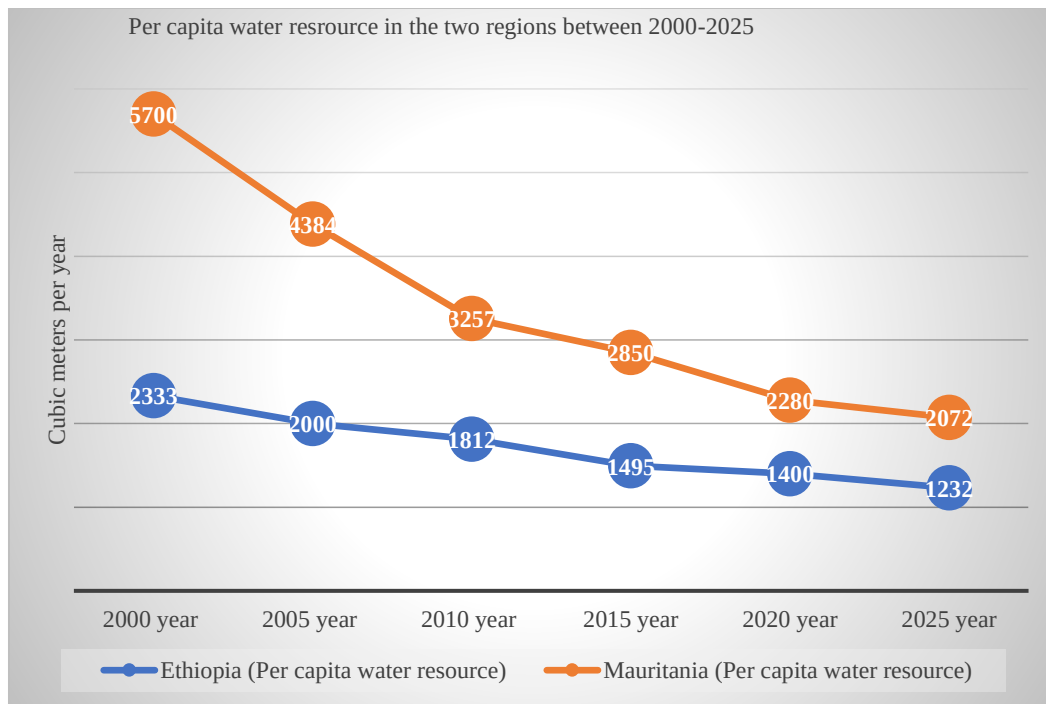


Figure 3. Water resource per capita in the two regions ($\text{m}^3/\text{person}/\text{year}$) [29,34,35]

Figure 3 shows that although Mauritania is a water-poor country in terms of availability, the country yet consumes significant water per capita taking into account its small inhabitants. Although Ethiopia has relatively abundant freshwater availability, rapid population growth effectively resulting in the country's per capita water potential to sharply decrease notably in the past two decades.

On the other hand, Mauritania heavily relies on the Senegal River, its tributaries, and dam reservoirs, an arch dam on the Gorgol River near Fom Gleita in the Golgol region of the country. Based on total water withdrawal (Figure 3) in 2000, the country ranked among the largest water consumption with more than 5000 m^3 per capita [32,35]. However, given they have very significant external water dependency, its population may still remain in an insecure water condition. Additionally, given the ratio of water withdrawal to water availability exceeds 40%; the country may be categorized as high stress in a short time and extremely high stress on the year 2025 [28, 29].

The challenge of sustainably managing water systems in Sub-Saharan Africa is highly complex and multifaceted, with key obstacles including the lack of robust mechanisms for sustainable resource utilization and infrastructure management. Both regions of SSA exhibit a deficiency in long-term planning that addresses current infrastructure management challenges while promoting social and economic development and ensuring the sustainability of water resources. Wilderer [36] have demonstrated that sustainability in water resources is achieved when water abstraction rates do not surpass natural or artificial recharge rates. Similarly, Loucks and Van Beek [37] underscores the importance of considering future and long-term objectives in water resources management, alongside immediate needs. Sustainability in water resources, therefore,

encompasses the planning and management of water systems to ensure availability, accessibility, quality, security, and affordability of water amidst social, environmental, and economic challenges. This is especially difficult for economically less-developed SSA region of Ethiopia and Mauritania. Table 1 describes a summary of comparable information about the water resources potential, country area, population, land use, differences in geographic or elevation in both countries.

Table 1. Summary of water resources potential, availability and hydrographic in both the region [16, 18, 27, 42]

Country/ region	Water resources potential	Country area/elevation	Population	Land use	Geographic/ hydrographic
Ethiopia	○ Relatively have abundant water resources (rivers, lakes and wetlands) ○ Annual rainfall varies widely across regions, with some areas receiving up to 2,000 mm per year.	○ Covers 1,112 million km² ○ Diverse topography, with elevations ranging from below sea level to over 4,500 meters above sea level	○ As of 2024 estimated to be about 132 million (Density 92.7/km²)	○ Agriculture is the dominant land use ○ Forests, grasslands, and wetlands cover significant portions of the country	○ Sub-Saharan Africa (Horn of Africa) ○ Predominantly tropical monsoon climate, with wide topographic-induced variation
Mauritania	○ Significant water insecurity, the near-absolute reliance on ground waters and transboundary waters ○ Annual rainfall is very low, often less than 100 mm per year	○ Covers 1,031 million km² ○ Generally flat, with vast desert plains (highest point stands at 915 meters above sea level)	○ As of 2024 estimated to be 4,5 million (Density 3.4/km²)	○ Pastoralism and nomadic herding are common land uses, with livestock being a significant part of the economy.	○ Sub-Saharan Africa (western region of the continent of Africa) ○ Arid and semi-arid climate (desert landscapes dominate much of the country)

3.2 Water resources policies and regulations

The water resources policies and regulations may vary across countries and regions, but there are some common elements and principles (Figure 4) that set water usage and quality standards [39,40]. It points out necessary arrangements considering human and environmental needs for various water uses such as agriculture, domestic, industry, power production, and preservation of the environment and the ecology of ecosystems. As pointed out by [41], an assessment of water resources policies and regulations in Mauritania reveals challenges in ensuring robust policies and regulations, as well as a general lack of water availability and sanitation services. In Ethiopia, the rapid population growth and increased water demand are identified as

significant factors exerting substantial pressure on the sustainability of water resource management and progress toward achieving the SDGs [42,43].

Therefore, the region must remain committed to developing additional strategies and practical applications such as utilizing non-conventional water sources, promoting water reuse, and enhancing water efficiency, to support and modernize regulations for the utilization and sustainable management of water resources through the construction of multifunctional water infrastructure.

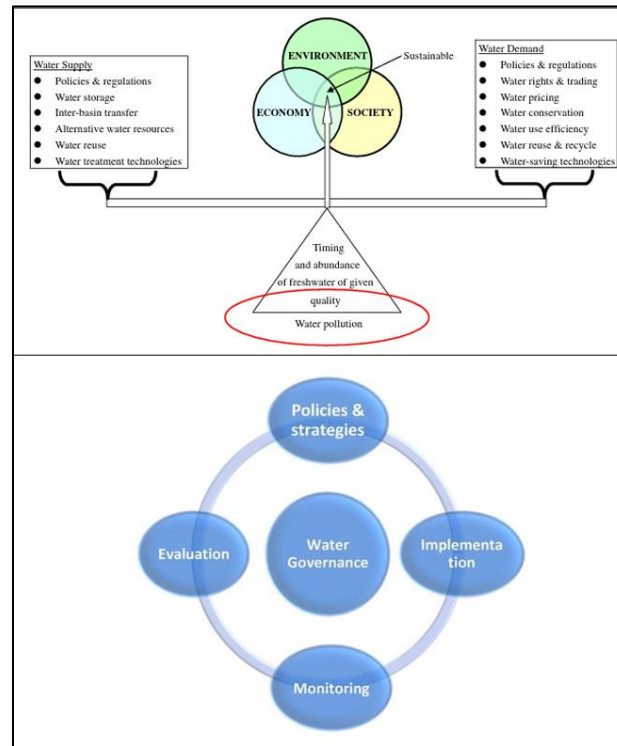


Figure 4. Schematic illustrations for sustainable water resources management and governance [39]

Water policy changes and reforms (Table 2) in Ethiopia, have been driven by the need to address water scarcity, promote sustainable water management, and enhance water security. Some notable water policy changes and reforms in the region are summarized in the following table.

Table 2. Water policy changes and reforms in Ethiopia [16]

Period	Title	Features
1997	Environmental Policy of Ethiopia	Determines water related national policy issues
1999	Water Resources Management Policy (EWRMP)	Leads water management and outline national goals for basins
2001	Water Sector Strategy	Guideline transboundary water management nationwide
2005	Water Resources Management Regulations	Determines the rights and obligations of water users

2007	Authorities Proclamation	Specify the framework of water basins and determine powers, responsibilities of the entities
2018	Powers and Duties of the Executive Organs Proclamation	Remark institutional structures and obligations for concerned authorities mainly basins authority

These policy changes and reforms in water management in Ethiopia aims to demonstrate a commitment to addressing water challenges, promoting sustainable water use, and enhancing water security. However, effective implementation and continuous monitoring and evaluation are essential to ensuring the success and impact of these reforms in achieving sustainable water management goals.

Mauritania has enacted legislative measures to define water rights and regulate water use, while also promoting community engagement and traditional practices [18]. The country's heavy reliance on groundwater underscores the critical need to prevent over-extraction and depletion of aquifers. This necessitates the implementation of clear legislative frameworks for sustainable groundwater management. Likewise, as shown in table 3, describes various ministries and institutions mandated for the leadership of governance system related to water resources management in Ethiopia and Mauritania.

Table 3. Water resources management institutions and their mandates [16, 23]

Region	Ministries and Entities	Scope, Mandate and Major Duties
Ethiopia	Ministry of Water and Energy (MoWE)	Responsible for designing water policies and legal frameworks as well as overall management of water resources
	Ministry of Irrigation and Lowland (MILL)	Mandated fort the development and management of lowland areas and irrigation schemes
	Ministry of Environment, Forest, and Climate Change (MEFCC)	Conduct Research Program on Environment, water and forest Develop environmental policies and regulations to ensure ecological integrity
	Water Development Commission	Provision of water and sanitation services
	Ministry of Agriculture (MoA)	Monitor optimum utilization of water for small-medium irrigation to promote food security
	Ministry of Industry (MoI)	Ensure environmental welfare and carry out pollution control studies, in accordance with state laws and regulations.
	Regional Water Bureaus (RWB)	Administer and supervise regional water utility
Mauritania	The Ministry of Waterworks and Sanitation (MHA)	Responsible for water policy, management, as well as water supply and sanitation services -supervises locally operating companies in the water sector
	National Water Corporation (SNDE)	Responsible for urban water supply

	National Rural Water Agency (ONSER4)	Responsible for rural water supply
	the National Water Resources Center (CNRE)	Lead in charge of water resource planning and monitoring
	the National Drilling Corporation (SNFP)	Responsible for borehole drilling
	the National Sanitation Agency (ONAS)	Responsible for urban sanitation

Table 3 provides an overview of the water resource management institutions and their mandates in Ethiopia and Mauritania, highlighting the structural and institutional differences between the two countries. In Ethiopia, water resource management is distributed across multiple ministries and commissions, each with a specialized focus. For instance, the Ministry of Water and Energy (MoWE) oversees overall water policies and resource management, while the Ministry of Irrigation and Lowland Development (MILL) focuses on irrigation and lowland areas. This decentralized approach enables Ethiopia to address specific challenges, such as small- and medium-scale irrigation needs (led by the Ministry of Agriculture) and pollution control (handled by the Ministry of Industry). However, this fragmentation can also create challenges in coordination and resource allocation, which might result in inefficiencies and overlapping mandates.

In contrast, Mauritania adopts a more centralized structure, with fewer institutions handling broader responsibilities. The Ministry of Waterworks and Sanitation (MHA) plays a dominant role in water policy and management, alongside a few specialized agencies such as the National Water Corporation (SNDE) for urban water supply and the National Rural Water Agency (ONSER4) for rural areas. While this streamlined approach allows for a more unified framework, it may limit the ability to address diverse and localized water management issues comprehensively. Notably, the National Water Resources Center (CNRE) plays a critical role in resource planning and monitoring, which is essential for a country facing significant water scarcity challenges.

Overall, the table highlights the importance of tailoring water resource management structures to a country's specific needs and challenges. Ethiopia's approach may be better suited to a larger, more diverse country with varying geographical and water-related challenges, whereas Mauritania's centralized system may align with its smaller scale and simpler administrative requirements. However, both countries can benefit from improving inter-agency collaboration and aligning their mandates to avoid redundancies and ensure sustainable water resource governance. These insights are critical for understanding the institutional challenges and opportunities in water management within Sub-Saharan Africa.

3.3. Emerging water management problems and subsequent implications in the two regions

3.3.1 Water pollution

As a developing region of SSA, Ethiopia and Mauritania experiencing serious water pollution and water stress which undermine human and ecosystem functionality. Caused by the absence

of adequate infrastructure, water treatment facilities and regulations, diffuse sources of pollution and sewage discharge into waterbodies are a common practice in both the countries. The significant amount of pollution originates from various sources, including sewage and improper wastewater disposal, agricultural runoff containing fertilizers and pesticides, industrial processes, and solid waste. Regarding water quality, approximately 80% of industrial waste is released into the environment worldwide without treatment, and nearly all major rivers in Africa are considered polluted [44,45]. This pollution has a detrimental impact on water systems, human health, and the health of other ecosystems.

For example, it is concerning that, after nearly a century, cholera has reemerged in Africa, accounting for 94% of the global cholera cases reported during this time. Besides cholera, the most widespread outbreaks of waterborne diseases like typhoid fever, viruses, rotaviruses, and the parasitic protozoan are frequently linked to inadequate water supply and poor hygiene. According to reports from the WHO [46,47,48], nine out of ten cases affect children, and 50% of childhood deaths occur in sub-Saharan Africa. Furthermore, due to a significant portion of the population lacking access to sanitation and safe drinking water, the overall economic loss is estimated to be around 5% of the gross domestic product (GDP).

3.3.2 Climate change

In this twenty first century, the challenges brought on by complex natural disasters and anthropogenic dimensions hinder the ability to cope with water security issues. Climate change is a formidable challenge affecting development, particularly in Sub-Saharan Africa. It directly affects water resources through changing the quantity, variability, timing, form, and intensity of precipitation, and indirectly impacts water resources by escalating water temperature, raising evapotranspiration rate, and reducing water quality [49,50]. As illustrated in figure 5, because of the major implications of climate change and anthropogenic activities on water, food security, and socio-economic development, there would be substantial reduction in freshwater resources and agricultural production.

Approximately one-third of Africa is comprised of subtropical deserts, and the region's biomass burning contributes around 14% of global greenhouse gas emissions (CO₂ equivalent to about 1.4×10^{12} kg/year) [30]. This significantly impacts the radiation reaching the Earth, contributing to global warming. Notably, warming trends of +0.05 °C per year are observed in the highlands of East Africa, Southern Africa, and across the Sahara Desert [30]. Furthermore, according to Misra [51], by 2050, rainfall in Sub-Saharan Africa could decrease by 10%, leading to a 17% reduction in drainage, thus resulting in critical water and food insecurity. Therefore, there is a pressing need for insightful solutions to adapt to and mitigate its impacts to ensure the sustainable efficiency of finite resources. Strengthening mitigation techniques, improving adaptability, and developing nature-based solutions are essential steps to take.

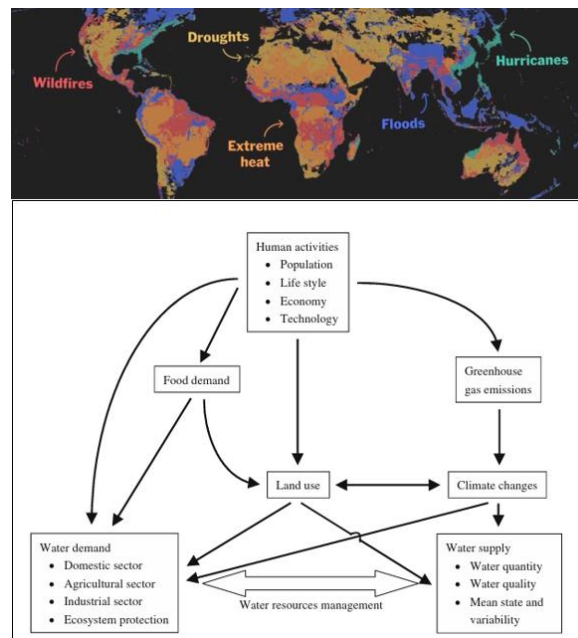


Figure 5. The evolution of natural hazards, anthropogenic activities, climate change, and water supply and demand [39]

Figure 5 effectively captures the systemic connections between environmental and human factors affecting water resources. The figure illustrates the complex interplay between natural hazards (e.g., droughts, floods, extreme heat, hurricanes), anthropogenic activities, climate change, and water resource management. It highlights how human activities such as population growth, economic activities, and technological advancements drive water and food demand, and land use changes. These, in turn, impact water demand across sectors (domestic, agricultural, industrial) and influence ecosystem protection efforts. The diagram also emphasizes the feedback loops, where climate change, driven by greenhouse gas emissions, alters water supply quality and availability, which necessitates adaptive water resource management.

3.3.3 Water demand-supply disproportionality

Water supply has been an integral part of social organization and the structural dynamics of human societies [45]. However, the disproportion between demand and supply in developing countries of SSA, especially in populous region, Ethiopia and the physically scarce region of Mauritania, will lead to unpredictable challenges over time. When the demand for water exceeds the available supply, or when its quality restricts its usability for specific purposes, water scarcity may occur [53,54]. In turn this can be driven by natural causes, such as prolonged droughts, or human-induced factors, including over-extraction, inefficient water use, and population growth. Similarly, water scarcity typically can be categorized as physical water scarcity (a shortage due to natural hydrological limits) and economic water scarcity (a lack of access due to insufficient infrastructure or investment) [55]. On the other hand, water stress describes the extent to which water demands outstrips supply in a given area, considering both

quantity and quality [56,57]. It provides a broader measure than scarcity, taking into account the availability of renewable freshwater resources, water withdrawals for agriculture, industry, and domestic use, and ecological needs. Regions experiencing water stress may have sufficient water resources in absolute terms but face challenges due to overuse, pollution, or seasonal variability.

On the other hand, water demand is influenced by several factors, including access, potential cost, socio-economic status, population, weather conditions, and water policies [58]. As such, with increased population growth, agricultural expansion, land use change, climate change, inefficient water management, and unsustainable water consumption practices, the demand for water exceeds the available supply in these two regions. This increase in demand and decrease in the supply of freshwater will put additional stress on regional countries that are already facing difficult water resource challenges. Therefore, there is a growing necessity to ensure proportionality and resilience in water infrastructure planning and management.

Water supply provision in Ethiopia is determined by various factors, primarily technical and financial, and facilities vary between urban and rural areas. The situation is dire in rural and semi-arid regions of the country, where accessing available water is challenging and boreholes can be up to 500 m deep, with the water being very hot. On the other hand, there is also a significant disparity between where most people live and where water is plentiful and easily accessible. For instance, more than 80% of Ethiopia's principal water resources are found only in the four major river basins, which contain no more than one-third of the country's population [16]. Conversely, Mauritania is arid, and its very limited freshwater resources are augmented by large rivers flowing from much wetter areas upstream of the Senegal river basin.

According to the WHO, the average water for household/domestic use per person per day to meet basic human needs should be in the range of 50–100 liters [59]. However, the average domestic water use in Ethiopia is approximately 20 liters per person per day, and in Mauritania, it is around 35 liters per person per day [60]. In Ethiopia, this lack of access is mostly due to economic and technical rather than physical scarcity, while in Mauritania, it stems from both economic and technical issues, as well as physical scarcity due to vast arid plains. Nonetheless, while it is important to better understand water demand patterns, it is essential to introduce incentives and sustainable approaches, develop context-specific financial policies, and implement alternative measures such as wastewater treatment, all tailored to the needs of the region.

3.3.4 Transboundary water issues

Roughly 40% of the global population resides within river and lake basins that span multiple countries, encompassing approximately 60% of the world's freshwater resources [61].

Transboundary water resources are especially important in Africa, where 63 international transboundary river basins cover about 62% of the region's land area and account for 90% of the total surface water [62]. They have the potential to stimulate economic growth, secure livelihoods, and alleviate poverty in Sub-Saharan Africa. However, they also pose significant challenges for cooperation, management, and governance. Additionally, many transboundary water agreements in Africa are outdated, incomplete, or poorly implemented. As a result, substantial challenges and limitations arising between upstream and downstream riparian

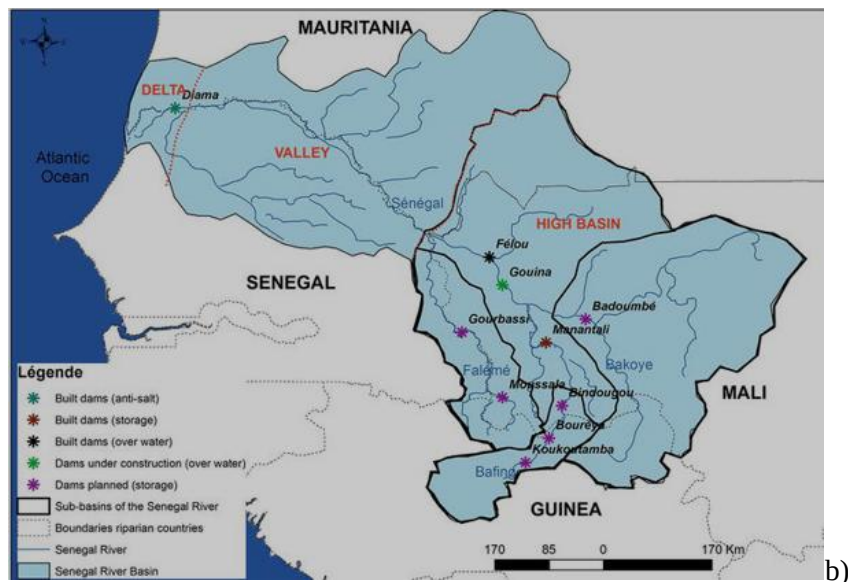


Figure 6. The Nile River (a) and The Senegal River Basin (b) [37,41]

3.3.5 Policy and institutional deficit challenge

Policy and institutional deficit are significant challenges faced by many countries in developing world [66]. Meanwhile, countries in SSA, particularly such as Ethiopia and Mauritania face significant challenges related to policy and institutional deficits that impede economic development and the sustainable management of their resources.

The region has been largely criticized for its weak institutional framework and insufficient financial resources needed to promote the sustainable socioeconomic transformation of its natural capital. Reports indicate that the two regions failed to achieve most of the Millennium Development Goals and have been performing poorly on the 2030 SDGs agenda [67,68]. Figure 7 summarizes gaps, challenges and limitations in both regions.

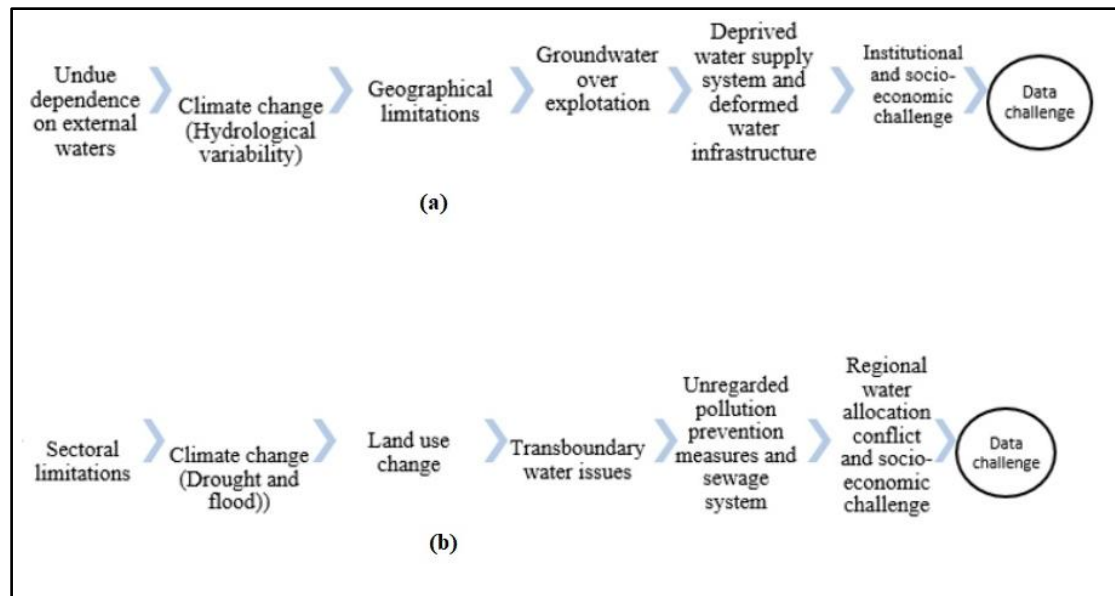


Figure 7. (a) Gaps, challenges and limitations in Mauritania; (b) Gaps, challenges and limitations in Ethiopia

The provided visualizations (Figure 7 and table 4) provide an insightful comparative analysis of water resource challenges and management strategies in Ethiopia and Mauritania.

The figure highlights the distinct, yet interconnected challenges faced by each country, while the table outlines their respective water availability, vulnerabilities, policy frameworks, governance structures, actions and outlooks. The diagram underscores the complexity of water resource issues in both Ethiopia and Mauritania. Ethiopia faces challenges such as climate variability, transboundary water issues and infrastructure gaps. Conversely, Mauritania struggles with limited water availability, heavy reliance on groundwater and rainfall, and high vulnerability to arid conditions [69,70]. Both countries face socio-economic challenges compounded by inadequate data availability, which hinders effective water resource management. While Ethiopia grapples with managing abundant but unevenly distributed water resources, Mauritania's reliance on small-scale systems and upstream transboundary waters highlights its vulnerability to external factors.

Table 4. Key aspects and water management practices in the two regions [16,33,34]

Aspects	Ethiopia	Mauritania
Water Availability	-Abundant water resources, including major rivers like the Blue Nile, but uneven distribution.	-Limited surface water; heavily reliant on groundwater and rainfall, which are highly variable.
Vulnerability	- Seasonal variability and droughts. - Over-dependence on agriculture. -Infrastructure gaps. - Transboundary water issues - Increasing challenges from climate change, including drought and reduced river flows.	-High water scarcity and arid conditions. - Vulnerable to climate impacts, such as desertification and prolonged droughts. - Dependency on small-scale agricultural water systems

		- Limited water supply infrastructure. - High reliance on transboundary waters and sensitive to upstream development.
Sectoral Provision	-Predominantly over 85% of water use is allocated for the agricultural sector, often inefficient due to limited technical and institutional capacity and outdated methods.	-Predominantly linked to small-scale farming and pastoralist activities, constrained by resource availability.
Water Policy Framework	- Environmental Policy of Ethiopia (1997). - Water Resources Management Policy (1999). - Powers and Duties of the Executive Organs Proclamation (2018).	- Code of Water (2005). - Strategic Water Supply and Sanitation Plan (2011). - Integration of water policy into national drought mitigation strategies.
Governance Structure	-Partly decentralized governance with regional and basin authorities managing water resources.	-Centralized governance, with a strong focus on strategic drought response and urban water supply.
Infrastructure Development	-Significant investments in dam projects like the Grand Ethiopian Renaissance Dam (GERD).	-Limited investment in large-scale infrastructure; focus on small-scale water access points.
International Cooperation	-Active in transboundary water negotiations (e.g., Nile Basin Initiative).	- Regional cooperation for transboundary waters (e.g., established Senegal River basin development organization (OMVS) initiative.
Mitigations and Future Priorities	-Establishing local and regional water security council that monitor and regulate the transboundary water issues -Improving water-use efficiency. -Developing infrastructures and appraising sectoral utilizations	-Enhancing infrastructures and water access in rural and urban areas. - Addressing water scarcity through sustainable practices. - Strengthening regional cooperation and climate resilience.

This analysis highlights the critical role of tailored, region-specific strategies for sustainable water management. Ethiopia's investments in large-scale infrastructure reflect its ambition to leverage abundant water resources for economic growth, while Mauritania's emphasis on localized solutions and international cooperation addresses its acute scarcity issues. Both nations must enhance data collection and monitoring systems to enable evidence-based decision-making and foster regional collaboration to manage shared resources effectively. These findings underscore the importance of integrating socio-economic and environmental considerations in water policy to ensure equitable access and sustainability. In summary, to address these challenges and limitations, the following measures and considerations are necessary:

-Developing alternative water sources: Exploring and utilizing alternative water sources like rainwater harvesting, and wastewater recycling can help supplement sources in the region

- Developing and implementing and sustainable WASH services: This encompasses developing and implementing policies and strategies that promote the best practices and tools such as utilizing non-conventional water sources, promoting water reuse, and enhancing water efficiency, implementing water-efficient irrigation methods, rainwater harvesting, water-saving technologies, raising awareness about responsible water usage can help to achieve water security goals.
- Development of modern and environmentally sound water frameworks. So that it facilitates and coordinates the cooperation and collaboration among different competing users and stakeholders.
- Managing transboundary water resources and enhancing the capacity and awareness of transboundary water actors: Managing transboundary water resources aligns with the Sustainable Development Goals, particularly Goal 6 (Clean Water and Sanitation) and Goal 13 (Climate Action). Successful management of transboundary water resources requires diplomacy, collaboration, and trust-building among riparian countries. Cooperation and effective management of these shared water resources are vital for promoting regional stability, economic development, and environmental sustainability.
- Establishing institutional and legal frameworks and agreements: developing and implementing policies and strategies. This involves reviewing and revising existing transboundary water agreements to incorporate climate change adaptation and mitigation measures, such as water conservation, water harvesting, water quality monitoring, flood and drought management, and ecosystem restoration.

3.4 Insights from other regions of the world

Water management challenges are not unique to Sub-Saharan Africa; they are also prevalent in other developing regions, such as Latin America and Asia, where social, economic, and environmental factors create intricate barriers to sustainable water management. In Latin America, for instance, countries like Bolivia, Ecuador and Peru face water access inequities exacerbated by population growth, urbanization, and the exploitation of water resources by industries such as mining and agriculture [71,72,73]. Similarly, Asia's densely populated nations, such as India, China and Bangladesh, grapple with pollution, seasonal variability, transboundary water issues, and the overexploitation of water resources to meet the demands of agricultural and urban expansion [74]. Both regions demonstrate that while water scarcity often originates from natural factors such as drought, it is the institutional and policy gaps that exacerbate the crisis, mirroring the findings from Sub-Saharan Africa.

In critical comparison, water management in Sub-Saharan Africa shares some similarities with these regions, particularly in the emphasis on agricultural water use, which constitutes over 70% of water consumption in all cases (Figure 8). However, while Africa faces acute challenges related to limited infrastructure and financing, countries in Latin America and Asia often struggle with the fragmentation of water governance frameworks and inadequate enforcement of environmental regulations. For example, the reliance on community-based water management in Sub-Saharan Africa contrasts with Latin America's frequent use of centralized governance models, which, although more resource-intensive, are not necessarily more effective in ensuring equitable access. Asia's experiences with large-scale river basin projects, such as the great Himalayan basin, and the basins of the Indus and Ganges rivers [75] highlight the potential and pitfalls of extensive infrastructure investments—an approach that Sub-Saharan countries are beginning to explore but with significant financial and logistical constraints. These

global comparisons underscore the universal importance of integrated water resource management while highlighting the region-specific nuances that shape water governance challenges and solutions.

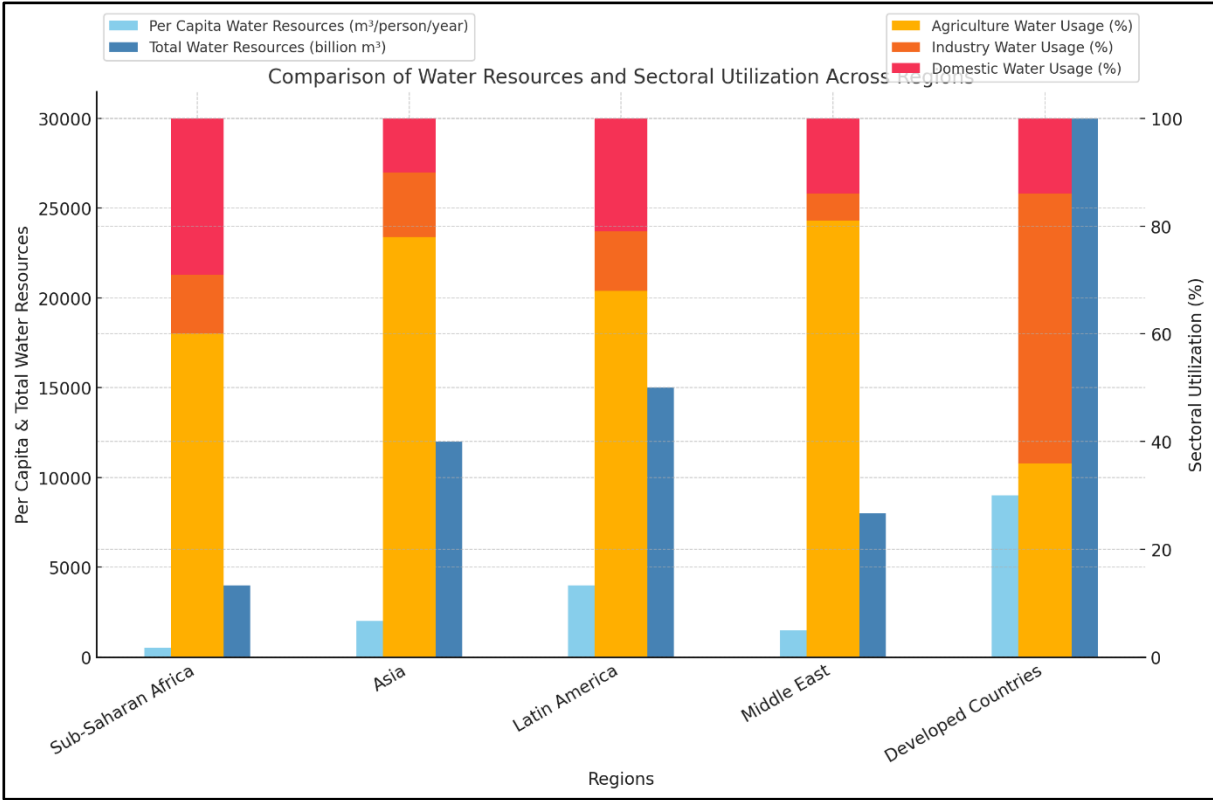


Figure 8. Worldwide water resources dimensions, sectoral and competing water uses [28,35,73]

Figure 8 illustrates comprehensive insights of water resources and competing water uses across Sub-Saharan Africa, Asia, Latin America, the Middle East, and developed countries. This broad representation underscores the disparities in water resource availability and usage patterns between different regions. For example, Sub-Saharan Africa and the Middle East exhibit relatively low per capita and total water resources compared to other regions, reflecting the chronic water scarcity issues prevalent in these areas. In contrast, developed countries and Latin America demonstrate higher water resource availability, showcasing more abundant water supplies.

On the other hand, as regards to sectoral utilization, agriculture dominates Sub-Saharan Africa, Asia, Latin America, and the Middle East, highlighting the heavy dependence on water for food production in these regions. However, in developed countries, industrial water use takes precedence, signaling a shift towards industrialization and more diversified water demands. Domestic water use remains a smaller fraction across all regions but is notably higher in developed countries due to advanced infrastructure and higher living standards. The above graph (Figure 8) effectively highlights the need for region-specific water management strategies. For instance, regions like Sub-Saharan Africa and the Middle East may prioritize

strategies to optimize agricultural water use and enhance efficiency due to limited resources, while developed nations could focus on industrial water recycling and conservation measures. Overall, the graph emphasizes the stark regional disparities in water availability and utilization, underscoring major shift in utilization and the importance of tailored, sustainable water management practices globally.

4. Conclusion

The region's water resource sufficiency and management performance lags behind the rest of the world. The water related issues in the two regions experience assorted challenges such as hydrological variability, rapid population growth, urbanization, and over abstraction. Sub-Saharan regions particularly highly populated countries such as Ethiopia and the desert climate arid countries like Mauritania endeavoring in finding sustainable solutions to water-related issues.

Ethiopia despite having tremendous potential, only a portion of this potential has been harnessed to contribute to the socio-economic development of the country meaningfully. On the other side, despite being reliance on transboundary waters, Mauritania consuming higher water withdrawal per capita and hence innovative water use practices are crucial to address water scarcity and ensure water sustainability.

The main competing uses of water in both countries within the agricultural sector require great improvement in order to ensure sustainability in water management that meets the needs of the present without compromising the ability of future generations to meet their needs. Given the rapid population growth and increasing water demand, there is an urgent need to develop stricter rules to control consumption, as well as the development of technologies that improve efficiency in this and other sectors.

In summary, addressing water management and the challenges associated with water resources in the two regions requires a collaborative and integrated approach, involving multiple stakeholders, including governments, communities, and international organizations. Moreover, it is essential to set up a water monitoring system, promote water sector financial facility, develop and implement sustainable WASH services. As a complement, the paper emphasizes revitalizing a legally binding agreement on shared water resources to increase cooperation and minimize potential water management related conflicts in the two regions.

References

- [1] Van Vliet, M. T., Jones, E. R., Flörke, M., Franssen, W. H., Hanasaki, N., Wada, Y., & Yearsley, J. R. (2021). Global water scarcity including surface water quality and expansions of clean water technologies. *Environmental Research Letters*, 16, 024020.
- [2] Bijekar, S., Padariya, H. D., Yadav, V. K., Gacem, A., Hasan, M. A., Awwad, N. S., Yadav, K. K., Islam, S., Park, S., & Jeon, B.-H. (2022). The state of the art and emerging trends in wastewater treatment in developing nations. *Water*, 14(16), 2537. <https://doi.org/10.3390/w14162537>

- [3] Cooper, P. J., Dimes, J., Rao, K. P. C., Shapiro, B., Shiferaw, B., & Twomlow, S. (2008). Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems & Environment*, 126(1-2), 24-35.
- [4] Li, P., & Wu, J. (2024). Water resources and sustainable development. *Water*, 16(1), 134. <https://doi.org/10.3390/w16010134>
- [5] Richards, N. (2019). Water users associations in Tanzania: Local governance for whom? *Water*, 11(10), 2178. <https://doi.org/10.3390/w11102178>
- [6] Chepyegon, C., & Kamiya, D. (2018). Challenges faced by the Kenya water sector management in improving water supply coverage. *Journal of Water Resource and Protection*, 10(1), 85-105.
- [7] Nkiaka, E., Bryant, R. G., Okumah, M., & Gomo, F. F. (2021). Water security in sub-Saharan Africa: Understanding the status of sustainable development goal 6. *Wiley Interdisciplinary Reviews: Water*, 8(6), e1552.
- [8] Wang, T., Tu, X., Singh, V. P., Chen, X., Lin, K., & Lai, R. (2022). Socioeconomic drought analysis by standardized water supply and demand index under changing environment. *Journal of Cleaner Production*, 347, 131248. <https://doi.org/10.1016/j.jclepro.2022.131248>
- [9] Shyroka, A., Pappenberger, F., Pechlivanidis, I., Messori, G., Khatami, S., Mazzoleni, M., & Di Baldassarre, G. (2023). Advances and gaps in the science and practice of impact-based forecasting of droughts. *WIREs Water*, e1698. <https://doi.org/10.1002/wat2.1698>
- [10] UN-Water. (2013). Water security & the global water agenda. UN Water Analytical Brief. UN University: Hamilton, ON, Canada.
- [11] UNEP. (2010). Africa Water Atlas. Nairobi: United Nations Environment Programme. ISBN: 978-92-807-3110.
- [12] Le Blanc, D. (2015). Towards integration at last? The sustainable development goals as a network of targets. *Sustainable Development*, 23(3), 176-187.
- [13] Abbas, F., Al-Naemi, S., & Farooque, A. A. (2023). A review on the water dimensions, security, and governance for two distinct regions. *Water*, 15(1), 208. <https://doi.org/10.3390/w15010208>
- [14] Abbas, F., Farooque, A. A., & Afzaal, H. (2020). Homogeneity in patterns of climate extremes between two cities—A potential for flood planning in relation to climate change. *Water*, 12, 782.
- [15] World Bank. (2023). World populations. Retrieved January 20, 2023, from <https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ET>
- [16] Ethiopian Wildlife and Natural History Society & Wetlands International. (2018). A first directory of Ethiopian wetlands: Descriptions, ecosystem services, causes of degradation & recommendations for restoration and sustainability.
- [17] World Meters. (2024). World populations by country. Retrieved May 5, 2024, from <https://www.worldometers.info/world-population/population-by-country/>
- [18] World Resources Institute. (2000). People and ecosystems: The fraying web of life. World Resources Institute: Washington, DC.
- [19] Marcal, J., Antizar-Ladislao, B., & Hofman, J. (2021). Addressing water security: An overview. *Sustainability*, 13(24), 13702. <https://doi.org/10.3390/su132413702>
- [20] Hoekstra, A. Y., & Mekonnen, M. M. (2012). The water footprint of humanity. *Proceedings of the National Academy of Sciences*, 109(9), 3232-3237.

- [21] George-Williams, H. E. M., Hunt, D. V. L., & Rogers, C. D. F. (2024). Sustainable water infrastructure: Visions and options for sub-Saharan Africa. *Sustainability*, 16(4), 1592. <https://doi.org/10.3390/su16041592>
- [23] FAO. (2020). Aquastat: FAO's Global Information System on Water and Agriculture. Retrieved September 19, 2024, from <http://www.fao.org/aquastat/en/databases/dams>
- [24] Ritchie, H.; Roser, M. Clean Water and Sanitation. Available online: accessed on 13 July 2024). <https://ourworldindata.org/clean-water-sanitation>
- [25] FAO. (2016). AQUASTAT Country Profile – Mauritania. Rome: FAO. Retrieved from <http://www.fao.org/aquastat>
- [26] World Health Organization. (2024). Retrieved July 14, 2024, from <https://apps.who.int/gho/data/node.main.WSHWATER?lang=en>
- [27] FAO. (2010). Water management and food security in Africa. Retrieved June 13, 2024, from <https://www.fao.org/family-farming/detail/en/c/317286/>
- [28] Verbist, K., Amani, A., Mishra, A., & Cisneros, B. J. (2016). Strengthening drought risk management and policy: UNESCO International Hydrological Programme's case studies from Africa and Latin America and the Caribbean. *Water Policy*, 18(S2), 245-261.
- [29] Jewaro, A. K., & Diler, İ. (2021). The state of water management in Ethiopia: Problems and solution approaches. *Acta Aquatica Turcica*, 17(4), 556-568. <https://doi.org/10.22392/actaquatr.915819>
- [30] Jury, M. R. (2024). A survey of African weather and climate extremes. *Climate*, 12(5), 65. <https://doi.org/10.3390/cli12050065>
- [31] Friedel, M. J. (2008). Inventory and review of existing PRISM hydrogeologic data for the Islamic Republic of Mauritania, Africa. USGS Open-File Report 2008-1138.
- [32] African Development Bank (AfDB). (2018). Mauritania water sector development strategy.
- [33] UNESCO. (2021). The United Nations world water development report 2021: Valuing water. United Nations.
- [34] World Bank. (2020). Mauritania - Water supply and sanitation profile. Retrieved from <http://www.worldbank.org>
- [35] World Bank. (2021). Africa development report. Retrieved from <https://www.worldbank.org/en/projects-operations/environmental-and-social-policies> (Accessed on June 10, 2023).
- [36] Wilderer, P. A. (2007). Sustainable water resource management: The science behind the scene. *Sustainability Science*, 2, 1–4. <https://doi.org/10.1007/s11625-006-0012-3>
- [37] Loucks, D. P., & Van Beek, E. (2017). Water resource systems planning and management: An introduction to methods, models, and applications. Springer. <https://doi.org/10.1007/978-3-319-44234-1>
- [38] Schlüter, T. (2008). Geological atlas of Africa (Vol. 307). Springer-Verlag.

- [39] Cheng, H., & Hu, Y. (2012). Improving China's water resources management for better adaptation to climate change. *Climatic Change*, 112(2), 253-282. <https://doi.org/10.1007/s10584-011-0222-5>
- [40] Lautze, J., & Giordano, M. (2005). Transboundary water law in Africa: Development, nature, and geography. *Natural Resources Journal*, 45, 1053.
- [41] Faye, C. (2023). Water resources management and hydraulic infrastructures in the Senegal River Basin: The case study of Senegal, Mali, and Mauritania. In *River basin management under a changing climate*. IntechOpen.
- [42] Sadoff, C. (2008). Managing water resources to maximize sustainable growth: A World Bank water resources assistance strategy for Ethiopia.
- [43] Sadoff, C., & Muller, M. (2009). Water management, water security, and climate change adaptation: Early impacts and essential responses. *Global Water Partnership*.
- [44] Kipping, M. (2009). Water security in the Senegal River Basin: Water cooperation and water conflicts. In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts* (pp. 675-684). Springer Berlin Heidelberg.
- [45] Julio, N., Figueroa, R., & Ponce Oliva, R. D. (2021). Water resources and governance approaches: Insights for achieving water security. *Water*, 13(21), 3063. <https://doi.org/10.3390/w13213063>
- [46] World Health Organization (WHO). (2023). Global Health Observatory data repository. Retrieved from <https://apps.who.int/gho/data/node.main.WSHWATER?lang=en> (Accessed on May 13, 2024).
- [47] Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., Von Gunten, U., & Wehrli, B. (2010). Global water pollution and human health. *Annual Review of Environment and Resources*, 35, 109–136. <https://doi.org/10.1146/annurev-environ-100809-125342>
- [48] Sharma, S. K., & Vairavamoorthy, K. (2009). Urban water demand management: Prospects and challenges for the developing countries. *Water and Environment Journal*, 23, 210–218. <https://doi.org/10.1111/j.1747-6593.2008.00124.x>
- [49] Van Niekerk, D., & Nema-konde, L. D. (2017). Natural hazards and their governance in Sub-Saharan Africa. In *Oxford research encyclopedia of natural hazard science*. Oxford University Press.
- [50] Ciampittiello, M., Marchetto, A., & Boggero, A. (2024). Water resources management under climate change: A review. *Sustainability*, 16(9), 3590. <https://doi.org/10.3390/su16093590>
- [51] Misra, A. K. (2014). Climate change and challenges of water and food security. *International Journal of Sustainable Built Environment*, 3(1), 153-165.
- [52] Tzanakakis, V. A., Paranychanakis, N. V., & Angelakis, A. N. (2020). Water supply and water scarcity. *Water*, 12(9), 2347. <https://doi.org/10.3390/w12092347>
- [53] Rijsberman, F. R. (2006). Water scarcity: Fact or fiction? *Agricultural Water Management*, 80(1–3), 5–22.

- [54] Mekonnen, M. M., & Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. *Science Advances*, 2(2), e1500323.
- [55] Kummu, M., et al. (2010). Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. *Environmental Research Letters*, 5(3), 034006.
- [56] Alcamo, J., et al. (2003). Global estimates of water withdrawals and availability under current and future “business-as-usual” conditions. *Hydrological Sciences Journal*, 48(3), 339-348.
- [57] Oki, T., & Kanae, S. (2006). Global hydrological cycles and world water resources. *Science*, 313(5790), 1068-1072.
- [58] Sharma, S.K.; Vairavamoorthy, K. 2009. Urban water demand management: Prospects and challenges for the developing countries. *Water Environ. J.* 2009, 23, 210–218.
- [59] Howard, G., Bartram, J., Williams, A., Overbo, A., & Geere, J.-A. (2020). Domestic water quantity, service level, and health. World Health Organization.
- [60] Africa’s water(2009). – Who uses how much? Retrieved from <https://showmesa.co.za/africas-water-who-uses-how-much/> (Accessed on July 15, 2024).
- [61] Gökçekuş, H., & Bolouri, F. (2023). Transboundary waters and their status in today’s water-scarce world. *Sustainability*, 15(5), 4234. <https://doi.org/10.3390/su15054234>
- [62] Cooley, H., & Gleick, P. H. (2011). Climate-proofing transboundary water agreements. *Hydrological Sciences Journal*, 56(4), 711-718.
- [63] Deribe, M. M., Melesse, A. M., Kidanewold, B. B., Dinar, S., & Anderson, E. P. (2024). Assessing international transboundary water management practices to extract contextual lessons for the Nile River Basin. *Water*, 16(14), 1960. <https://doi.org/10.3390/w16141960>
- [64] Lajaunie, M. L., Bonzanigo, L., Fraval, P., & Scheierling, S. M. (2021). World Bank engagement in transboundary waters in West Africa: Retrospective and lessons learned.
- [65] (2022). African river basins. Retrieved from <https://journals.co.za/doi/pdf/10.10520/ejc-waterb-v21-n3-a5> (Accessed on March 5, 2024).
- [66] Rogers, P., & Hall, A. W. (2003). Effective water governance (Vol. 7). Global Water Partnership.
- [67] Rjoub, H., Ifediora, C. U., Odugbesan, J. A., Iloka, B. C., Xavier, R. J., Dantas, R. M., Mata, M. N., & Martins, J. M. (2021). Implications of governance, natural resources, and security threats on economic development: Evidence from Sub-Saharan Africa. *International Journal of Environmental Research and Public Health*, 18(12), 6236. <https://doi.org/10.3390/ijerph18126236>
- [68] Achuo, E. D. (2023). Resource wealth and the development dilemma in Africa: The role of policy syndromes. *Resources Policy*, 83, 103644.
- [69] Tang, X., & Adesina, J. A. (2022). Integrated watershed management framework and groundwater resources in Africa—A review of the West Africa sub-region. *Water*, 14(3), 288. <https://doi.org/10.3390/w14030288>

- [70] Gaye, C. B., Diaw, M., & Malou, R. (2013). Assessing the impacts of climate change on water resources of a West African transboundary river basin and its environmental consequences (Senegal River Basin). *Science in Cold and Arid Regions*, 5, 140-156.
- [71] Mera-Parra, C., Massa-Sánchez, P., Oñate-Valdivieso, F., & Ochoa-Cueva, P. (2022). Territorial prospective to sustainability: Strategies for future success in water resource management on Andean basins. *Land*, 11, 1100. <https://doi.org/10.3390/land11071100>
- [72] Food and Agriculture Organization (FAO). (2017). Transboundary water management in Asia: Challenges and progress. Retrieved from <https://www.fao.org/home/en/> (Accessed on December 22, 2024).
- [73] Tortajada, C., & Biswas, A. K. (2018). Achieving universal access to water and sanitation: Perspectives and challenges for Latin America and the Caribbean. *Environmental Development*, 25, 176-185.
- [74] Park, S.-Y., Kim, J.-S., Lee, S., & Lee, J.-H. (2022). Appraisal of water security in Asia: The pentagonal framework for efficient water resource management. *Applied Sciences*, 12(16), 8307. <https://doi.org/10.3390/app12168307>
- [75] Ojha, H., Neupane, K. R., Pandey, C. L., Singh, V., Bajracharya, R., & Dahal, N. (2020). Scarcity amidst plenty: Lower Himalayan cities struggling for water security. *Water*, 12(2), 567. <https://doi.org/10.3390/w12020567>