

The Gambia Water Resources Climate Risk Assessment

Technical report

15 March 2026



GLOBAL
CENTER ON
ADAPTATION

AUTHORS & ACKNOWLEDGMENTS

This report was developed by:

Global Center on Adaptation: Martin Garcia Perez, Program Officer; Merita Salihu, Senior Program Officer; Edwina Mercer, Senior Program Office; Anne-Laure Solnon, Senior Specialist; Adele Cadario, Global Lead, Infrastructure and Nature-based Solutions.

Partnerships: The World Bank Group

Consultants: Haskoning, Lobelia Earth, City Scape Associates, and Rebel Group.

Acknowledgements :

This report builds on analyses conducted by GCA under the Africa Adaptation Acceleration Program (AAP), an initiative launched by the GCA in collaboration with the African Development Bank, endorsed by the African Union. The work benefited from collaboration with the World Bank teams for The Gambia Infrastructure Project and CCDR, as well as insights shared by the Ministry of Transport Works & Infrastructure, the Ministry of Environment and Climate Change, the Department of Water Resources, and the National Roads Authority of The Gambia.



**GLOBAL
CENTER ON
ADAPTATION**

ABOUT THE GLOBAL CENTER ON ADAPTATION

The Global Center on Adaptation (GCA) is an international organization, hosted by the Netherlands, which works as a solutions broker to accelerate action and support for adaptation solutions from the international to the local, in partnership with the public and private sector, to ensure we learn from each other and work together for a climate resilient future.



AFRICA ADAPTATION ACCELERATION PROGRAM

GCA is providing technical assistance under the African Adaptation Acceleration Program (AAP), a joint initiative launched by the GCA and the African Development Bank in 2021.

In Partnership with:



WORLD BANK GROUP

Consultants:



CONTEXT

The Global Center on Adaptation (GCA) is an international organization working to accelerate action on adapting to climate change and building resilient economies.

Under the African Adaptation Acceleration Program (AAAP), GCA supports The Gambia in embedding climate resilience into national planning and infrastructure investment projects – including The World Bank Gambia Infrastructure Project, The African Development Bank Banjul Port 4th Expansion and Senegambia Bridge Asset Recycling projects. Since 2024, GCA has partnered with IFIs, the Ministry of Transport Works and Infrastructure, the Ministry of Environment and Climate Change, NAWEC, the Water Resources Department and the National Roads Authority of The Gambia to assess climate risks to the transport sector, water resources, identify adaptation solutions, and strengthen local capacity through training activities.

In this context, GCA is supporting the World Bank and governmental institutions on a \$50 million investment to enhance climate resilience in The Gambia's transport and energy infrastructure. The project focuses on improving last-mile connectivity by expanding low-voltage electricity access in 225 rural communities, strengthening urban energy grid redundancy, and upgrading 150 kilometers of seasonal roads to ensure reliable year-round access. Additionally, the project focuses on strengthening The Gambia's transport and energy sectors through policy reforms, institutional capacity building, and improved planning for sustainability, resilience, and universal access. It includes support for road sector management, climate-resilient design standards, and enabling frameworks for renewable energy investment, energy efficiency, and private sector participation.

GCA's support focuses on prioritizing infrastructure investments from an adaptation perspective, with the aim of strengthening connectivity, identifying and assessing targeted adaptation measures, and developing implementation guidelines to improve existing design standards. In parallel, GCA is contributing to related initiatives. This work seeks to reinforce sectoral ambitions by integrating climate change considerations with development objectives, while promoting the incorporation of long-term strategies for climate resilience.

Table of Contents

- Glossary 5
- Executive Summary..... 6
- 2. Introduction..... 8**
 - 2.1 Assignment background..... 8
 - 2.2 This report..... 8
 - 2.2.1 Report objectives 8
 - 2.2.2 Report structure 8
- 3. An introduction to water resources in The Gambia 10**
 - 3.1 Climate and environmental setting 10
 - 3.2 Water Resources 11
 - 3.2.1 Surface water..... 11
 - 3.2.2 Groundwater 13
 - 3.3 Water users..... 14
 - 3.3.1 Domestic users..... 14
 - 3.3.2 Agricultural users..... 15
 - 3.3.3 Industrial users..... 15
 - 3.4 Public water supply 16
 - 3.5 Stakeholders & Legislative overview 17
 - 3.5.1 History of the legislative framework regarding water resources in the Gambia..... 17
 - 3.5.2 Stakeholders 18
 - 3.5.3 Legislative overview..... 18
 - 3.5.4 Institutional challenges..... 19
 - 3.6 Key challenges experienced in the water resources sector 20
 - 3.6.1 Feedback during field visit..... 20
 - 3.6.2 Key challenges according to literature..... 20
- 4. Water use and demand 22**
 - 4.1 Domestic..... 22
 - 4.2 Agricultural..... 23
 - 4.2.1 Current agricultural water demand..... 23
 - 4.2.2 Future projections of agricultural water demand 24
 - 4.3 Industrial 26
 - 4.3.1 Current industrial demand..... 26
 - 4.3.2 Future projections of industrial water demand 26
 - 4.4 Environmental..... 26
 - 4.5 Other water use 27
- 5. Water balance assessment..... 28**
 - 5.1 Introduction 28
 - 5.2 Input data..... 29
 - 5.3 Water balance model approach 31
 - 5.4 Sustainable water availability and total renewable freshwater 32
 - 5.5 Water balance components..... 33

6. Water indicators	35
6.1 Sustainable water availability	35
6.1.1 Current situation.....	35
6.1.2 Under future (climate) scenarios	36
6.2 Total renewable freshwater	37
6.2.1 Current situation.....	37
6.2.2 Under future (climate) scenarios	38
6.3 Water quality.....	38
6.3.1 Current situation.....	38
6.3.2 Under future (climate) scenarios	40
6.4 Water trends	41
6.4.1 Trends in groundwater levels.....	41
6.4.2 Trends in precipitation	42
7. Key (climate) risks & adaptation measures	46
7.1 Key hotspots of climate risk for water resources	46
7.2 Identification of climate adaptation measures	47
7.2.1 Water availability	48
7.2.2 Water quality	50
7.2.3 Infrastructure development	52
7.3 Risks & adaptation measures matrix	53
8. References	56
Annex A – Water Balance components – Gambia River Basin	59
Annex B – Water Balance components – The Gambia	60
Annex C – Environmental water demand	61
Annex D – Precipitation trend plots	63

GLOSSARY

Acronyms	Definitions
AfDB	African Development Bank
CBA	Cost-Benefit Analysis
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CRA	Climate Risk Assessment
DWR	Department of Water Resources
EbA	EcoSystem-based Adaptation (Project)
ECMWF	European Centre for Medium-Range Weather Forecast
ESA	European Space Agency
IMF	International Monetary Fund
GBA	Greater Banjul Area
GbS	Gambia Bureau of Statistics
GCA	Global Center on Adaptation
GDP	Gross Domestic Product
GPA	Gambia Ports Authority
MOA	Ministry of Agriculture
MECCNAR	Ministry of Environment, Climate Change & Natural Resources
MOTWI	Ministry of Transport, Works & Infrastructure
MSD	Multi-Stakeholder Dialogue
NAWEC	National Water & Electricity Company
NbS	Nature-based Solutions
NDMA	National Disaster Management Agency
NEA	National Environment Agency
NEMC	National Management Council
NRA	National Road Authority
O&M	Operation & Maintenance
PIR	Policy, Institutional & Regulatory
PPP	Public-Private Partnership
PURA	Public Utilities Regulatory Authority
RHDHV	Royal HaskoningDHV
SRTM	Shuttle Radar Topography Mission
TANGO	The Association of Non-Governmental Organizations
TRWR	Total Renewable Water Resources
WAPOR	Water Productivity Open-Access Portal
WTP	Water Treatment Plant

EXECUTIVE SUMMARY

Background & Objectives

This assignment, commissioned by the Global Center on Adaptation (GCA), assesses climate risks and develops integrated adaptation strategies that strengthen climate resilience. This report specifically focusses on the water resources in The Gambia and identifies key hotspots of climate risk and adaptation measures to address those. The findings aim to enable climate adaptation policy recommendations to be developed for the water resource sector that can inform future discussions on national policy reform.

Key (Climate) Risks to Water Resources

The Gambia's water resources are facing significant challenges from both climate change and population growth, with the latter expected to have a greater impact. Climate change is projected to reduce freshwater availability due to saltwater intrusion, mainly affecting agriculture productivity in areas along the river.

Based on the performed analyses the current available water resources (0.19km³/y) will be enough to provide fresh water for the domestic sector in a sustainable way up to 2050 (0.18km³/y). However, this leaves hardly any room for the sharp increase in projected industrial demand (0.28 km³/y in 2050), which therefore is projected to exceed sustainable water availability.

Both industrial and agricultural sectors will be able to abstract water from the country's available resources – which are ample, but at a cost for the environment. Meaning that – assuming the projected abstraction rates are abstracted from groundwater sources – the additional projected abstractions for these sectors will reduce the water availability for natural assets. For example, the abstractions will reduce baseflow of the Gambia river, exacerbating the saltwater intrusion up the Gambia river.

Local hotspots in domestic supply still pose a threat to water resources, such as in the Greater Banjul Area, where groundwater depletion is a concern due to over-extraction for domestic and industrial use. This issue is exacerbated by rapid population growth and industrial expansion, which are expected to further strain groundwater resources and will increase saltwater intrusion into the aquifers.

Additionally, wetlands are at risk from increased evaporation and land-use changes, potentially leading to their degradation or drying up. This will result in decreased natural ecosystem services - such as flood resilience and the provision of fresh water for irrigation - and decreased biodiversity.

Population growth, at an annual rate of 2.3%, will increase water demand, pollution, and strain on infrastructure, further complicating water management in the country. This growth is expected to lead to increased competition for limited water resources, impacting both availability and quality.

Adaptation Measures & Recommendations

To increase water availability, several strategies can be implemented. Transboundary water management can foster cooperation and equitable resource sharing across political boundaries. Promoting water-saving technologies and practices in agriculture, industry, and households can reduce overall water consumption and minimize waste. Rainwater harvesting techniques can be utilized to capture and store precipitation for various uses, reducing reliance on traditional water sources. Additionally, Managed Aquifer Recharge (MAR) can be applied to intentionally recharge aquifers, providing storage, treatment, and improved water security.

To address decreasing water quality due to increased salinity and pollution, several approaches can be taken. Cultivating salt-tolerant crop varieties can help maintain agricultural productivity in affected areas. Consideration should be given to relocating water-intensive activities upstream to areas with better water quality and availability. Implementing stricter regulations and practices can reduce pollution from agricultural runoff, industrial waste, and sewage. Preserving and restoring wetlands can also act as natural filters, improving water quality and supporting ecosystem services.

To deal with infrastructure vulnerabilities, it is crucial to develop robust water supply infrastructure to ensure reliable water supply and distribution systems. Additionally, designing climate-resilient water systems that can withstand and adapt to changing environmental conditions is essential for long-term sustainability.

Conclusion & Next Steps

Strengthening The Gambia's climate resilience in water resources requires policy action, investment in infrastructure, and integration of climate risk assessments into national planning. By implementing these adaptation measures, The Gambia can enhance water security, protect livelihoods, and ensure sustainable development in the face of both climate change and anthropogenically driven change.

2. INTRODUCTION

2.1 Assignment background

The Gambia is highly vulnerable to climate risks. Under the Africa Adaptation Acceleration Program (AAP), the Global Center on Adaptation (GCA) is providing technical assistance support to integrate climate adaptation into the transport, energy and water resource sectors in The Gambia.

Royal HaskoningDHV (RHDHV), in association with Rebel Group, Lobelia Earth, and CityScape Associates (together 'the Consultant'), has been appointed by the Global Center on Adaptation (GCA) ('the Client') to carry out the assignment *Integrated Adaptation Options for Transport, Energy and Water Sectors in The Gambia*.

The broad objective of this assignment is to provide an assessment of climate risks and vulnerability of the transport sector (nation-wide and project-specific), water resource sector (nation-wide) and energy sector (project-specific), that in turn informs the definition of adaptation measures to address these risks. Furthermore, consideration of the implementation of these adaptation measures, and discussion in that regard with national stakeholders, will enable climate adaptation policy recommendations to be developed that can inform future discussions on national policy reform. To achieve these objectives, the assignment is structured into 5 components, as follows:

- Component 1: Climate Change Analysis
- Component 2: Transport systems climate-risks analysis and adaptation options for roads and fluvial network
- Component 3: Supporting specific transport and energy investment project to include climate risks and adaptation and resilience options
- Component 4: Water resource and risks related to climate change assessment
- Component 5: Policy Analysis for the Transport and Water sector

2.2 This report

2.2.1 Report objectives

This report relates to Component 4 of the assignment.

The objective of this component is to provide a high-level assessment of water resource availability and demands for agriculture, domestic, industrial, and environmental uses. The assessment is carried out at the national / Gambia River Basin (GRB) level, under different climate change scenarios, with a focus on the trends in both quality and quantity of water.

2.2.2 Report structure

The report is structured as follows:

- **Chapter 2:** First, an **introduction to the water resources sector in The Gambia** is provided. This provides an in-depth look at the climatic conditions, the different water resources and water users. Specific attention is raised to the public water supply in The Gambia.
- **Chapter 3:** Next, the **water use and demand** is assessed. This is required in order to define the current situation of The Gambia in terms of water stress. The demand for the different users – i.e., domestic, agricultural, industrial and environmental – are assessed for the current situation as well as for in the future - by performing an assessment of economic and demographic trends.
- **Chapter 4:** A **water balance method** is adopted to determine the in- and outputs of the GRB system.
- **Chapter 5:** The water balance model is used to assess the sustainable water yield as well as the total renewable water resources (TRWR). Along with the water quality and water trends on groundwater and precipitation, these **water indicators** are used to identify the main challenges in the water sector in The Gambia. The effects of climate change to the water indicators are also assessed in this section.

- **Chapter 6:** Finally, the **key Climate Risk & Adaptation Measures** that are suitable for implementation in the context of the Gambian water sector are identified.
- **Chapter 7:** Provides a list of references used in the Report.

The identification of key climate risks on the water resources of The Gambia have been used to inform identification of possible adaptation measures. These outcomes are intended as inputs to the policy analysis in Component 5. Component 5 then considers recommendations for adjustments to the Policy, Institutional & Regulatory (PIR) landscape to support implementation of these measures.

3. AN INTRODUCTION TO WATER RESOURCES IN THE GAMBIA

3.1 Climate and environmental setting

The Gambia experiences a rainy season that typically lasts from May to November. Most of the rain (80% or more) falls during July, August, and September. Yearly rainfall decreases gradually from 1,000 mm in the southern and southeastern parts to 700 mm in the northernmost areas (Njie, 2009). The country averaged yearly, and monthly precipitation totals according to CHIRPS (1981 – 2025) are presented in Figure 3-1. Over this period, the mean precipitation was 765 mm per year.

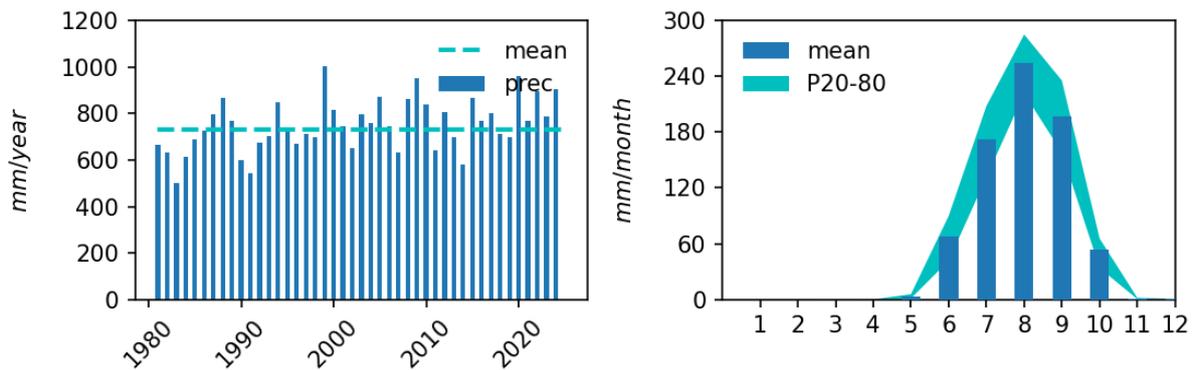


Figure 3-1: Country averaged rainfall statistics for the Gambia according to CHIRPS. The left figure presents the country averaged cumulative rainfall totals, the right figure the average monthly totals. The P20-P80 presents the 20-80th percentile range – source: CHIRPS.

Temperature patterns across the country are influenced by various factors, including location and rainfall. Generally, temperatures tend to be higher inland compared to coastal areas – see Figure 3-2. For example, in March, which is the hottest month, Banjul experiences temperatures between a daily low of 19°C and a daily high of 35°C. Basse, located about 400km inland at a similar latitude to Banjul, experiences higher temperatures. During the wet season, the temperature difference between these two locations is less pronounced but still noticeable. In Banjul daily average high temperatures range between 31°C to 35°C, and in Basse between 31°C to 41°C. This pattern shows that inland areas tend to have more extreme temperatures compared to coastal regions throughout the year.

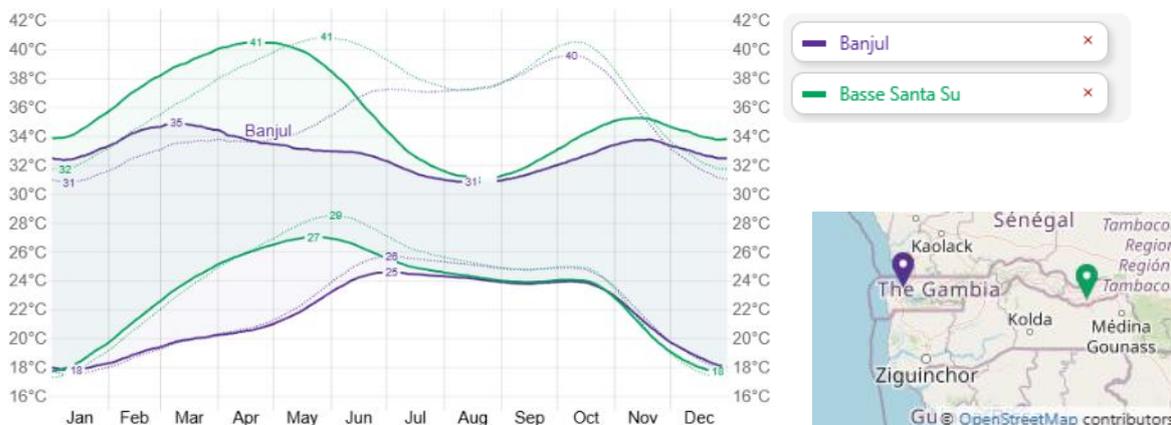


Figure 3-2: The daily average high and low air temperature at 2 meters above the ground. The thin dotted lines are the corresponding perceived temperatures. When available, historical temperature and dew point measurements are taken directly from the Banjul weather station. The values for Basse Santa Su are based on NASA's MERRA-2 Modern-Era Retrospective Analysis (Weatherspark, 2025)

The Gambia is mainly characterized by being the delta area of the River Gambia. Within The Gambia, there are small elevation differences. The elevation ranges from sea level, to approximately 51 m above sea level at its highest point. The country is rich in renewable water resources from surface water of the river tributaries and groundwater sources, both inland and inflows from outside of the country. The river Gambia originates in the Fouta Djallon mountains of Guinea, and flows through Senegal before entering The Gambia, where it extends for approximately 400 km before it reaches the Atlantic Ocean in the west (see Figure 3-3).

Dams in the Gambia River catchment were considered in the past – including the Yelitenda barrage (or Balingho) in The Gambia and the Kekreti dam in Senegal (Degeorges, 2007). The Yelitenda option included a study about an anti-salinity barrage 128-134 km upstream of the river mouth. The Kekreti dam in the upstream area of the river catchment was meant to serve as a multipurpose dam for hydropower and irrigation, just as the Sambangalou hydropower dam in Senegal. The Yelitenda and Kekreti dams were thoroughly researched and due to significant environmental and social concerns neither of them was constructed.

The only dam which is currently under construction is the Sambangalou dam in Senegal (see Figure 3-3). Construction has started in 2021 and is expected to be finalised in 2025. This dam is meant to serve as a multipurpose dam, supplying electricity to Senegal, Gambia, Guinea-Bissau, and Guinea, and to supply irrigation water to farming communities in the region, and providing a source of drinking water to the residents in the area. The dam will not serve as water supply to The Gambia. The dam is situated upstream in the Gambia River catchment close to the Senegal-Guinea border. The construction and operation of the Sambangalou Dam will have significant environmental impacts, including loss of natural resources and displacement of populations, but may also offer positive outcomes such as improved electricity supply and economic development opportunities (ONEC, 2014).

3.2 Water Resources

The Gambia’s water resources can be categorized into two main types: surface water and groundwater.

3.2.1 Surface water

The Gambia River is the primary surface water resource, with a highly seasonal flow. The maximum flow occurs at the end of the rainy season, which is from June to October¹. It can reach up to 1,500 m³/s (measured at Gouloumbo, near the border with Senegal), while the minimum flow in the dry season is less than 4.5 m³/s (Boussouga, Sacher, & Schäfer, 2023).

Within the Gambia River, three major sections may be distinguished:

1. The Upper Valley, where water is always fresh
2. The Central Valley, where tidal influences exist but water is also fresh
3. The Lower Valley, where water is permanently



Figure 3-3: The Gambia River drainage basin. Elevation data from SRTM, drainage basin from GTOPO

saline because of the tidal influences

¹ Gambia, The - Climatology | Climate Change Knowledge Portal

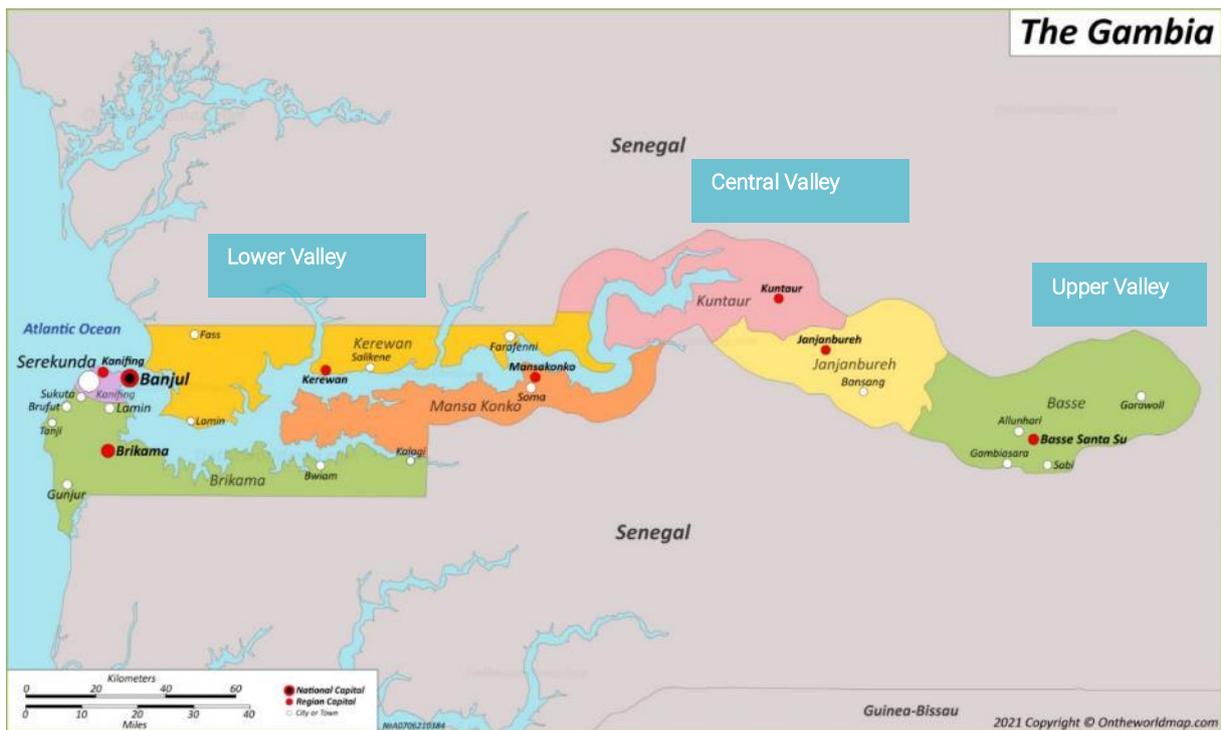


Figure 3-4: Lower valley (green, yellow, orange), Central Valley (pink, light-yellow), and Upper Valley (green)

In addition to the River Gambia, the country relies on a few other ephemeral coastal streams and a transboundary river. The Allahein River (San Pedro) is a low volume river system that delineates the south-western border between The Gambia and Senegal, south of Gunjur (situated near the coastline, see Figure 3-4). The river is mainly dominated by tidal influences from the Atlantic Ocean, with relatively insignificant river flows of $10 \text{ m}^3/\text{s}$.

Wetlands

As part of the Gambia River's hydrological system, there is a high abundance of wetlands that store a vast amount of freshwater - see Figure 3-5. The wetlands play a crucial role in supporting biodiversity, regulating hydrological cycles, and providing livelihoods for local communities. Some of the wetlands are listed as a RAMSAR site, i.e. the Tanbi Wetland Complex, the Niimi National Park and the Bao Bolon Wetland Reserve (RAMSAR, 2025). The Tanbi Wetland, located near Banjul, is a Ramsar site featuring extensive mangrove forests that aid in shoreline stabilization and groundwater replenishment. The Bao Bolon Wetland Reserve, situated on the North Bank of the River Gambia, comprises diverse ecosystems such as estuaries, woodlands, salt marshes, and mangroves. The Niimi National Park is a diverse wetland ecosystem located on the north bank of the River Gambia, encompassing mangrove forests, freshwater marshes, and coastal areas. These wetlands support a rich biodiversity, hosting vulnerable species and providing grounds for fish breeding. They also play crucial hydrological roles, including water retention, flood prevention and sediment management.

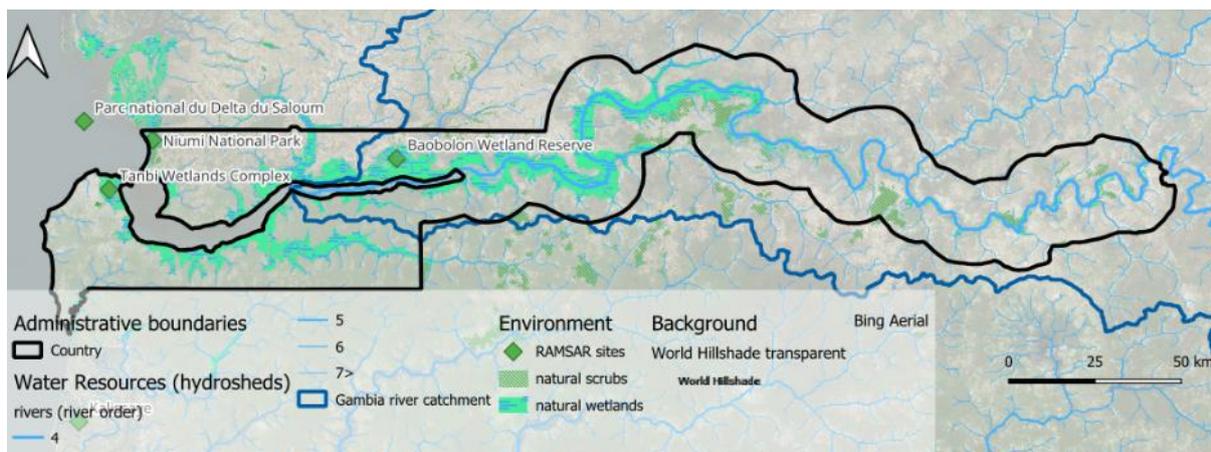


Figure 3-5: Wetlands and Ramsar sites in The Gambia

3.2.2 Groundwater

A second source of water in The Gambia is groundwater. Groundwater forms one of the main sources used, due to its accessibility and relatively good quality. The country is part of the Mauritania-Senegal-Gambia-Guinea-Guinea-Bissau basin (MSGGGB), that is characterized by two main aquifers.

Firstly, the shallow unconfined sandy aquifer, which is found at depths ranging from 4 to 30 meters below ground level (in the top layer, see Figure 3-6). It is mainly composed of unconsolidated sand that is part of older fluvial depositions. The bottom of the aquifer is defined by a semi-confined aquifer between 30 and 50 meters below ground level. The recharge of the shallow sand aquifer is determined mainly by rainfall and is expected to decrease over time due to increasing rainfall variability as a consequence of climate change effects (Government of The Gambia (GOTB), 2020).

Secondly, the deep sandstone aquifer, located at greater depths. It comprises of Maastrichtian (late Cretaceous) sedimentary deposits, and recharges through lateral flow from the southern part of Senegal.

The deep aquifer is currently not exploited in The Gambia, and all water is abstracted from the shallow sand aquifer (NIRAS, 2013).

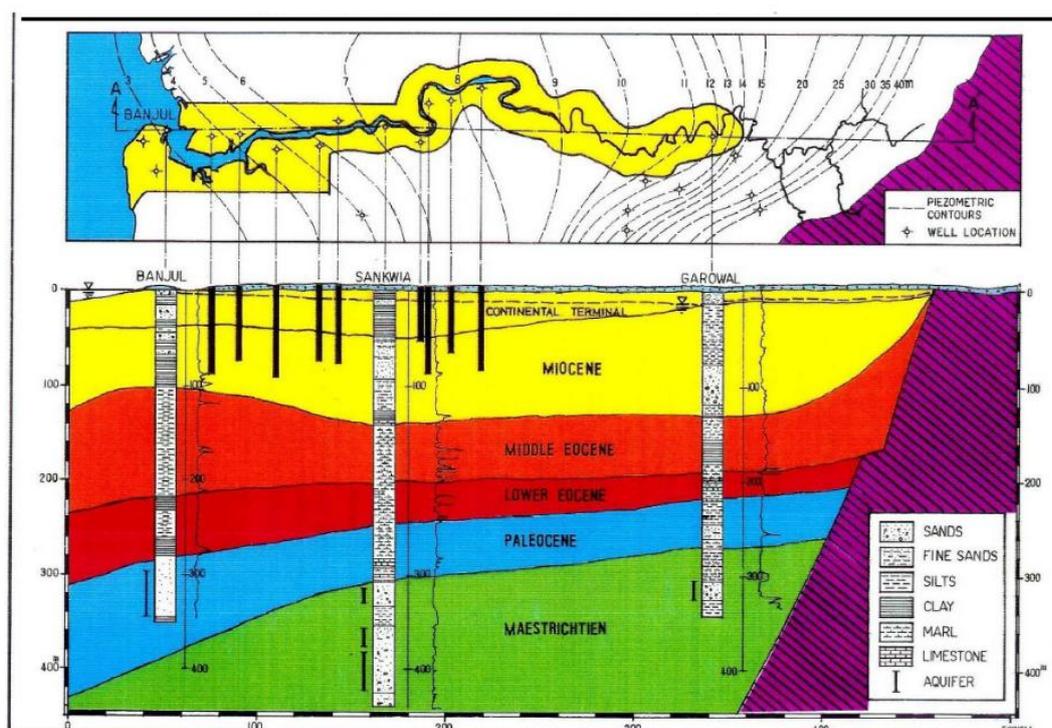


Figure 3-6: Schematic east-to-west cross section of The Gambia (Feasibility Study Report, SNC Lavalin International, GAMECS)

The availability of groundwater in The Gambia is mainly determined by its quality. Generally, groundwater is available in all parts of The Gambia. Water tables are shallow near the coast and along the river and its tributaries and increase in depth (with respect to ground level) at distances further from the river. The shallow aquifer generally contains suitable water for potable use. However, there are risks for depletion and pollution. Groundwater depletion is mainly linked to an increasing demand (both domestic, industrial as well as agricultural) associated with population growth. In urban areas, the reduced recharge rates are amplified due to the increased impermeable surface area (Njie, 2002).

3.3 Water users

The Gambia has three main anthropogenic water users: domestic users, agricultural users, and industrial users (Figure 3-7). In 2016 the total water withdrawal was estimated to be 91 million m³. The domestic (or municipal) water withdrawal was estimated at 45%, agricultural on 33% and industrial withdrawal at 22%. To illustrate the rapid increase in the water demand and to show the shift in relative importance of each sector the figures of 2000 are also presented. In 2000 the total water withdrawal was estimated to be 32 million m³ (67% agricultural, 22% domestic, and 11% industrial) (FAO, 2005).

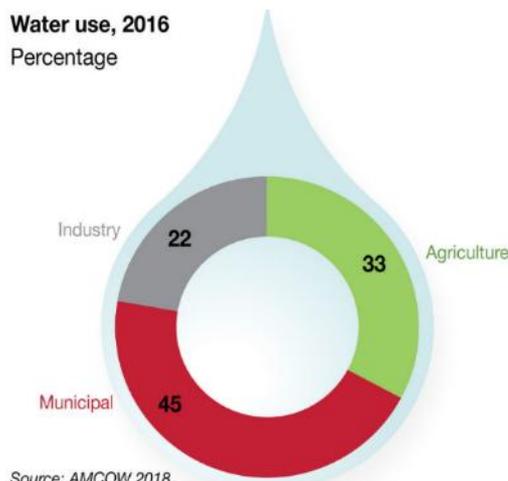


Figure 3-7: Water use in The Gambia in 2016 (AMCOW, 2018)

3.3.1 Domestic users

The amount of domestic water demand in The Gambia is determined by the total population. The current population (2025) is estimated to be 2.42 million people, with 64% of the total population residing in the Greater Banjul Area (GBA) near the coast (Gambia Bureau of Statistics, 2024). The most densely populated areas are Banjul, Kanifing, and Brikama at the west coast, and Basse in the east (Figure 3-8).

2024 Population Density by LGA

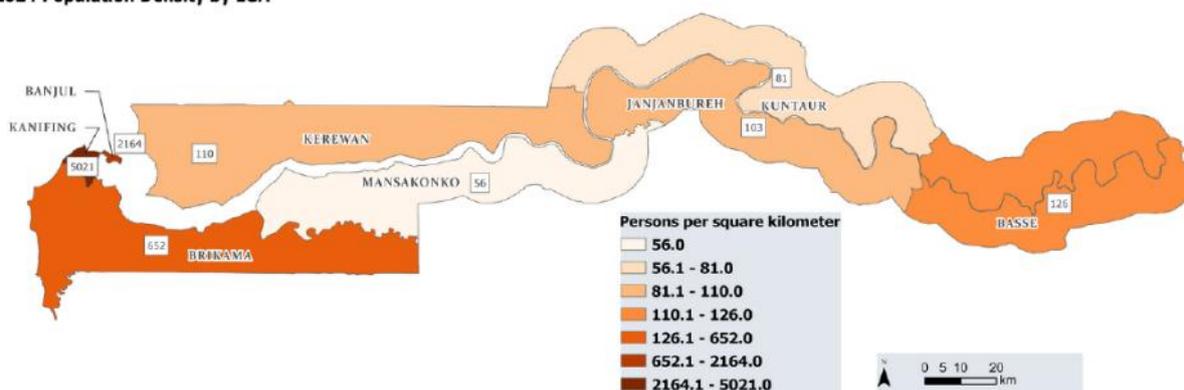


Figure 3-8: Population density per Local Government Authority in The Gambia (Gambia Bureau of Statistics, 2024)

The majority of Gambians rely on groundwater as potable water. In many areas, surface water is often saline and unsuitable for drinking. Domestic use includes water needs for households, tourism, and sanitation. In a large part of the country there is limited water supply infrastructure. Most of the infrastructure is concentrated in the Greater Banjul Area (GBA). Rural and peri-urban communities face challenges to access safe drinking water. As of 2018, it was estimated that 86.1% of the population had access to potable water, with 95% in urban areas and 77% in rural areas (UNICEF, 2018). The access to water has significantly improved over the years, with urban areas generally having better access compared to rural regions. These disparities persist, particularly in riverine communities and among extremely poor households (Africa FMM, 2020).

3.3.2 Agricultural users

The agricultural sector is the second greatest water user in The Gambia accounting for ~33% of the total water withdrawals (AMCOW, 2018). The sector is crucial in The Gambia, due to the large amount of subsistence farming. 70% of the labour force is employed in agriculture and it is the main source of income for 72% of the extremely poor households (GNAIP, 2015). The sector is dominated by small-scale, subsistence rain-fed crop production sites which are also irrigated during the dry season. The Gambia cultivates a variety of crops, including groundnuts (the main cash crop), rice (a staple food), millet, sorghum, maize, cassava, sesame, vegetables, and pulses like cowpeas. Groundnuts dominate export production, while rice, millet, sorghum, and maize are primarily grown for subsistence purposes. While the country’s agriculture is largely rain-fed, irrigation is used in certain areas to enhance productivity. Rice is the most irrigated crop in the country. Near the coastal area, tidal irrigation systems are used that utilize the natural flow of the river. Pumped irrigation is employed more in areas upland where groundwater is mainly used as source for irrigation (FAO, 2018).

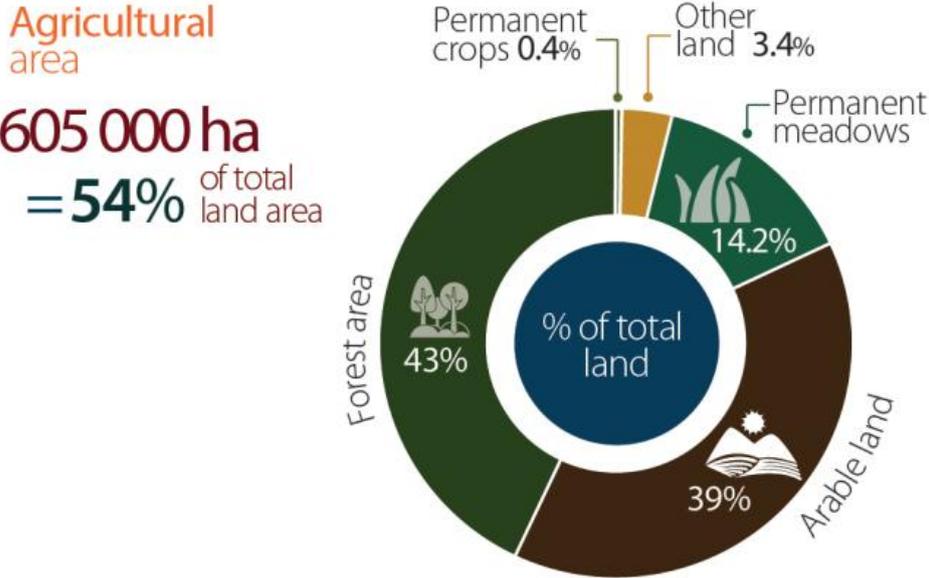


Figure 3-9: Agricultural area and percentage land use of total land in The Gambia (FAO, 2018)

3.3.3 Industrial users

The industrial sector in The Gambia is the smallest water user among the three main categories, with a share that is estimated at approximately 22% of the total withdrawals (AMCOW, 2018). The industrial water use in The Gambia is concentrated in the western part of the country, mainly the GBA. Water in the area is used for several purposes including manufacturing, cooling, or cleaning processes. It has been found that the value generated per cubic meter of water increased gradually beginning 2000s, indicating that the efficiency of water use has been improved over the years.

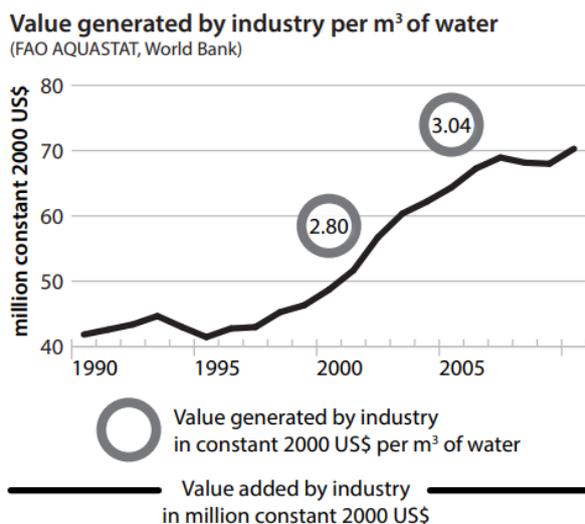


Figure 3-10: Value generated by the industrial sector in The Gambia per m³ of water (UN Water, 2017)

3.4 Public water supply

The public water supply in The Gambia can be divided into two separate systems:

- **The GBA and urban areas – managed by NAWEC**

In urban areas, particularly in the GBA, domestic water is supplied through large systems including wellfields, storage & treatment facilities, pumping stations, and distribution networks with household connections. Outside of the GBA, the National Water and Electricity Company (NAWEC) manages other boreholes in approximately 9 different urban locations that range from Barra in the east to Basse in the west (see Figure 3-12).

- **Rural areas and peri-urban areas – managed by local communities**

In the rural and peri-urban areas, domestic water supply is organised through point sources (boreholes & wells), rainwater harvesting methods and public stand-taps which are operated and managed by local communities. These systems heavily rely on external funding for development and maintenance. The Saudi Fund for Development, for example, has stated that they have developed around 360 wells in The Gambia supplying more remote villages with drinking water.

If there are no public taps or boreholes within reasonable walking distance, people fall back to hand-dug wells – which are still common in rural areas. These hand-dug wells are often susceptible to contamination. Rainwater harvesting is increasingly promoted, especially in schools and public buildings. In areas with unreliable piped supply, private vendors truck and sell



Figure 3-11: Well developed by the Saudi Fund for Development

water from tankers.

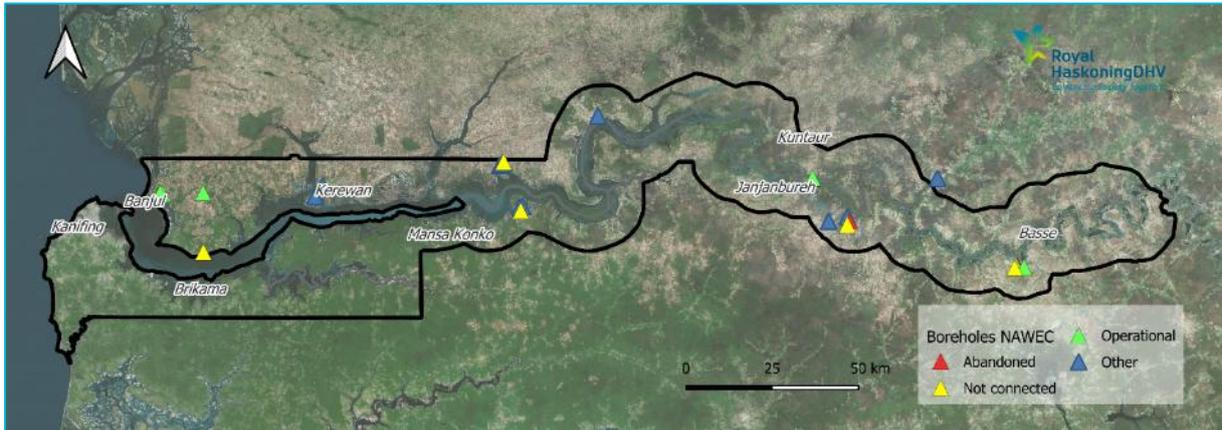


Figure 3-12: Locations of boreholes managed by NAWEC (Adapted from Feasibility Study Report, SNC Lavalin International, GAMECS)

In The Gambia, water quality issues are common, with high levels of contamination in both piped water and groundwater from boreholes. Often contamination comes from inappropriate sanitation causing faecal contamination of the water sources. Aging infrastructure leads to frequent service interruptions and water losses. There are also significant disparities in water access and quality between urban and rural areas, with riverine communities particularly underserved. Only in Bansang there is groundwater treatment by aeration, mainly to remove iron and manganese contaminants. Other water production plants use chlorination to disinfect abstracted water.

In the past decades, there has been an upward trend in the access to water sources and sanitation in The Gambia (see Figure 3-13). According to a study done by UN Water in 2017, the percentage of population in The Gambia with access to improved drinking water sources improved from 80% in 1995 to 87% in 2011 (UN Water, 2017). For sanitation, the country was still below the SDG target with 42% of the population having access to basic level of sanitation (Sanitation and Water for All, 2022). The World Bank has reported that 86% of the population in The Gambia had access to at least basic drinking water services in 2022. This includes improved water services such as piped water, boreholes, protected wells, and springs, provided collection time is not more than 30 minutes for a round trip (Trading Economics, 2025). Only 48% of the population had access to safely managed drinking water services in 2022, which ensures water is accessible on premises, available when needed, and free from contamination.

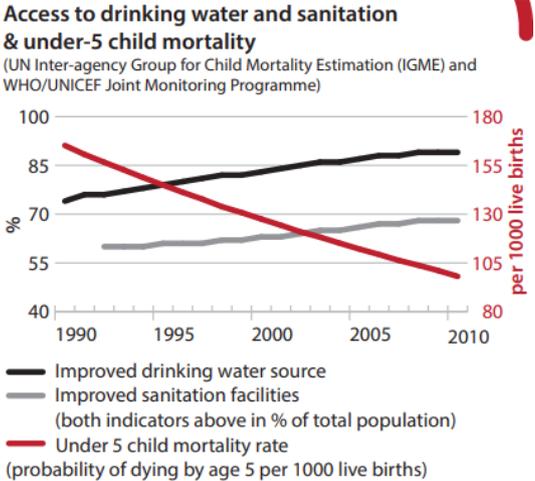


Figure 3-13: Access to drinking water and sanitation in The Gambia in relation to under-5 child mortality from 1990-2010 (UN Water, 2017)

3.5 Stakeholders & Legislative overview

3.5.1 History of the legislative framework regarding water resources in the Gambia

Before 1989, The Gambia lacked a formal written water policy. The National Water Resources Council Act of 1979 provided initial direction by regulating water use and establishing the Department of Water Resources to develop an integrated water resources management framework. In 1989, guidelines were introduced to decentralize water management, promote community ownership of infrastructure, and incorporate private sector participation. These principles continue to shape the legal framework today.

The National Water Policy of 2006 built on the 1989 guidelines, emphasizing decentralization, equal resource distribution, and private sector involvement. It incorporated international agreements ratified by The Gambia and was supported by an integrated water resource management (IWRM) roadmap developed between 2007 and 2009 with African Development Bank funding (Njie, IWRM roadmap for the Gambia, 2009).

In 2012, the Gambia Country Water Partnership was established to coordinate national water resource management (NIRAS, 2015). The national water resources management plan was concretized with the development of a national water resources assessment strategy in 2015, focusing on institutional capacity building, transboundary cooperation, and improved monitoring.

The Gambia joined Sanitation and Water for All (SWA) in 2013, integrating WASH initiatives into national policies with ambitious goals for universal access to safe drinking water and improved sanitation by 2021. Despite progress, challenges persist in institutional capacity and enforcement frameworks. This underlines the need for the government to continue working on the alignment of its water policies with existing laws and strengthening its institutional capacity to manage water resources effectively.

3.5.2 Stakeholders

In the realm of water management in The Gambia there is a network of stakeholders, each with distinct roles, interests, and levels of influence. It includes governmental bodies, operational institutions, communities, business entities, and international organisations. The stakeholders range from high-power entities such as the Ministry of Fisheries and Water Resources (MoFWR) or the National Water and Electricity Company (NAWEC), to local communities whose livelihoods are directly affected by changes in water availability. Below the key stakeholders in water resources management are listed, including their main role:

- **MoFWR:** Oversees water resources management and is responsible for policy development and implementation. It is the lead government body responsible for the water sector.
- **Department of Water Resources (DWR):** As part of the MoFWR, the DWR is responsible for water resources management, provision of water supply to rural areas, groundwater levels and quality monitoring, and coordinating hydrological data collection. It also has a unit responsible for meteorological services.
- **NAWEC:** A state-owned enterprise that manages urban water supply and sanitation in the Greater Banjul Area, peri-urban areas, and provincial growth centers. NAWEC is responsible for water production, distribution, and infrastructure maintenance.
- 1. **National Environment Agency (NEA):** Handles water quality standards, pollution control, and environmental protection related to water resources.
- 2. **Public Utilities Regulatory Authority (PURA):** Regulates the provision of electricity, water supply, and sanitation services. Sets water quality regulations and standards, monitors groundwater quality, wastewater systems, and infrastructure related to water supply.
- 3. **Department of Physical Planning and Housing (DPPH):** Has statutory duties and powers in relation to conservation and protection of water resources.
- 4. **Local Government Authorities (LGAs):** Play a role in water resources management at the regional level.
- 5. **Gambia River Basin Development Organization (OMVG):** Promotes regional cooperation on transboundary water management for the Gambia River Basin.
- **Economic Community of West African States (ECOWAS):** Supports regional water policies and initiatives through its Water Resources Coordination Center.
- 6. **Ministry of Environment, Climate Change and Natural Resources (MECCNAR):** Involved in addressing climate change issues, also related to water resources.
- 7. **Gambia Country Water Partnership (GWP Gambia):** Coordinates national water resources management work, facilitates participatory planning processes, and provides technical assistance.
- 8. **Local communities:** Rely on groundwater for drinking, agriculture, and other uses.
- 9. **Farmers:** Engaged in agriculture and horticulture that depend on water resources.
- 10. **International donors and organizations:** Various donors provide development assistance to The Gambia's water sector, such as the African Development Bank (AfDB), World Bank (WB), or the African Water Facility (AWF).

3.5.3 Legislative overview

Water resources management is laid down in several different regulations in the Gambian law and in international agreements. This section provides some of the key regulations.

- National Water Resources Council Act 1979

The act established the National Water Resources Council to oversee the use, development, conservation, and regulation of water resources. It promotes rational use of water resources while addressing issues like flooding, soil erosion, and salinization.

- **Public Health Act 1990**
This act empowers authorities to regulate sanitary waste disposal and abate public health nuisances. It ensures that waste management practices do not harm public health or pollute water resources.
- **Local Government Act 1990 (revised in 2002)**
This act empowers local councils to prevent soil erosion, manage forests, regulate waste disposal, and oversee health and sanitation within their jurisdictions.
- **National Environment Management Act (NEMA) 1994**
This act provides the framework for environmental legislation in The Gambia. It established the National Environment Management Council (NEMC) and the National Environment Agency (NEA) to oversee environmental protection and management. The act enforces coordination of environmental policies and ensures compliance with environmental standards.
- **Discharge Permit Regulation 2001**
This regulation requires registration of processes with pollution potential. The NEA can refuse permits for discharges exceeding environmental quality standards, ensuring pollution control and safeguarding water quality.
- **National Water Policy 2006**
This policy sets a framework for sustainable water management based on Integrated Water Resources Management (IWRM) principles, emphasizing equitable resource allocation.
- **The Gambia Water Bill 2014**
This bill incorporates principles from the National Water Policy to create a unified legal framework for water resource management. It prioritizes basic human needs in water allocation, introduces permits for abstraction or discharge, establishes reserved flows to protect ecosystems during droughts or emergencies, and enforces penalties for non-compliance.
- **National Water Resources Management Authority Bill 2014**
This bill proposed the establishment of the National Water Resources Management Authority (NWRMA) as the lead agency for managing water resources. It includes provisions for water permitting systems, pollution prevention measures, data collection on water use, and enforcement mechanisms.
- **The Gambia National Policy for Sanitation and Hygiene 2015**
This policy provides a framework for acceptable, affordable, and sustainable sanitation and hygiene services across the country.

3.5.4 Institutional challenges

The application for permits to abstract groundwater in The Gambia is currently ineffectively enforced, and borehole data are not centrally collected or monitored. This has created a gap in groundwater governance. Even between the National Water and Electricity Company (NAWEC) and the Department of Water Resources (DWR) there is no comprehensive mechanism for data sharing. While international organizations occasionally request licenses due to their internal compliance processes, local compliance remains minimal.

In 2014, an inventory of groundwater points was conducted by NIRAS, as part of the National Water Sector Reform Project (NIRAS, 2015). This inventory identified approximately 1,000 groundwater points from various sources. The data was stored in an online database which, soon after, became inactive. There has been no budget allocated for updating the inventory, and it remains outdated. Despite this, the 2014 efforts included the establishment of a network of 38 observation boreholes distributed across The Gambia. Initially equipped with automatic data loggers, many failed over time due to maintenance challenges. As a result, only six boreholes currently have functioning loggers, while others are measured manually at irregular intervals due to funding delays and inadequate mobility (OMVG OMVS, 2020). Currently, no central monitoring network is operated neither by the DWR or by NAWEC.

3.6 Key challenges experienced in the water resources sector

3.6.1 Feedback during field visit

During a field visit to The Gambia (6-14 Dec 2024), information gathered from the Ministry of Fisheries and Water Resources (MoFWR) highlighted several challenges and gaps in water resource management. These concerns include:

- **Water Quality Issues** in open areas, with a focus on providing clean water to communities. The lack of access to clean water supply severely impacts women and livestock in affected regions.
- **The declining groundwater table** due to ongoing droughts poses a significant threat to long-term water sustainability.
- **Flooding** also presents challenges, as heavy rainfall overwhelms the water and drainage systems. This situation is exacerbated by the risk of downstream impacts from floods in Senegal.
- There is an urgent need for **regulated well drilling** and controlled extraction to prevent over-extraction of groundwater. Private companies are extracting large amounts of water without restrictions, further straining resources.
- **Pollution from septic tanks** – which leak contaminants into groundwater - is another critical issue that should be addressed to protect water quality.

3.6.2 Key challenges according to literature

Looking into the studies on water resources done over the last years in the Gambia, the concerns as highlighted by the MoFWR (see above) can be supplemented with the challenges as described below.

Changing weather patterns

The Gambia faces challenges that are likely to impact water resources in the country, exacerbating existing vulnerabilities. Over the past six decades, The Gambia has experienced a 1.0°C rise in average temperature, with projections indicating a potential increase of 3-6°C by the end of the 21st century (Xuehui Han, 2024). The warming trend is likely to change rainfall patterns making them more variable and less continuous.

Increased flood risk

Due to the changing precipitation patterns, extreme weather events such as floods are becoming more frequent. For instance, severe flooding in 2022 displaced over 50,000 people and caused widespread damage to infrastructure (UN Water, 2017). Floodwaters often contaminate drinking water sources with pollutants or saline intrusion. Deforestation for fuelwood further exacerbates soil erosion and sedimentation in rivers and wetlands.

Overexploited groundwater sources

Groundwater serves as a vital source of drinking water and irrigation in The Gambia. However, overexploitation of aquifers—particularly in urban areas such as the Greater Banjul Area—has raised concerns about declining groundwater levels. While specific data on trends are limited, increased abstraction for domestic use, agriculture, and industry puts pressure on the aquifers. Without effective monitoring or regulation of groundwater abstraction, these resources risk depletion (NIRAS, 2015).

Saltwater intrusion into groundwater

Because of overexploited aquifers, salinity intrusion into groundwater is becoming a critical issue in The Gambia, particularly in coastal areas where more than half of the population resides. Rising sea levels and reduced freshwater flows in the Gambia River exacerbate this problem (Global Water Partnership, 2010).

Saltwater intrusion upstream of the Gambia river

Due to the sea level rise and reduced river discharges, saltwater intrusion is prevailing further inland (Global Water Partnership, 2010). This intrusion compromises drinking water quality and affects agricultural productivity by rendering soils unsuitable for cultivation. The situation is particularly severe in the lower reaches of the river, where saline conditions persist throughout the year (UNESCO, 2015).

Water scarcity

As a result of the climate change and human induced impacts as described above, seasonal and localized water scarcity is becoming increasingly frequent in The Gambia. Projected water stress levels show an increasing trend that is likely to affect the Gambia and the northern coastal region in particular (see Figure 3-14). The rapid population growth and increased agricultural and industrial demands, places significant stress on water resources, especially in the highly urbanising west coast region. During the dry season, when rainfall is scarce, many communities face acute shortages, particularly in rural areas where access to alternative sources is limited (Global Water Partnership, 2010).

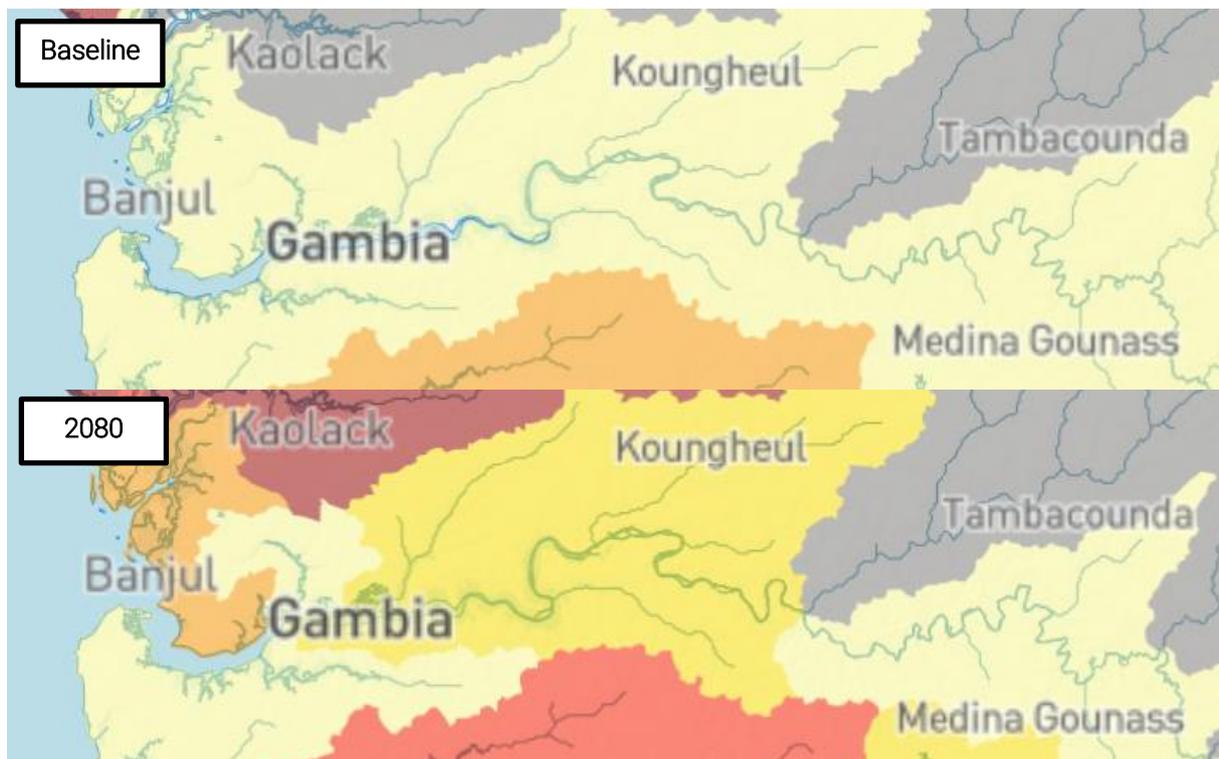


Figure 3-14: Water stress in The Gambia in the baseline and future (RCP8.5, 2080). Water stress means the ratio of total water demand to available renewable surface and groundwater supplies (Aqueduct Water Risk Atlas, WRI)

4. WATER USE AND DEMAND

4.1 Domestic

In this section the domestic water demand is assessed. The domestic water demand is defined as the water demand per capita that includes everything that is not agricultural, industrial or environmental demand. Meaning that institutional demands (i.e. schools, hospitals and governmental organizations) are also considered. This is also referred to as municipal use.

The following assumptions are made with respect to assessing the domestic demand:

- There is no consensus in global literature regarding the domestic water use. In this study, the numbers as presented in the water fact sheet from 2016 are used (AMCOW, 2018). Here a total water withdrawal of 91 million m³/year is presented which comes down to a water withdrawal per capita of 48 m³/year. Assuming that 45% is allocated for domestic use, the resulting domestic use is assessed to be 59L/capita/day in 2016.
- Comparing the daily water use to international water use patterns, this is a very low per capita use. This is mainly explained by the fact that a major part of the population is still making use of point sources which comes with a high effort of accessing water. With increased accessibility, the water use will increase as well. It is assumed that NAWEC will further improve its water services and coverage which will further increase the water consumption per capita. We assume that this will lead to a per capita consumption of 100 L/capita/day in 2100.
- A constant non-revenue water (NRW) percentage of 20% is used to account for water that is lost in production and conveyance. This 20% is based on a report of (Haskoning, 2004)
- According to the 2024 census of Gambia, the current population is 2.422.712. The population is assumed to increase according to the UN world population prospects. The annual growth rate of the population is currently around 2.45% but is expected to steadily decrease (Table 4-1). Nonetheless, the current population is expected to be doubled with respect to the current population between 2050 and 2060.

The resulting domestic demand projections are presented in Table 4-1. The annual demand is currently about 0.09 km³ and is projected to increase to more than 0.30 km³ by 2100.

Table 4-1: Expected population, and annual growth rate for Gambia, based on the United Nations – World Population Prospects

Year	Expected population	Expected annual growth rate (%)	Water use [L/c/day]	NRW [%]	Water demand [L/c/day]	Annual water demand [km ³]
2016	1,900,000	2.84	59	20%	74	0.05
2020	2,161,356	2.6	66	20%	82	0.07
2024	2,422,712	2.47	78	20%	97	0.09
2030	3,263,651	2.23	80	20%	100	0.12
2040	3,984,778	1.83	83	20%	103	0.15
2050	4,673,743	1.43	85	20%	106	0.18
2100	6,667,396	0.15	100	20%	125	0.30

4.2 Agricultural

4.2.1 Current agricultural water demand

Reliable data on the actual water use for irrigation purposes in the agricultural sector in The Gambia is not available. Therefore, the estimations on water consumption are made by combining a number of publicly available datasets and studies. To obtain the total surface area of agricultural land, the Worldcover 10m dataset from the European Space Agency (ESA) is used. This dataset is based on satellite imagery from the Sentinel-1 and Sentinel-2 satellites from the year 2021. The spatial resolution is 10 x 10 meters. The spatial distribution of the landcover is given by the map in Figure 4-1, and the associated surface areas by Table 4-2.

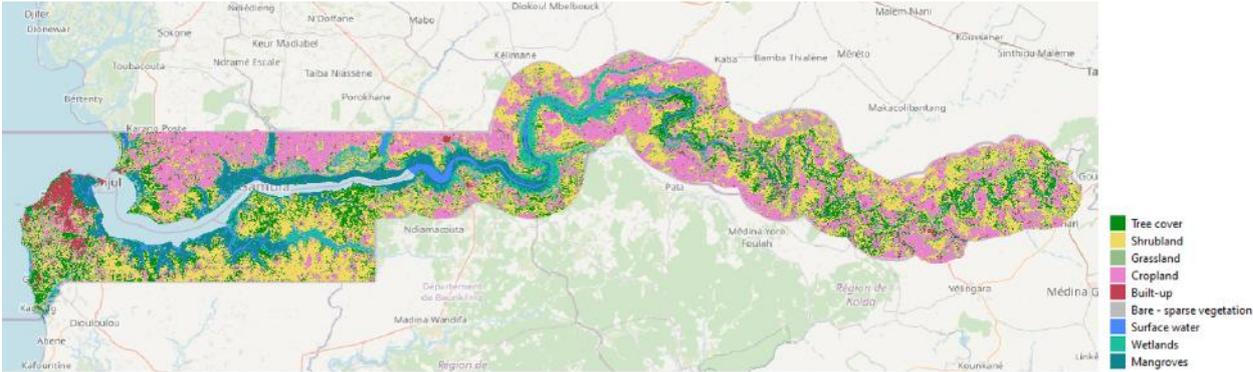


Figure 4-1: Land cover of Gambia, based on the Worldcover 10m dataset by the ESA (2021).

Table 4-2: Surface areas of the respective land cover types in Gambia (based on Worldcover 10m - ESA, 2021)

Land cover	Area (km ²)	Area (%)
Tree cover	1607	14.4
Shrubland	3387	30.4
Grassland	1185	10.6
Cropland	3004	27.0
Built-up	248	2.2
Bare - sparse vegetation	45	0.4
Permanent water bodies	325	2.9
Herbaceous wetland	629	5.7
Mangroves	711	6.4

While this is a recent dataset of high spatial resolution, it does not always reflect the right areas for cropland. The ESA Landcover map sometimes struggles to accurately represent cropland areas due to the heterogeneous nature of land cover, persistent cloud cover affecting satellite data availability, and the small, fragmented nature of crop fields such as in The Gambia. However, given the absence of a detailed land use map, this dataset is the most accurate which can be used for this study.

The dataset does not differentiate between different crops either whereas the water demands of different crops are an important factor to consider. A study by the FAO (FAO, 2018) does provide an overview of the contribution of different crops to the total harvested area.



Figure 4-2: Land use and yields of the main agricultural crops in the Gambia (FAO, 2018).

By combining the % of harvested area from Figure 4-2 with the total agricultural surface area from Table 4-2, the total surface area per crop can be determined. The most important crops are millet, groundnut (peanut) and rice (paddy), contributing to 75% of the total harvested area. The crop water requirements are obtained from the FAO Irrigation Water Management: Irrigation Water Needs, chapter 2 (FAO, Irrigation Water Management: Irrigation Water Needs, 1986), and are provided in Table 4-3. Crop water needs are the total needs of a crop within the growing season.

Table 4-3: Surface areas and crop water requirements per crop.

Crop	Area (% of total)	Area (km ²)	Crop water needs [mm]
Millet	30	901.2	450 – 650
Groundnut	28	841.1	500 – 700
Rice (paddy)	17	510.7	450 – 700
Maize	9	270.3	500 – 800
Sorghum	8	240.3	450 – 650
Pulses	3	90.1	350 – 500
Remaining	5	150.2	500 – 600

Combining the crop water needs with the respective surface areas leads to an estimated agricultural water demand of 1.4 – 2.0 km³. Note that these are the total crop water needs for the entire growing season. A large part will be partially or fully rainfed crops, and therefore the actual water demand for irrigation - through abstraction by groundwater wells, for example - will always be less than the total demand.

4.2.2 Future projections of agricultural water demand

The future agricultural water demand projections are assessed by identifying the future growth of this sector. The figures on economic growth showed that the growth will mainly be in the services and manufacturing sectors (Aikins, 2024). The relative importance of agriculture in the economic growth will therefore decrease over time – see Figure 4-3.

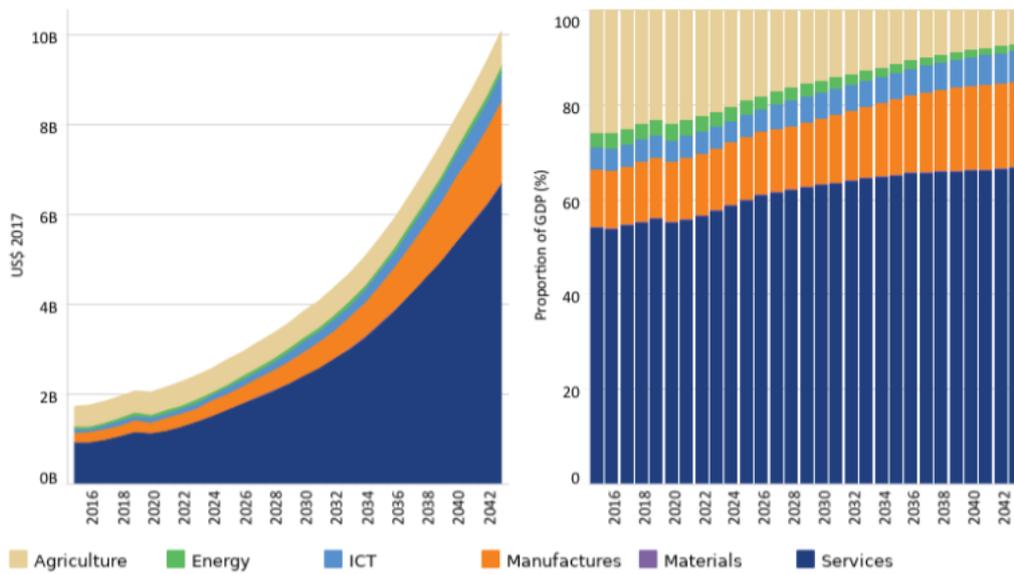


Figure 4-3: Projected added value per sector - Gambia (Aikins, 2024)

The FAO provides data on the projected agricultural production and demand (FAO, Gambia, 2024) up to 2043 – expressed in millions of tons of crops (Figure 4-4). It shows that the gap between the demand for agricultural products and the agricultural production will further increase. The demand for water from agriculture is therefore assumed to develop according to the projected increase agricultural production as per Figure 4-4.

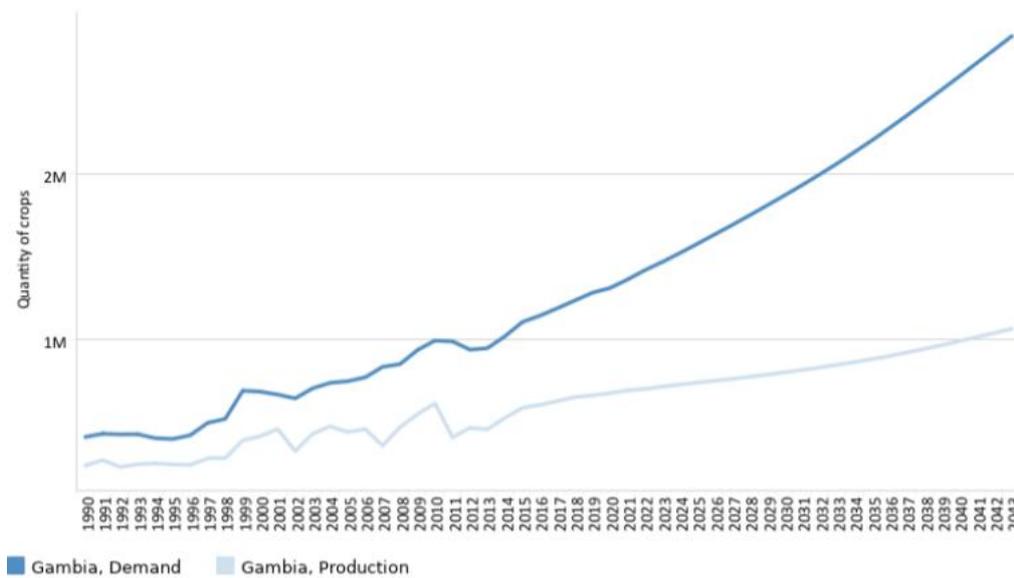


Figure 4-4: The projected agricultural demand versus the projected agricultural production for Gambia in millions of tons of crops (Aikins, 2024)

Assuming no changes in the type of crops and water efficiency, the expected future agricultural water demands can be determined up to 2043 (Table 4-4).

Table 4-4: Projected growth (with 2025 as reference) and associated agricultural water demands

Year	Growth in Agricultural production	Expected agricultural water demand
2025	0 % (baseline)	1.4 – 2.0 km ³
2030	14 %	1.6 – 2.3 km ³
2035	29 %	1.8 – 2.6 km ³
2040	43 %	2.0 – 2.9 km ³
2043	57 %	2.2 – 3.1 km ³

4.3 Industrial

4.3.1 Current industrial demand

As mentioned in Chapter 3.3.1, a study by (AMCOW, 2018) estimated the total annual water withdrawal to be 91 million m³. This is the total water withdrawal, of which approximately 22% is estimated to be used in the industrial sector. This reflects a total volume of 0.019 km³ per year in 2016.

4.3.2 Future projections of industrial water demand

The future industrial demand is assumed to increase according to the growth rate of the manufacturing sector as per (Aikins, 2024) and presented in Figure 4-3. This allows for industrial water demand projections in the Gambia up to 2050 – see Table 4-5. According to the presented methodology, the industrial water demand will increase almost ten-fold up to 2050 taking 2025 as a reference.

Table 4-5: projected growth of industrial manufacturing sector and associated water demand

Year	Annual growth rate manufacturing sector	Industrial demand (km ³ /y)
2016	2%	0.02
2025	7%	0.03
2030	9%	0.05
2040	9%	0.13
2050	8%	0.28

4.4 Environmental

Our definition of the environmental water demand is the amount of water necessary to maintain ecosystem structure, functioning, and dependent species. Assessing environmental water demand involves quantifying the water needs of diverse environmental components. This includes water for maintaining river flows, supporting aquatic and riparian vegetation, sustaining wildlife populations, and preserving water quality.

The data to perform this analysis thoroughly is not available for The Gambia. Therefore, we adopted a method that estimates the environmental water demand based on the inputs of Normalized Difference Vegetation Index (NDVI) and temperature – see Annex C. We assumed that the water requirements for maintaining the ‘greenness’ of the environment is a fair estimation of the environmental water demand. However, when validating this approach, it appears that it overestimates the actual evapotranspiration and hence the environmental demand.

While it's crucial to consider environmental water requirements in water resource management, accurately assessing these needs for an entire country like The Gambia presents significant challenges. Methods exist for determining water demand for specific ecosystems like wetlands, but they may not be applicable to other environment types such as shrublands or grasslands – which are also important to sustain livestock and wildlife populations. The diversity of ecosystems, varying water dependencies, and complex interactions between different environmental components make it difficult to produce an accurate quantitative assessment of environmental water demand at a national scale.

In order to make sure that it is still possible to assess the safe yields from groundwater without harming the environment, a methodology to assess the sustainable water availability is adopted – see section 5.4.

4.5 Other water use

Navigation

As explained in more detail under component 2 of this assignment, the Gambia River, traversing the country, possesses substantial potential to boost The Gambia's economy through inland water transport and tourism. Currently, however, the river lacks inland transport for import or export. The only existing river transport consists of ferry services. The most prominent ferry route connects Banjul and Barra, linking the capital city to the North Bank region and serving as a vital conduit for people, vehicles, and goods. Several ferry crossings further upstream facilitate transport in inland areas. Despite its numerous advantages, inland water transport remains the least developed transportation mode.

5. WATER BALANCE ASSESSMENT

5.1 Introduction

A water balance model is developed for The Gambia river basin to gain a basic understanding of the main relevant water fluxes through the water cycle and to obtain a comprehensive overview of the physical water availability. A conceptual visualization of the water balance model is presented in Figure 5-1. The fluxes that are considered in the water balance model are precipitation, river discharge and evapotranspiration. Note that in the approach, the lateral in- and outflow components are neglected – both because the terms are not quantifiable as well as because literature suggests that this component is limited compared to the other water balance components (<10%) (Njie, IWRM roadmap for the Gambia, 2009). The resulting change in storage presents the net water per timestep that resides or leaves the catchment area. The water balance is described by the following equation:

$$\frac{\Delta V}{\Delta t} = P - Q - ET$$

Equation 1: Water balance formula, where $\Delta V/\Delta t$ is the change in storage, P the total precipitation, Q the river flows into the ocean, and ET the evapotranspiration within the system.

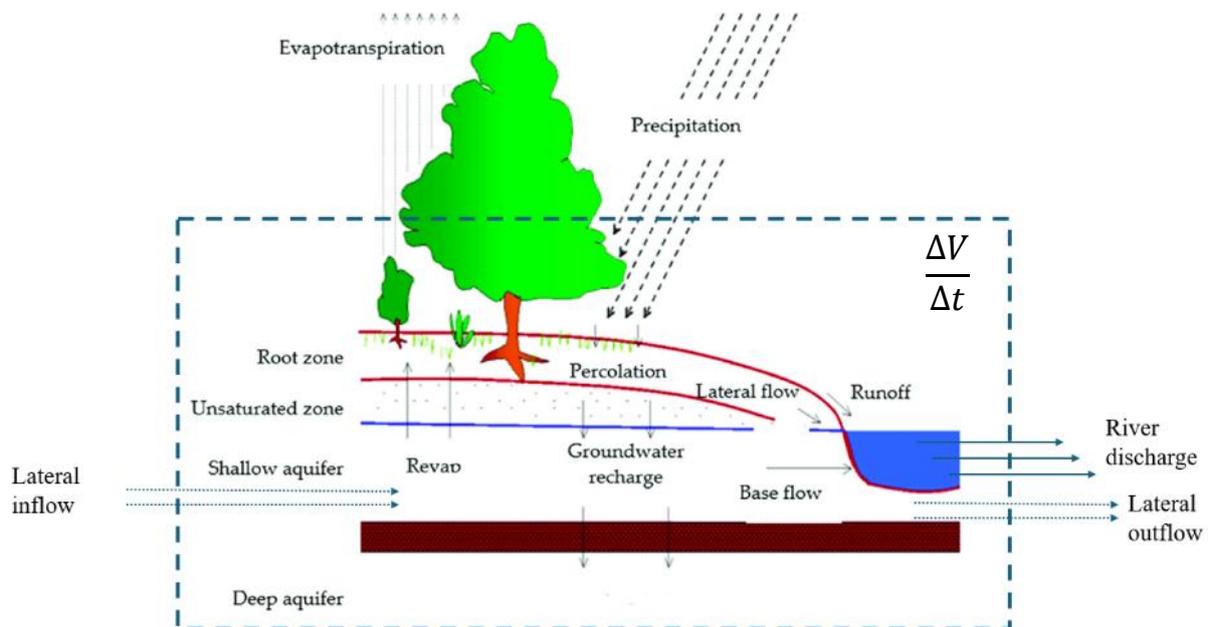


Figure 5-1: Conceptual visualization of the water balance model

The analysis will be done for the entire GRB (Figure 5-2). The outline of the GRB corresponds to the dashed line in Figure 5-1. This means that the water balance model takes into account both surface and groundwater bodies within the catchment boundaries. Note that within the GRB there are internal flows such as lateral flow, runoff, baseflow and groundwater recharge which are not taken into consideration in the water balance approach. Only the bigger picture of the catchment area is considered.

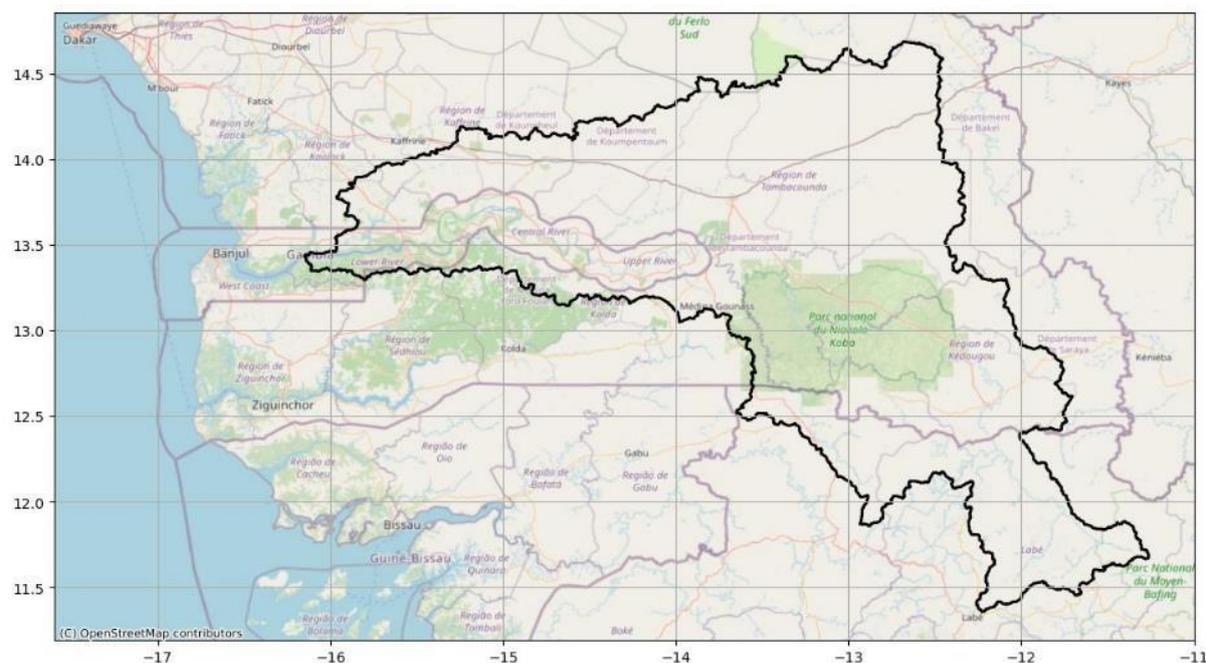


Figure 5-2: The location of The GRB, covering the entire country of The Gambia, and parts of Senegal and Guinea.

5.2 Input data

Since no actual river discharge measurements were available for this study, open-source data were considered. River discharges of the Gambia were collected from Global Flood Awareness System (GloFAS). GloFAS provides gridded modelled daily hydrological time series forced with meteorological reanalysis data. It is produced by the Copernicus Emergency Management Service (CEMS), and is developed by forcing the open-source LISFLOOD hydrological model with ERA5 meteorological reanalysis data. This provides us with daily estimations of the river discharge (m^3s^{-1}) and a spatial resolution of 0.05 degrees or around 5566 meters. The GloFAS data was sampled for the period 1995 – 2024, on the location where the Gambia river leaves the catchment area (X: -16.155, Y: 13.422 (EPSG:4326)), see Figure 5-3.

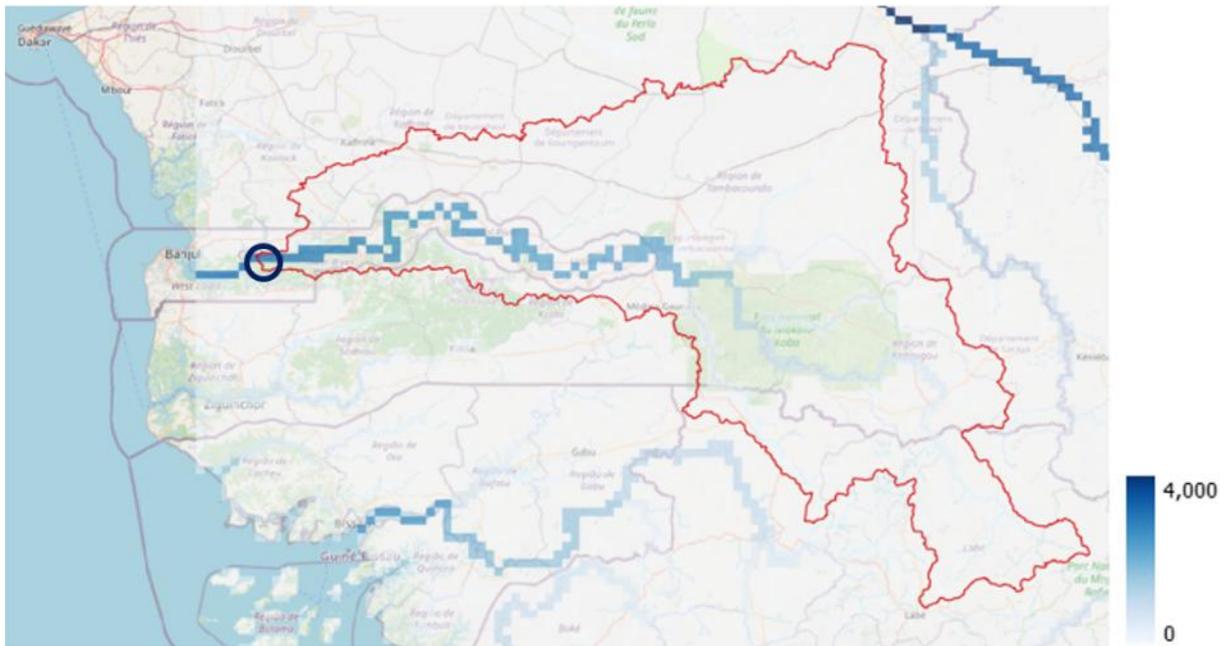


Figure 5-3: Visualisation of the GloFAS output for the Gambia river basin (discharge in m^3s^{-1}), and the location of sampling for the water balance model input (black circle).

The meteorological inputs of this assessment are based on ECMWF Reanalysis v5 – LAND (ERA5-Land) product, released by the Copernicus Climate Change Service. This is a globally available reanalysis dataset providing a consistent view over several decades (1950 – current) at an enhanced resolution compared to ERA5 (11.132 meters / 0.1 degrees). Since the GloFAS hydrological simulations are also created by using the ERA5 Reanalysis product as meteorological forcing, this gives us consistent inputs for both the river discharge, the total precipitation and the total evapotranspiration. For this assessment, a period of 30 years was used: 1995 – 2024. Daily aggregates were collected for the entire Gambia river basin for the following parameters:

- Total evapotranspiration: This is the accumulated volume of water that has evaporated from the Earth's surface, including evaporation from bare soil, evaporation from open water, evaporation from the top of canopies, and the transpiration through vegetation.
- Total precipitation: This is the sum of large-scale precipitation (generated by large-scale weather patterns such as cold fronts) and convective precipitation (such as thunderstorms generated by rising air). It does not include fog or dew.

Both parameters are provided as a depth in meters. The average annual evapotranspiration and precipitation for The Gambia river basin are provided in Figure 5-4 and Figure 5-5. The total annual precipitation ranges from 500 mm in the north of the basin, up to 1200 mm in the south of the basin. The total annual evapotranspiration follows the same spatial pattern, except directly above and around The Gambia river. The evapotranspiration from ERA5 is the actual evapotranspiration, and therefore also takes the water availability into account. Direct evaporation from the surface water, and through wetlands and irrigated fields on the banks lead to these higher evapotranspiration rates of up to 1000 mm per year.

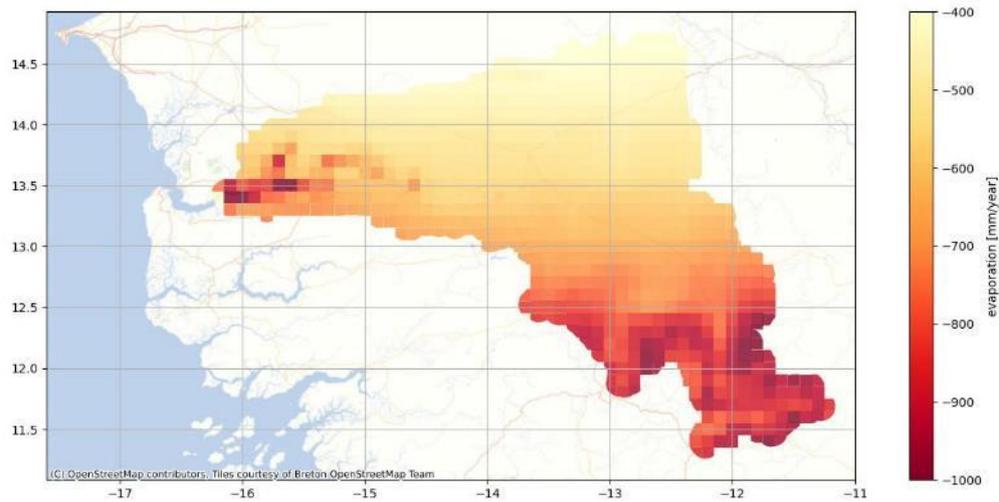


Figure 5-4: The average annual evapotranspiration in mm/year (1995 - 2024) based on the ERA5 daily aggregates.

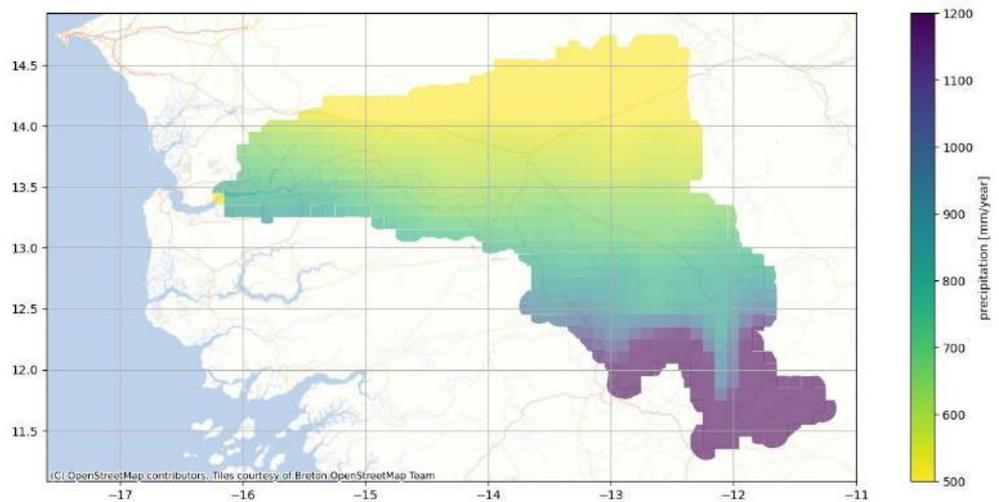


Figure 5-5: The average annual precipitation in mm/year (1995 - 2024) based on the ERA5 daily aggregates.

The discharge of The Gambia river follows a clear pattern of low discharges from November / December up to August, and high discharges peaking in September and October. The height of the peak however is highly variable, ranging from $400 \text{ m}^3\text{s}^{-1}$ up to $3400 \text{ m}^3\text{s}^{-1}$ within the 30-year period that is considered in this study (Figure 5-6).

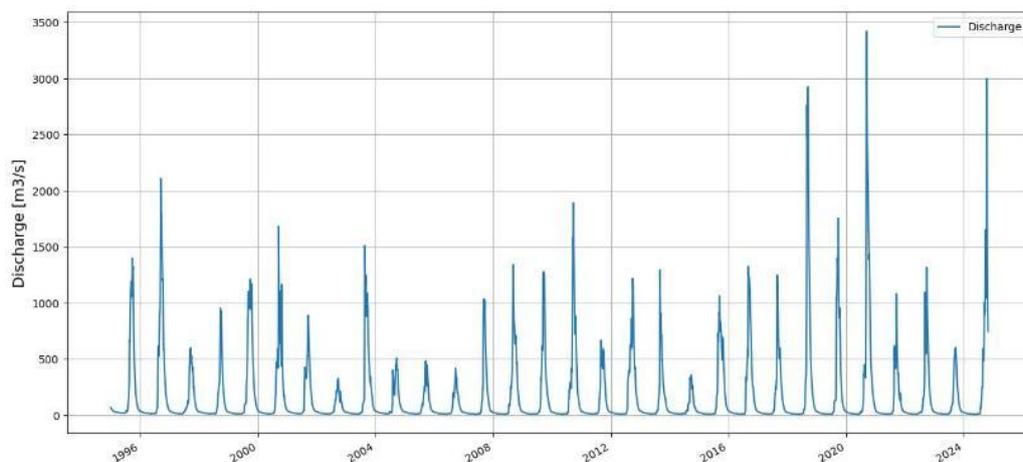


Figure 5-6: The discharge of the Gambia river (1995 - 2024) based on GloFAS simulations.

5.3 Water balance model approach

The incoming and outgoing volumes of water are determined for every 24-hour timestep. Based on these fluxes, the change in storage is determined for all timesteps using the formula. All volumes are total volumes for the entire GRB.

Zooming in to a specific year, the seasonal patterns become clear (Figure 5-7). While there is practically no precipitation in the dry season, some evapotranspiration can still be observed through direct evaporation from surface water, and transpiration through vegetation. After precipitation events, the evapotranspiration follows directly. The river discharges only start rising towards the second half of the rainy season. Furthermore, the total volume of river discharge is much lower than the volumes of precipitation and evapotranspiration.

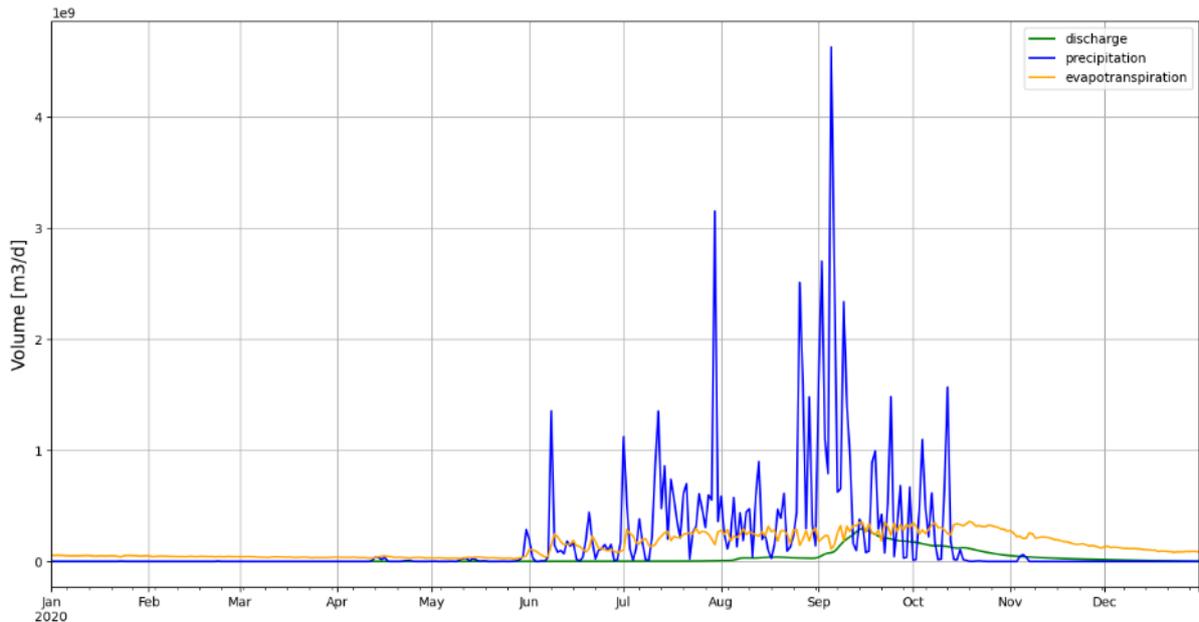


Figure 5-7: Example of the aggregated water fluxes for the entire Gambia catchment varying over time.

By overlaying the annual patterns of each individual year in the entire 30-year period, a good impression is created about the variability in precipitation, evapotranspiration and river discharges (Figure 5-8). Furthermore, it shows the inter-seasonal variation (e.g. how constant the start of the wet / dry seasons are).

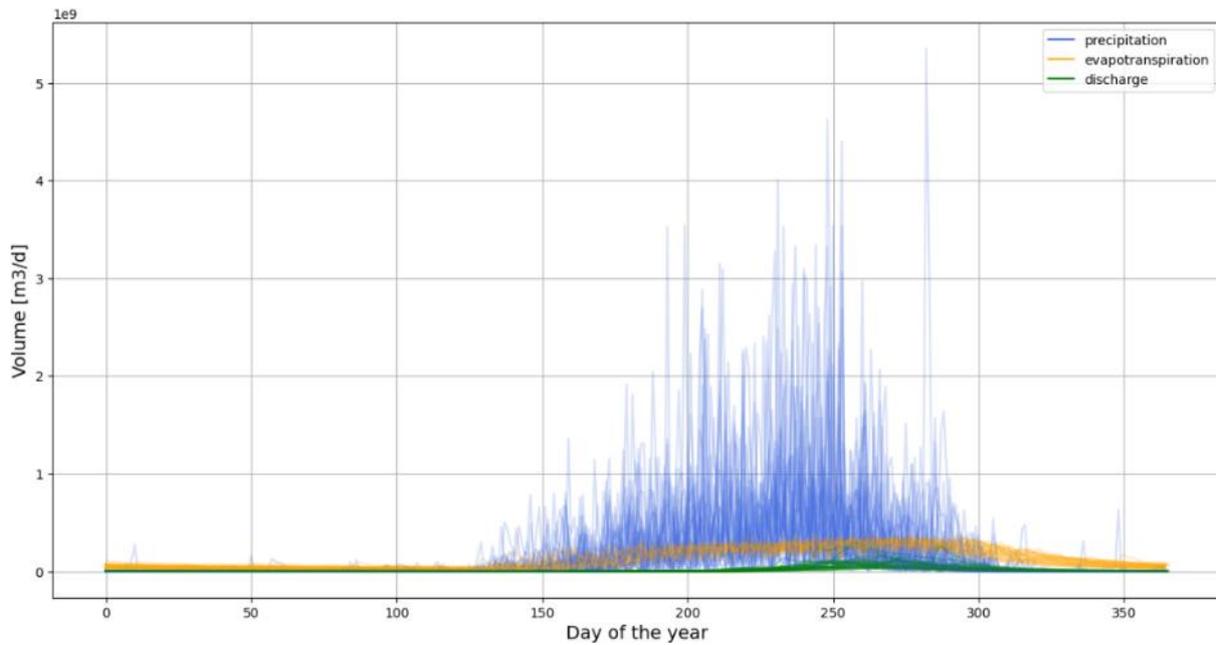


Figure 5-8: The annual patterns of the precipitation-, evapotranspiration -, and discharge fluxes in m³/day, based on the period 1995 – 2024.

5.4 Sustainable water availability and total renewable freshwater

As explained in section 5.1, the water balance approach considers the catchment as a whole and does not take into account the internal processes. The cumulative yearly change in volume is assumed to reflect a safe yield for the catchment area. Taking more water out of the catchment is possible, but will influence other parameters, such as the base flow or the groundwater levels – see Figure 5-1. Therefore, this safe yield is used as a proxy for **sustainable water availability** – which is defined as the water that can sustainably be abstracted from an area without negatively impacting the natural environment. This parameter can be used to determine the water stress specifically for domestic use and industrial use since the agricultural and environmental use are already reflected in the outgoing flux of the evapotranspiration parameter. In order to assess the sustainable water availability within the country boundaries of Gambia, we will consider the surface area of the country relative to the total catchment surface area as a best estimate.

Existing studies on water availability (AMCOW, 2018) present a different method to determine water availability. Here, the **Total Renewable Water Resources (TRWR)** is defined as the sum of internal and external renewable water resources in a country. Internal renewable water resources are then defined as “the long-term average annual flow of rivers and recharge of groundwater generated from endogenous precipitation” and the external renewable water resources as “flows of water entering the country”. A conceptual visualization of this method is presented in Figure 5-9. Note that this water might be renewable, but not all water is available. For example, if all the water that is calculated under TRWR would be abstracted, all surface water bodies would fall dry since there will be no more water left to feed the rivers from baseflow and all water that is flowing in from Senegal would then also be abstracted. The TRWR can therefore not be considered to fully contribute to the total volume of available water.

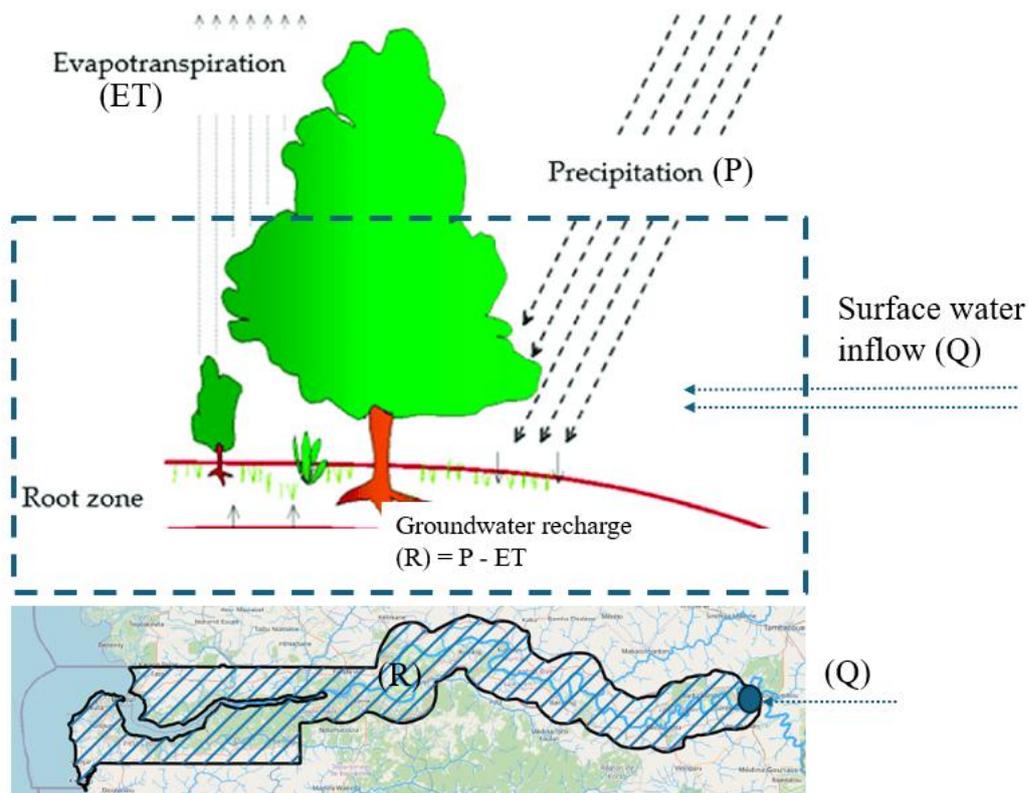


Figure 5-9: Conceptual visualization of total renewable freshwater resources: $TRWR = R + Q$

5.5 Water balance components

For every year, the total change in storage and the fractions of storage change compared to the total precipitation are determined. The resulting figures are provided in Annex A. These numbers are total volumes over the entire Gambia river basin and present the water balance components. The long term average annual fluxes are presented below.

Table 5-1: Water balance components

Component	km ³ /y
Precipitation (P)	51.8
Evapotranspiration (E)	45.4
Discharge (Q)	5.1
Storage change (ΔV)	1.3

Note that the average annual storage change is positive. However, no increasing water levels – neither in surface nor groundwater bodies – have been observed. In addition, no lateral components have been included in the water balance assessment. Given these factors, the positive storage change suggests that there is a lateral component of water flowing out of the GRB, indicating that the basin may be losing water to neighbouring areas (probably the ocean) through underground flows.

6. WATER INDICATORS

6.1 Sustainable water availability

6.1.1 Current situation

The change of storage is considered an indicator of the sustainable water availability in The Gambia river basin. By plotting the change in storage throughout the year, for each individual year in the period 1995 – 2024, a clear seasonal pattern is observed (Figure 6-1). During the first 150 days of the year a negative storage change is observed, due to the absence of rain, and ongoing evapotranspiration. From the start of the rainy season, the storage component of the water balance becomes positive. Storage change is positive from day 250 for all years (September). From October, the evapotranspiration and river discharge exceed the precipitation again. In most of the years, the net storage changes are positive, with cumulative storage changes at the end of the year ranging from -3 to 6 km³ per year.

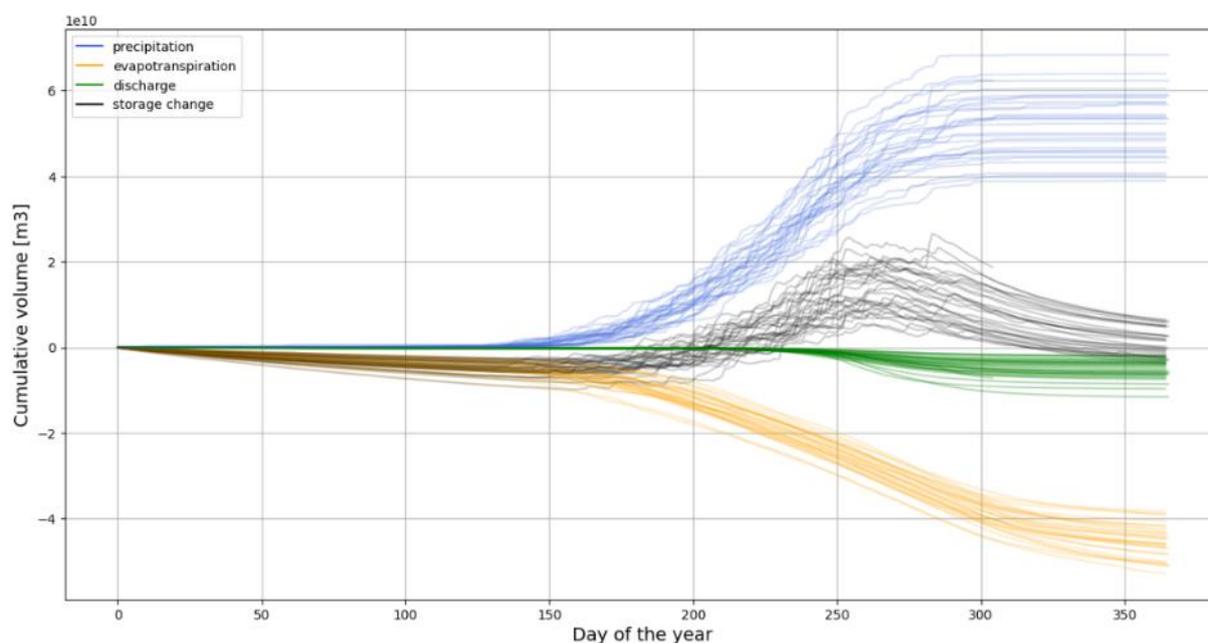


Figure 6-1: The annual patterns of the cumulative precipitation, evapotranspiration and discharges volumes, based on the period 1995 – 2024. The cumulative volume change is calculated as the net storage change of the beforementioned volumes over time.

To estimate the storage-change for the country of The Gambia, the surface area of the country relative to the total catchment surface area times the storage change for the entire catchment is considered as a best estimate. The surface area of Gambia is 11,300 km², and therefore about 15% of the entire Gambia basin (77,100 km²). The estimated yearly averaged volume change for Gambia is therefore calculated to be $0.15 * 1.3 \text{ km}^3 = 0.19 \text{ km}^3$. This 0.19 km³ is taken as a proxy for the long-term sustainable water availability for domestic and industrial use in the Gambia.

Water stress

The Gambia's yearly average sustainable water availability is 0.19 km³. This exceeds the current combined water demand for domestic (0.09 km³) and industrial (0.035 km³) purposes, which totals 0.125 km³. Therefore, the country's sustainable water supply is currently sufficient to meet its domestic and industrial water needs. However, locally the situation may be different. Note that the sustainable water availability is a total sum for the country, meaning that locally the domestic and industrial demand may already surpass the sustainable availability. This would become apparent, if for example, surface water bodies fall dry due to a reduction in baseflow or if declining groundwater levels are observed. As presented in section **Error! Reference source not found.**, the reducing groundwater levels are already experienced – specifically in the GBA. In addition, since the sustainable water availability of 0.19 km³/year is a yearly averaged value within a range from -0.56 to 0.96 km³/year. There are years where the sustainable water

availability is negative and hence the negative consequences of abstracting more than sustainable water availability are experienced more severely.

6.1.2 Under future (climate) scenarios

From the current water balance (Figure 5-7) it is observed that the actual evapotranspiration is mainly driven by water availability in the Gambia basin. Through the entire dry season, the actual evapotranspiration is fairly low, and directly after rain events, the evapotranspiration spikes. The assumption that the evapotranspiration will rise with increasing temperatures is therefore not valid, as long as the water availability does not increase. Therefore, although future temperatures are projected to increase within The Gambia and the GRB, we only considered the expected change in precipitation throughout the year to represent the changes in water availability.

The changes in annual cumulative precipitation are based on the results from the climate hazard report – under component 1 of this project. In Figure 6-2 the projected change in precipitation in the GRB is presented. The colours present the projected in- or decrease in precipitation whereas the grey dots indicate whether there is model agreement about the projected changes. In case there is a grey dot present, it is assumed that the projected change is not valid and no change in precipitation is adopted.

The hazard assessment showed that for most of the GRB, there is no model agreement and therefore no projected change in precipitation. By mid-century (2041 – 2060), under the RCP4.5 scenario, only the far south-eastern part of the GRB shows a significant increase in precipitation. Likewise, under the RCP8.5 scenario, no notable changes in annual precipitation are expected across the GRB except for the south-eastern part.

Change in Raccm mean (2041-2060)

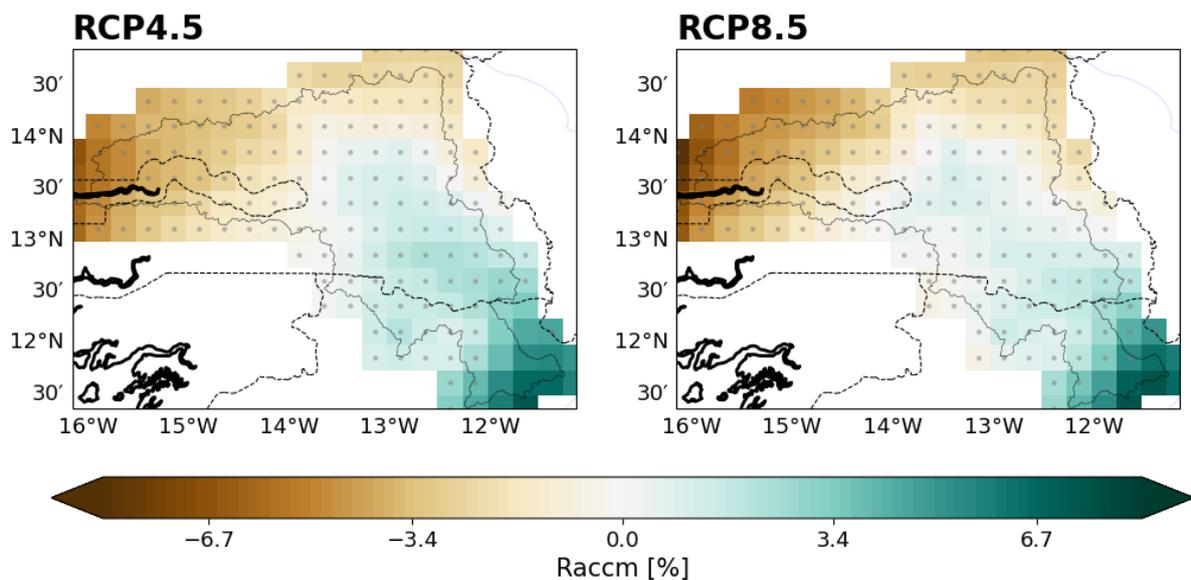


Figure 6-2: Change of projected Mean accumulated precipitation per year for the GRB. The left panel corresponds to the change for the RCP4.5 climate scenario and the right panel for the RCP8.5. Lack of agreement between models on significant change is indicated with grey dots.

In this case, the part of the GRB which shows an increase in precipitation of ~7% accounts for approximately 5% of the GRB surface area. That means that for the total GRB, the areal averaged increase in precipitation is 0.4%. Considering the uncertainties in climate modelling, this incremental change is considered too small to be relevant to changing the hydrological dynamics of the GRB.

Water stress

According to the demand projections as presented in chapter 4, the domestic demand for the projection year 2050 will reach 0.15 km³ and the industrial demand will reach up to 0.28 km³. Considering the long-

term sustainability water availability will remain at approximately 0.19 km³ per year, it is concluded that there is enough water available to provide the local population with domestic water up to 2050 but that the projected sharp increase in industrial demand will exceed the long-term sustainable water availability.

Assuming all domestic and industrial demand will still be abstracted, the water balance will be impacted. That means that groundwater levels will drop – which in turn will further exacerbate the saltwater intrusion and upconing in the aquifers in the coastal areas. The base flow of the river will also reduce – which allows the saltwater from the sea to penetrate further inland.

Note that there is a large disparity in the climate projections. According to climate projections by the World Bank, there are many models which predict a decline in precipitation throughout the entire wet season under different climate scenarios – i.e., SSP3-7.0, SSP2-4.5 and SSP1-1.9 scenarios (World Bank, 2021). Therefore – even though it is not significantly projected by all models- The Gambia should apply the precautionary principle and prepare for a situation with decreasing precipitation and reduced water availability.

6.2 Total renewable freshwater

6.2.1 Current situation

The total renewable water resources (TRWR) are determined by adding the inflow of the Gambia river to the recharge (precipitation - evapotranspiration) within the country boundaries for each time step – see section 5.4. The TRWR for each year is plotted in Figure 6-3. Similar to the sustainable water availability, a clear seasonal pattern is observed. During the first 150 days of the year negative TRWR values are found, due to limited river inflow, the absence of rain, and ongoing evapotranspiration. From the start of the rainy season, the TRWR quickly rises. From October, the TRWR stabilizes and slightly reduces towards the end of the year. Total TRWR volumes ranging from 0.6 to 11 km³ per year with an average of 5.1 km³ over the 1995 – 2025 period.

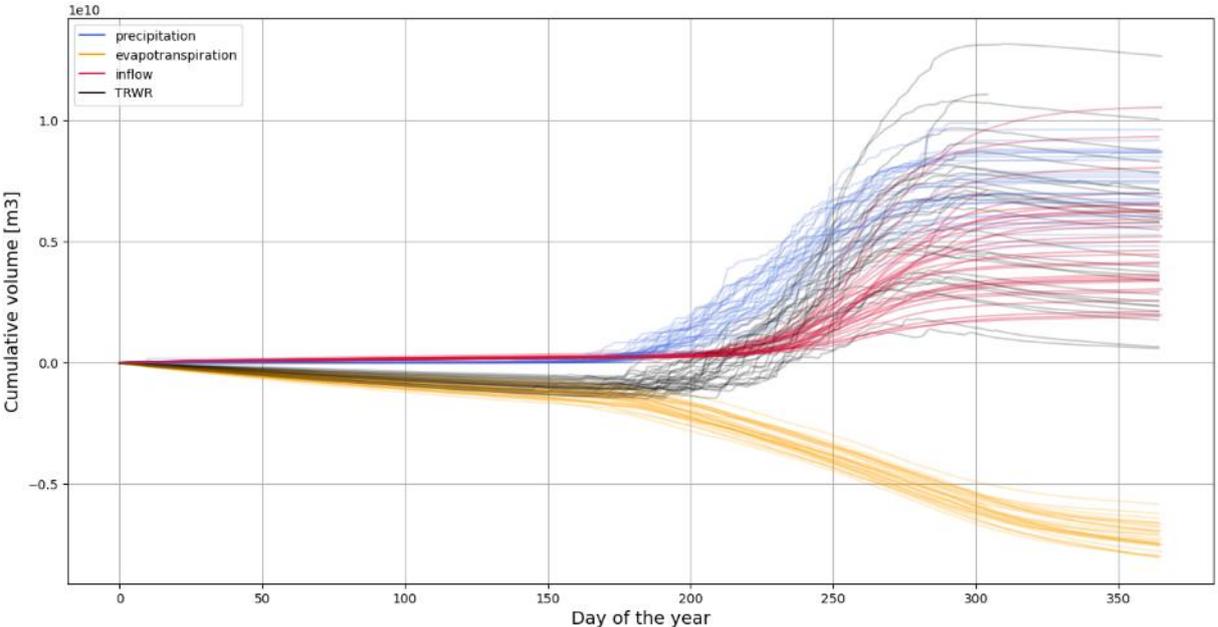


Figure 6-3: The annual patterns of the cumulative precipitation, evapotranspiration, inflow volumes and TRWR, based on the period 1995 – 2024.

For every year, the cumulative TRWR and the fractions of recharge and river inflow compared to the total precipitation are determined. The resulting figures are provided in Annex B. These numbers are total volumes over the Gambia country boundaries.

Note that the TRWR highly depends on the inflow of the Gambia river. In almost 50% of the presented years, the recharge is even assessed to be negative. Meaning that in almost half of the years there is a precipitation deficit instead of a surplus.

The results of the TRWR are compared to previous studies on water availability (AMCOW, 2018). In this study, a total renewable freshwater volume of 4210 m³ per person, and a population of 1.9 million is presented. This gives a yearly total renewable volume of 8.0 km³. This is in the same range as calculated in the presented analysis but is higher than the average TRWR of 5.1 km³. Note that because of the coarseness of the used data the evapotranspiration might be overestimated at pixels which have an overlap with the river – see Figure 5-4 – which leads to an underestimation of the TRWR in the current analyses.

6.2.2 Under future (climate) scenarios

The impact of climate change on the TRWR is assessed in a similar way as for the sustainable water availability – see section 6.1.2. In this case the cumulative precipitation totals within The Gambia boundaries are considered (Figure 6-4). Note that for most of the country, there is no model agreement and therefore no projected change in precipitation. By mid-century (2041 – 2060), under the RCP4.5 scenario, only the northwestern part of the country shows a significant decrease in precipitation (without grey dots). Under the RCP8.5 scenario, no significant changes in annual precipitation are expected across the country.

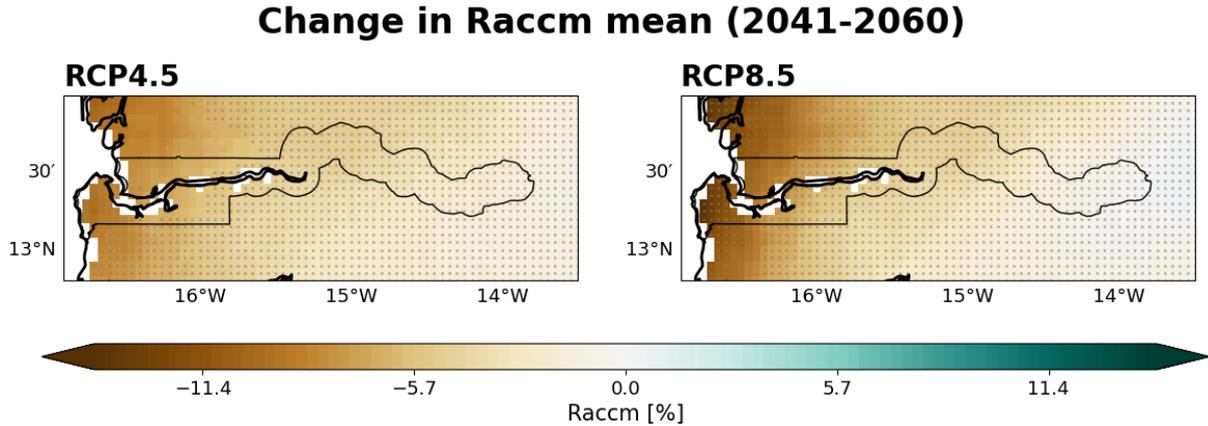


Figure 6-4: Change of projected Mean accumulated precipitation per year for the Gambia country boundaries. The left panel corresponds to the change for the RCP4.5 climate scenario and the right panel for the RCP8.5. Lack of agreement between models on significant change is indicated with grey dots.

In this case, the part of the country which shows a decrease in precipitation of 8% accounts for approximately 11% of the country surface area. That means that for the Gambia country, the total areal averaged reduction in precipitation is 0.9%. Similar to the changes in the GRB, considering the uncertainties in the climate modelling, this incremental change is considered too small to be relevant to change the hydrological dynamics of The Gambia as a whole. However, locally, the impacts of reduced precipitation rates may be more pronounced.

6.3 Water quality

Water quality has a major impact on water availability. Not all water that is physically available is fit for use. This section describes the current status of both surface and groundwater water quality. Subsequently, the effects of climate change on these sources are assessed.

6.3.1 Current situation

Surface water

The Gambia's geography has a large impact on the water quality in the country. Saltwater from the Atlantic Ocean can flow into the River Gambia, especially during high tides, low river discharge, and/or droughts. This happens because the river's estuary has a strong tidal range and experiences large changes in

freshwater flow throughout the year. During the dry season (Jan – June), the river flow is much lower than in the rainy season, which allows more saltwater to enter the river (Bagbohouna, Yaffa, & Bah, 2018).

As a result, the River Gambia is salty or brackish for most of its length due to its flat terrain and varying river water levels. This natural cycle of saltwater intrusion into the river is linked to the flow of freshwater from the continent. By late June or early July (at the end of the dry season), the saltwater can be detected as far as 250 kilometers inland from Banjul which is at the coastline– see Figure 6-5. In the wet season, the saltwater can be detected 180km inland.

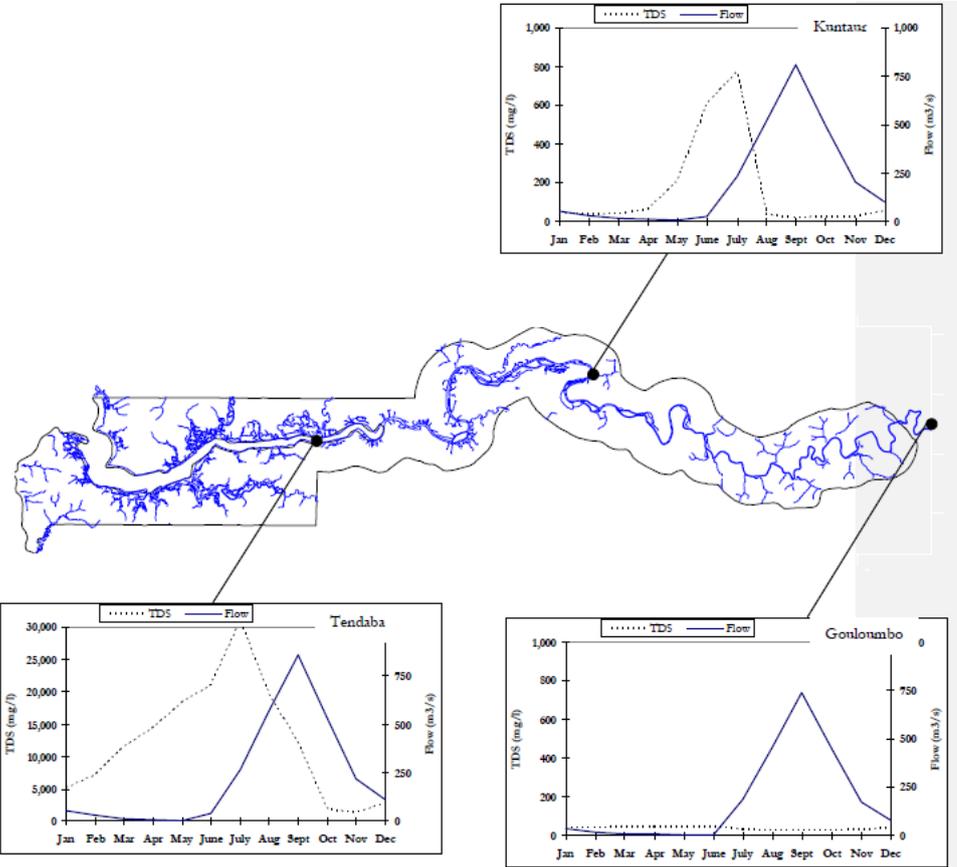


Figure 6-5: Total dissolved solids (TDS) and flow hydrographs at three locations along the river: Tendaba (river km 103), Kuntaur (river km 254) and Gouloumbo (river km 526). In effect, water in the river Gambia can be considered perennially saline oceanward from Tendaba, seasonally fresh between Tendaba and Kuntaur, and perennially fresh upstream of this location. Note that sea water has a mean TDS of 35,000mg/L. (Njie, IWRM roadmap for the Gambia, 2009).

This saline intrusion is mainly important for the irrigation practices near the river and coastal areas – and most importantly for the rice farms. Research by (Bagbohouna, Yaffa, & Bah, 2018) has shown that whilst the area of rice fields in the Gambia has increased over the past years, the total productivity has decreased. This could be attributed to the increasing salinization of farmlands. However, although it is widely known that the extent of saline-water intrusion in River Gambia is mainly governed by the balance of outward freshwater river discharge, no research to date has shown the salinity of the river is increasing (Bagbohouna, Yaffa, & Bah, 2018).

Other than the risks of saltwater intrusion the pollution from untreated effluents poses a threat. Industrial and domestic wastewater is often discharged directly into surface water bodies without treatment, introducing harmful contaminants into surface water bodies (UN Water, 2017). Pollutants have been detected in urban areas near the river mouth but in general remain below EU drinking water guidelines (Boussouga, Sacher, & Schäfer, 2023). However, due to the lack of a systematic surface water monitoring program, the full extent of pollution remains unclear.

Groundwater

Groundwater in The Gambia is generally of good quality and serves as a critical resource for domestic, industrial, and agricultural purposes across the country. Based on our previous work in the Gambia, we know that groundwater quality in The Gambia's shallow sand aquifer is generally excellent and well-suited for drinking water supply. The aquifer exhibits low electrical conductivity values, typically below 100 $\mu\text{S}/\text{cm}$, indicating fresh groundwater recharge with minimal dissolved solids (Haskoning, 2004).

However, there are several risks which threaten its quality.

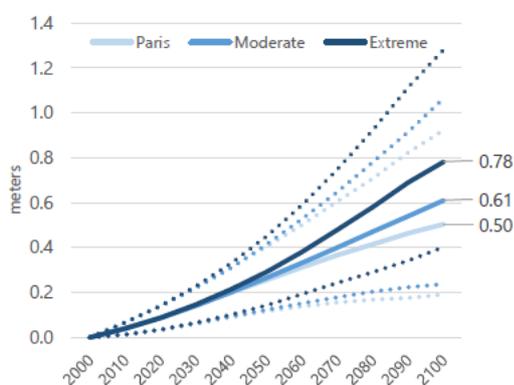
- The first is the **salinization of the groundwater**. In the coastal zone, seawater intrusion into freshwater aquifers is a significant concern, driven by rising sea levels and increased abstractions because of the rising water demand. Similarly, along the Gambia River, abstractions which are close to the river may induce an additional saline water recharge which further deteriorates the groundwater quality. For the deeper aquifer, there are higher concentrations of salinity in the west (Banjul, 2,000 mg/l TDS) than in the east (Garowal, 1,000 mg/l TDS) (NIRAS, 2013). The same pattern is visible for chloride which is high in the west (above 600 mg/l) and declining eastward (less than 20 mg/l).
- The second risk is the expansion of urban populations near water sources and poor waste management resulting in **seepage of contaminants into groundwater bodies**. Sources of pollution include 1) quarries/surface mines, 2) leaky sanitary soakaways at public standpipes, 3) on-site sanitation infrastructure (such as pit latrines), 4) solid waste tip/landfills, 5) underground storage tanks containing dangerous goods and 6) chemical fertilizers used in agriculture. This contamination affects both urban and rural areas, posing severe health risks. An inventory by UNICEF showed that more than 45% of the population of Gambia uses water from sources which contain E. Coli bacteria – underlining the major health risk of the poor waste management (UNICEF, 2018).
- Thirdly, there are **naturally occurring minerals** which can limit the use for groundwater. Fluoride, has been observed in groundwater over the country. The concentration of fluoride in general increases from 0.4 mg/l in the east to above 5 mg/l in the west. Other minerals such as iron are present, but do not necessarily pose a health threat.

6.3.2 Under future (climate) scenarios

Surface water

As mentioned under the current situation, the surface water quality in the Gambia is mainly governed by the saltwater intrusion from the Atlantic Ocean. This risk is exacerbated by climate change through two mechanisms.

The first being the **increased sea water levels**. The Gambia River estuary already experiences seasonal saltwater intrusion, reaching 180 km inland during the rainy season and 250 km during the dry season (see Figure 6-5). The seawater level in the Gambia is expected to increase somewhere between 0.2 to 1.2



m by 2100 depending on the climate scenario – see Figure 6-6. Due to its flat topography, a sea level rise would push the "salt front" further upstream, increasing the salinity of groundwater and surface water used for drinking and irrigation. How much further the saltwater front would reach under various sea level rise scenarios has not been investigated.

Because of the sea level rise, low-lying areas will inundate mainly in the coastal regions, including critical rice-growing wetlands. For example, a 1-meter rise could drown 64% of Gambia's rice croplands, which are vital for domestic food production.

Figure 6-6: Sea level rise projections. source: (IMF, 2024)

Groundwater

Out of the three highlighted risks for groundwater quality, presented under the current situation, the salinization of groundwater is most susceptible to climate change. Seepage of contaminants into groundwater bodies is expected to increase due to the increasing population growth and urbanization but is not driven by climate change effects.

There are two drivers for the saltwater intrusion into groundwater bodies; abstractions and sea-level rise—see Figure 6-7. While rising sea levels are often cited as a primary concern, research suggests that coastal aquifers are more vulnerable to groundwater extraction than to predicted sea-level rise under various hydrogeologic conditions (Ferguson & Gleeson, 2012). This is particularly relevant in The Gambia, where a lot of groundwater is abstracted for domestic, industrial and agricultural purposes. Efforts to adapt to

sea-level rise must not overlook the importance of better water management, as excessive groundwater extraction is already impacting diverse regions globally (Ferguson & Gleeson, 2012). In The Gambia, addressing these challenges will be essential to maintaining freshwater quality and availability.

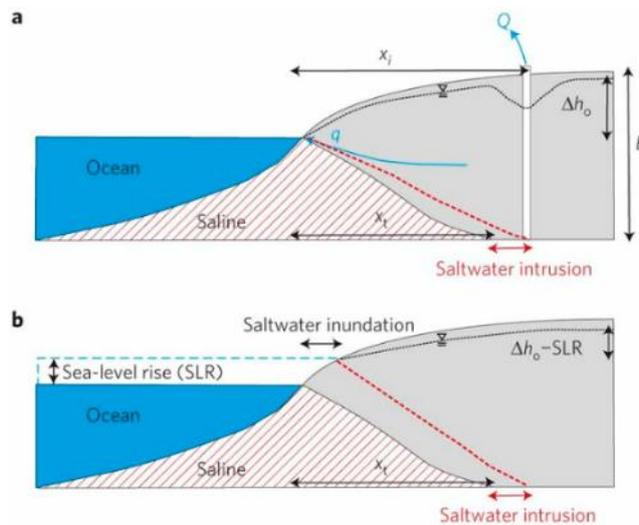


Figure 6-7: Conceptual model showing the drivers for saltwater intrusion into groundwater bodies, with (a) impact of groundwater extraction and (b) and sea-level rise. The grey area shows the distribution of the fresh aquifer water before extraction or sea-level rise. Source: (Ferguson & Gleeson, 2012).

6.4 Water trends

6.4.1 Trends in groundwater levels

According to our conversation with representatives from the MOFWR, problems arising from declining groundwater levels are reported from multiple locations in the Gambia. In this section a potential trend in groundwater levels is assessed in order to quantify the reported issues. If the rate of groundwater decline is assessed, future projections of groundwater levels will also be possible.

Firstly, an inventory of available groundwater measurements is performed. A data query was put forward at the relevant government bodies to obtain a comprehensive overview of the groundwater levels across the country. This query is supplemented with data accessed through the IGRAC (International Groundwater Resources Assessment Centre) portal - which provided more structured and accessible information on groundwater levels in The Gambia (IGRAC, 2023). An overview of the monitoring locations is presented in Figure 6-8.

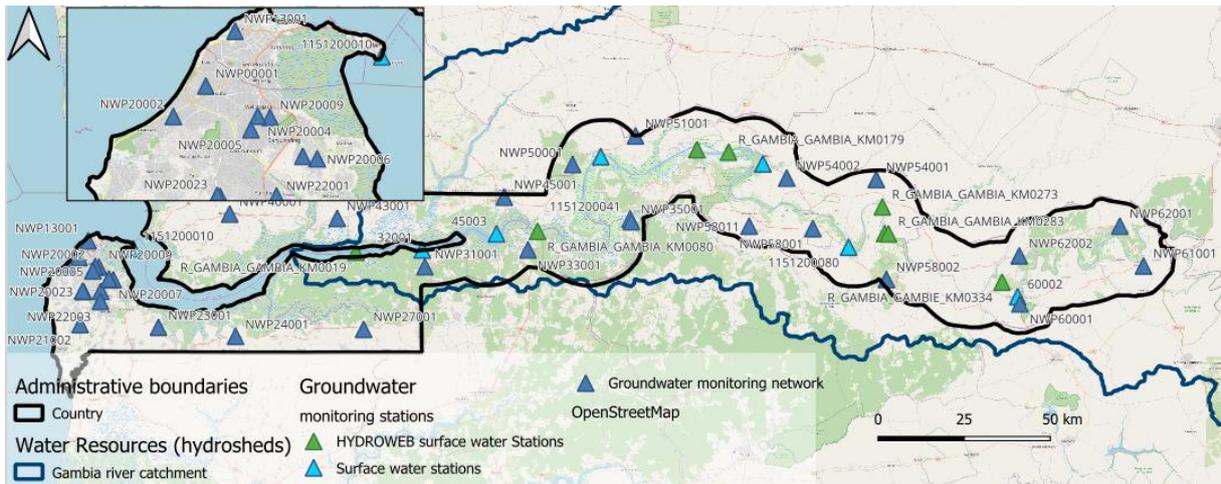


Figure 6-8: Ground- and surface water monitoring stations

The groundwater levels for a selection of monitoring stations that had a relevant number of readings in the greater Banjul area are presented in Figure 6-9. It is observed that for all groundwater levels there was a period of intensive monitoring during 2015, but that from 2016 on the measurements are very scarce. The same holds for all groundwater levels measured in other parts of the country. Regarding the groundwater levels in the greater Banjul area, it is observed that the levels in the central parts of the Greater Banjul Area (NWP20004, NWP20025) are generally higher than the ones closer to the coast (NWP20002). This indicates that there is a mounding of groundwater and underlines the observations that there is a freshwater lens present in the coastal areas.

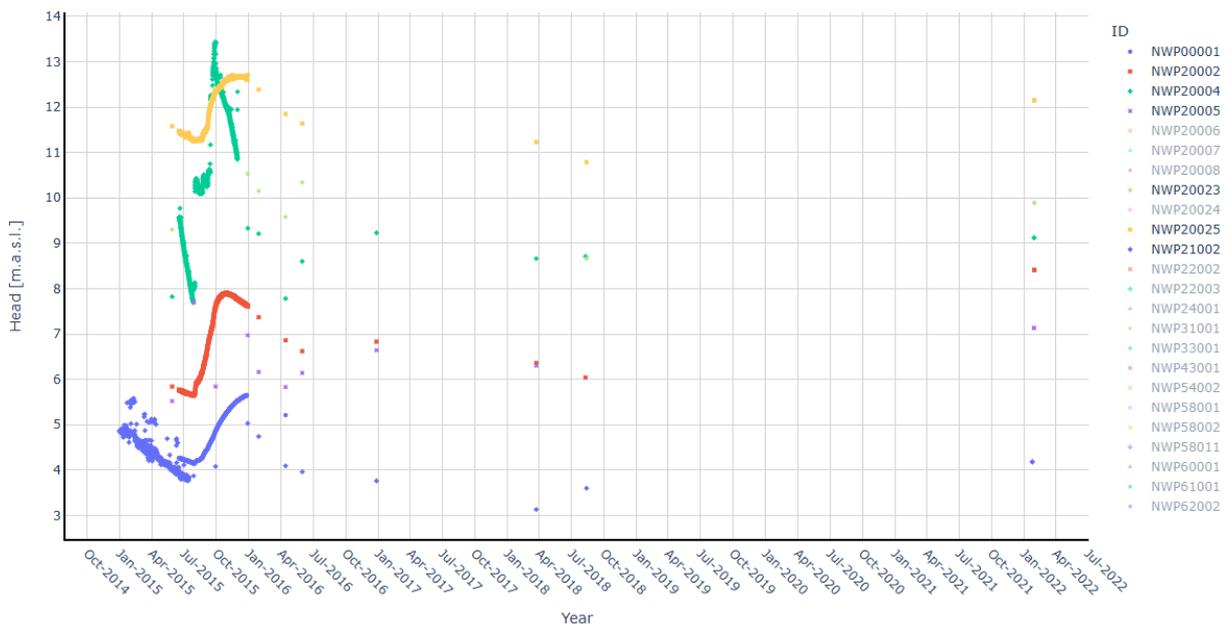


Figure 6-9: Groundwater levels in the greater Banjul area

Because the measurements are limited between 2015 – 2022 and the temporal resolution is very coarse, the current dataset is insufficient to establish definitive trends in groundwater levels across the country.

6.4.2 Trends in precipitation

Data from 11 meteo stations across the country have been analysed in order to assess any trends in precipitation over the last decades. The location of the meteo stations is presented in Figure 6-10. The data acquired yielded measurements from 1943 up to the end of 2007. Note that there are some significant data gaps in the dataset – see raw dataset provided in Annex D. Therefore, before further

analysis a subset of the data is acquired which have a maximum of 10 missing data entries per year. This is referred to as a valid year. The valid years together with resulting metadata of the subset are presented in Table 6-1.



Figure 6-10: Locations of meteo stations

Table 6-1: Metadata of precipitation dataset

Station	Start date	End date	Max Daily Precipitation [mm]	Average Yearly Precipitation Sum [mm]	Max Yearly Precipitation Sum [mm]	Min Yearly Precipitation Sum [mm]	Total Valid Years
Banjul	1/1/1943	12/31/2007	351	959	1629	358	64
Basse	1/1/1943	12/31/2007	218	938	1578	539	58
Fatoto	1/1/1976	12/31/2007	114	790	1340	556	30
Janjanbureh	1/1/1946	12/31/2007	177	859	1376	439	61
Jenoi	1/1/1974	12/31/2007	121	749	1081	383	33
Kaur	1/1/1950	12/31/2007	180	763	1287	223	29
Kerewan	1/1/1949	12/31/2007	130	883	2047	453	44
Kuntaur	1/1/1974	12/31/2007	105	691	1032	385	23
Sapu	1/1/1973	12/31/2007	266	804	1782	419	33
Sibanor	1/1/1985	12/31/2007	136	885	1455	584	21
Yundum	1/1/1946	12/31/2007	305	1032	1854	425	61

Standard Precipitation Index (SPI)

The standardized precipitation index (SPI) for all locations is calculated. The precipitation subsets are fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero. One of the fundamental strengths of SPI is that it can be calculated for a variety of time scales (Edwards & McKee, 1997) . The following SPI scales are assessed:

- **SPI-6:** The 6 months SPI allows to monitor short-term water supply, such as soil moisture – which responds to precipitation anomalies on a relatively short scale. This is mainly important for rainfed agricultural production.
- **SPI-12:** The 12-month SPI allows for the comparison of the cumulative precipitation of 12 consecutive months every year within the selected study period. Groundwater, streamflow, and reservoir storage are best reflected by these long-term precipitation anomalies.

The resulting SPI-6 and SPI-12 graphs are presented in Annex D (Figure 8-5) and allow for further assessment of historically wet or dry periods. Note that the period around 1984, for example, has been an historically extremely dry period. Conversely, the millennium change (around 2000) has been an historically wet period in the Gambia for most of the locations. Currently – at the start of 2025, the conditions are also relatively wet – which can be observed from the SPI graph of the country averaged daily totals based on the CHIRPS dataset – see Figure 8-6.

Moreover, the graphs allow for further analysis of any given historical trends in the precipitation rates. At a first glance, the precipitation rates at Banjul and Yundum seem to have significantly decreased compared to the period before 1970. Conversely, the precipitation rates in Fatoto seem to have been increased. This trend can also be observed from the SPI-12 based on the country averaged daily totals based on the CHIRPS dataset – see Figure 8-6.

Mann-Kendall

In order to quantify a given trend, a Mann-Kendall test has been performed on the yearly precipitation totals for each station.

The Mann-Kendall test is a widely used non-parametric statistical method for detecting trends in time series data. It is particularly useful in environmental and climate studies, where data may not follow a normal distribution. The test assesses whether there is a monotonic upward or downward trend in the data over time.

The Mann-Kendall test does not require the data to be normally distributed or linear, making it robust against outliers and missing values. It works by comparing each data point with all subsequent data points in the series. A positive trend is indicated if later values tend to be higher than earlier values, while a negative trend is suggested if later values tend to be lower.

The test provides a p-value to indicate the statistical significance of the trend. A p-value less than the chosen significance level (typically 0.05) suggests a significant trend, while a higher p-value indicates that there is not enough evidence to conclude a significant trend (Kendall, 1975).

The results for the valid years in the precipitation dataset are presented in Table 6-2. At the locations of Banjul, Basse, Janjanbureh and Yundum, a significant decreasing precipitation trend is observed. These locations coincide with the meteo-stations that had data from before 1950 – see Table 6-1. Conversely the location of Sapu showed an increasing precipitation trend. Note that at this location the dataset started in 1973.

In order to assess whether there are other stations which show an increasing trend from the 1980's onwards an additional subset has been made on which the Mann-Kendall trend test has been performed – see results in Table 6-3. Note that for Fatoto, Kaur, Kerewan and Sapu a significant increasing trend has been observed from 1980 - 2007 whereas there is no trend for this period observed at the other locations.

Table 6-2: Results of Mann-Kendall test for all available and valid data

Station name	trend	p_value	Significant	Slope [mm/year]
Banjul	decreasing	0.00	TRUE	-7.8
Basse	decreasing	0.05	TRUE	-3.0
Fatoto	no trend	0.06	FALSE	8.9
Janjanbureh	decreasing	0.03	TRUE	-3.4
Jenoi	no trend	0.26	FALSE	3.4
Kaur	no trend	0.20	FALSE	-0.5
Kerewan	no trend	0.16	FALSE	-5.8
Kuntaur	no trend	0.07	FALSE	7.6
Sapu	increasing	0.00	TRUE	13.8
Sibanor	no trend	0.74	FALSE	-0.1
Yundum	decreasing	0.00	TRUE	-10.5

Table 6-3: Results of Mann-Kendall test for valid data from 1980 onwards

Station name	trend	p_value	Significant	Slope [mm/year]
Banjul	no trend	0.23	FALSE	6.5
Basse	no trend	0.07	FALSE	9.0
Fatoto	increasing	0.04	TRUE	10.6
Janjanbureh	no trend	0.20	FALSE	8.6
Jenoi	no trend	0.07	FALSE	6.6
Kaur	increasing	0.02	TRUE	14.4
Kerewan	increasing	0.02	TRUE	9.6
Kuntaur	no trend	0.13	FALSE	9.1
Sapu	increasing	0.01	TRUE	16.5
Sibanor	no trend	0.74	FALSE	-0.1
Yundum	no trend	0.30	FALSE	5.0

Conclusion

Based on the observations and trend analyses provided in this section, it can be concluded that compared to the historical baseline of the 1940's the yearly precipitation totals have significantly decreased. This trend has been confirmed for stations located in the east (Basse), the west (Banjul) as well as the middle of the country (Janjanbureh). The rates of change range from 3 to 10 mm of decrease per year.

From the 1980s onward, no decreasing trend in precipitation is observed at any weather station. This observation indicates that the previously noted decreasing trend in precipitation, which was observed from the 1940s to the 1980s, has not continued into more recent decades. An increasing trend is even observed for stations in multiple parts of the country as well – i.e. in the east (Fatoto), in the west (Kerewan) and in the center (Kaur). This increasing trend is also observed from the country averaged daily totals based on the CHIRPS dataset.

7. KEY (CLIMATE) RISKS & ADAPTATION MEASURES

7.1 Key hotspots of climate risk for water resources

Agriculture in the areas that are irrigated by water sourced from the river system

As mentioned in section 3.3.2, the farmers in the agricultural areas along the river and in the coastal areas make use of the river to source water for irrigation purposes. As saltwater is expected to intrude further upstream in the future because of climate change (mostly due to sea level rise and partially because of potential reduced precipitation rates), freshwater availability is anticipated to be reduced. This will limit crop productivity and reduce the income for these farmers.

Additionally, the limited freshwater availability in the river will urge the farmers to target freshwater resources elsewhere, such as the groundwater bodies. This will put additional stress on the groundwater bodies - which is further exacerbated by the expected increasing agricultural sector and hence increasing demand for irrigation.

Domestic water production in the greater Banjul area

Problems related to declining groundwater levels have been reported – most specifically in the Greater Banjul Area. This area yields the highest domestic water demand for which the only source is groundwater. Since there is no clear trend predicted regarding precipitation in the Greater Banjul area, the recharge rates are not expected to decrease as a consequence of climate change. The quality of the groundwater may be impacted due to the effects of sea level rise, but the saltwater intrusion into the aquifers as a consequence of sea level rise is generally lower than the anthropogenic effects of over abstractions (Ferguson & Gleeson, 2012).

Industrial water production in the greater Banjul area

The same risks for the domestic production also apply to the industrial water production in the Greater Banjul area – considering the main source of water for industry is also groundwater. Because of the rapid population growth and expected exponential growth of the manufacturing sector, the industrial demand is expected to rapidly increase. This will further exacerbate the upcoming and saltwater intrusion into the aquifers.

Navigation possibilities

The Gambia River is a lifeline for transportation, agriculture, and fishing. However, seasonal fluctuations in river flow—exacerbated by climate change—affect its navigability. During periods of low flow in the dry season, navigation becomes difficult or impossible in certain sections of the river (UNESCO, 2015). Although the Climate Hazard Assessment (Component 1) did not predict any significant reduction in cumulative annual precipitation sums within the Gambia river catchment by mid-century, research done by (Séne, 2024) shows a downward trend in the Gambia river discharge rates towards the year 2100, especially in the SSP5-8.5 scenario.

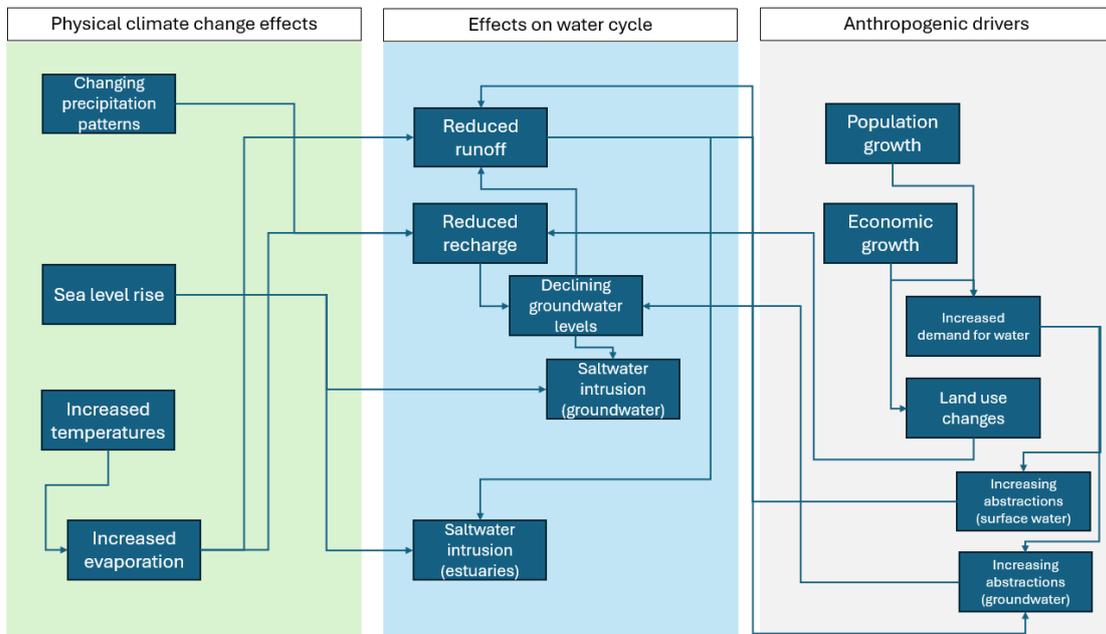
Wetlands

Wetlands provide a variety of essential ecosystem services that benefit both people and the environment. Key ecosystem services provided by wetlands are water purifications (wetlands act as natural filters removing pollutants and reduce erosion), flood control (detention and retention of stormwater), habitat for biodiversity (supporting a range of plant and animal species), and carbon sequestration (storage of carbon in organic matter).

Wetlands are under threat from climate change, deforestation, and land-use changes. As per the Climate Hazard Assessment (Component 1), climate change is projected to result in increasing temperatures for all climate scenarios. As a result, the potential evaporation rates will increase. Since the water availability in the wetlands is high, the actual evaporation rates will increase here as well. This hazard may lead to the risk of drying up of some wetlands, while others may be degraded due to encroachment for agriculture or urban development. This will reduce the ecosystem services as described above.

SIDE-NOTE: Climate risks vs. population growth

Water availability and the effect of climate change on the water cycle is a complex system with many feedback loops. As an illustration – an overview of the effects on the water cycle which are relevant for this project are presented below. Note how the population and economic growth are intertwined with the water cycle and the effects on water availability.



Population growth is anticipated to have a greater impact on the country's water resources than climate change. Population is growing at an estimated annual rate of 2.3% (World Bank Databank) which leads to a significant pressure on the water resources in the country, affecting both availability and quality.

Population growth is expected to result in the following four key points:

1. **Increased Demand:** Rapid population growth leads to higher demand for water for domestic, agricultural, and industrial use. This can strain existing water supplies, especially in urban areas.
2. **Water Pollution:** More people mean more waste, which can lead to increased pollution of water bodies. This includes contamination from sewage, agricultural runoff, and industrial activities.
3. **Over-extraction:** Over-extraction of groundwater and surface water to meet the needs of a growing population can deplete water sources, leading to shortages and ecosystem degradation.
4. **Infrastructure Pressure:** The existing water infrastructure may become inadequate to meet the needs of a larger population, leading to issues with water distribution and access.

7.2 Identification of climate adaptation measures

Various adaptation measures can contribute to alleviating the risks associated with climate change and population growth on water resources in The Gambia. Potential adaptation measures are described below, grouped by foreseen impact: water availability, water quality, and infrastructure development.

Several measures outlined below are Nature-based Solutions (rainwater harvesting, managed aquifer recharge, mangrove reforestation, and wetland conservation). They are measures or strategies that use

natural processes and ecosystems to address environmental, social, and economic challenges. These solutions leverage the power of nature to provide sustainable and cost-effective benefits.

7.2.1 Water availability

Transboundary Water Management



Implementing integrated water resources management (IWRM) to optimize the use and distribution of water resources, with inclusion of the initiatives for the Sambangalou dam. As an example, the Gambia River Basin Development Organization (OMVG) has been working on integrated water resources management to optimize water use across the region. This includes coordinating water usage among different sectors and countries to ensure sustainable management.

Decision Support System (DSS)



A DSS can be used to develop plans for managing water shortages and prioritizing water users and sectors during times of scarcity. The DSS integrates data on water availability, demand, and usage patterns to support informed decision-making. It helps identify critical areas and sectors that need priority during water shortages. By using a DSS, authorities can make transparent, science-based decisions that balance the needs of different sectors and users, ensuring equitable water distribution. Monitoring of water availability (surface water and groundwater), demand and usage is a crucial

component. It is highly recommended to expand and maintain the ground- and surface monitoring stations to allow for an informed decision-making strategy. Integration of weather forecasts can be used to allow for early warnings for potential threats like droughts or floods.

A water hierarchy sequence – as per the Dutch example on water hierarchy (Rijkswaterstaat, 2025) - is a practical example of how monitoring and prioritization should be embedded in water management during shortages. The water hierarchy sequence is a legally established ranking system used to determine the order in which water users lose access to a certain water source during times of scarcity. This system is a cornerstone of drought management and is directly supported by continuous monitoring of water resources. An example of how this could be implemented in The Gambia is by using an early warning system for saltwater intrusion. By setting threshold levels at certain monitoring wells which trigger the start of the hierarchy sequence, the critical users of the water resources can be protected.

Water Efficiency



Promoting water-saving technologies and practices in agriculture, industry, and households to reduce overall water consumption and minimise waste. Agriculture accounts for ~33% of the total water consumption. Significant savings can be realised through efficient irrigation techniques. In agriculture, this can be achieved through efficient irrigation systems, real-time monitoring, and the adoption of climate-appropriate crops. In industry and households, water-efficient appliances and behavioral changes can further drive down consumption.

As an example, drip irrigation is a highly efficient method that delivers water directly to the root zone of crops, significantly reducing evaporation and runoff losses. This technique can cut water use by 30–70% compared to traditional methods. When combined with soil moisture sensors, farmers can precisely monitor soil conditions and irrigate only, when necessary, further minimizing waste.

Move water-intensive activities upstream



A lot of the pressure on groundwater resources is concentrated in the GBA. In addition, the saltwater intrusion in the coastal areas is expected to increase the strain on groundwater reserves in the western part of the country. The location of existing and future water-intensive activities, such as industries and agriculture, should be informed by local water availability. In addition, water supply schemes sourcing freshwater from further upstream can be considered to augment the water supply in the western part of the country.

As an example, the Gambian government should encourage new water-intensive industries, such as food processing or beverage manufacturing, to establish operations in upstream areas with more reliable freshwater access. This can be facilitated through spatial planning policies and incentives that direct industrial investment to regions with lower salinity risk and adequate water supply. This can be in the form of a Special Economic Zone (SEZ) to stimulate rapid economic growth upstream of the Gambia River.

Alternatively, the Gambian government could conduct a feasibility study to assess whether it is possible to construct water intake and treatment infrastructure upstream to supply freshwater to downstream urban centers, such as the GBA. For instance, a pipeline or bulk water transfer system could be developed to transport treated river water from less saline sections upstream to supplement the potable water supply in coastal cities, reducing reliance on overexploited coastal aquifers – following the Dutch example of the Water-dunes (Waternet, 2025).

Rainwater Harvesting



Using rainwater harvesting systems to collect and store rainwater for agricultural and domestic use. This helps reduce dependency on groundwater and surface water sources during dry seasons and makes communities more self-sufficient.

This is mainly applicable in rural areas, where the water supply is managed through community owned public stand taps and there are no household connections. For example, in rural Gambian communities, simple gutter systems can be installed along the edges of tin or thatch roofs to channel rainwater into storage tanks or large covered drums. The combination of a gutter system and a storage tank at a school can provide a reliable source of water for drinking, handwashing, and cleaning during the dry season, reducing the need for children (especially girls) to fetch water from distant sources.

Managed Aquifer Recharge (MAR)



MAR is a water management option that provides a means of intentionally recharging and storing water underground for subsequent recovery and beneficial use. There are many different types of MAR and feasibility is informed by local hydro(geo)logical conditions and land use. MAR technologies can be classified based on recharge and storage technique into four categories: 1) Recharge wells, 2) Bank filtration, 3) Water spreading and 4) Streambed channel modifications.

As an example of the first category, the Gambian government can investigate the installation of recharge wells in vulnerable coastal zones near the GBA. These wells can be used to inject treated surface water/wastewater or harvested rainwater directly into the aquifer, creating a freshwater barrier that helps prevent saltwater from moving inland. This approach can be especially effective where natural recharge is limited due to urbanization or impermeable soils.

Alternatively, a water spreading technique such as diversion channels for precipitation so the rainwater doesn't run off should be considered. This would significantly help the rural agricultural areas – especially during the drier moments in the rainy season.

In urban areas, it is important to use spreading techniques to make sure that precipitation is still able to percolate into the subsurface. Therefore, urban planners should strive to limit the paved areas in urban areas. This could be implemented by setting a threshold on the % of paving in residential compounds, enforced by the Department of Physical Planning.

Sustainable deep aquifer exploitation



Currently, the shallow sandy groundwater system is being utilised as a water source to cater for domestic usage. Pollution and over-abstraction are putting this resource at risk. Instead, the use of climate-robust deeper aquifers can be considered for exploration. The deep aquifer is currently not exploited in The Gambia. This will require hydrogeological investigations to ascertain the groundwater potential for sustainable groundwater exploitation. In addition, the current drilling companies in the Gambia generally lack the equipment for drilling to the deeper aquifers.

A concrete measure can be to conduct a study including systematic hydrogeological mapping and geophysical surveys, such as test drilling and aquifer pump tests, to delineate the extent, depth, and yield of the deep sandstone aquifer. This includes collecting data on aquifer thickness, transmissivity, storage capacity, and water quality (e.g., salinity, acidity, presence of dissolved solids). These surveys should also assess the hydraulic connection between shallow and deep aquifers to prevent unintended cross-contamination.

Another measure could be to provide an incentive for the private drilling companies to drill deeper, for example by means of a subsidy on new equipment.

7.2.2 Water quality

Mangrove reforestation



As a result of saltwater intrusion, the salinity of the estuary is expected to increase and to intrude further upstream. This puts all users of river water at risk due to increased salinity of the water. Mangroves can be considered because they can protect coastal water sources from saltwater intrusion and erosion, ensuring the sustainability of freshwater supplies. Research shows that the density and extent of mangrove forests can significantly delay and reduce saltwater intrusion into groundwater and surface water systems. Certain mangrove species, such as *Avicennia marina* and *Rhizophora*

stylosa, are particularly effective due to their salt-tolerance mechanisms and ability to secrete excess salt. In addition, mangroves support critical ecosystem services, such as providing nursery grounds for fish and shellfish, enhancing local fisheries, and sustaining biodiversity.

A practical example is the engagement of local communities in collecting mangrove propagules (seeds) from healthy stands and establishing nurseries for species like *Rhizophora* and *Avicennia*. Once seedlings are mature, organize planting campaigns in degraded or deforested estuarine and coastal areas, prioritizing zones most vulnerable to saltwater intrusion. Many good examples of projects initiated by the Ministry of Environment can be used as a standard. In order to build further on these initiatives, the Ministry should ensure regular monitoring and maintenance to improve survival rates, including protection from grazing and human disturbance (such as oyster harvesting).

Salt-resilient crops



Salt-resilient crops, also known as salt-tolerant crops, are specifically adapted to grow and produce yields in soils with elevated salinity levels - a condition increasingly prevalent in coastal and estuarine regions due to saltwater intrusion, sea-level rise, and irrigation practices. These crops possess physiological and biochemical mechanisms that allow them to tolerate or even thrive in saline environments, such as the ability to exclude or compartmentalize salt, secrete excess salt, or maintain water uptake despite osmotic stress.

Introducing salt-resilient crops is a practical adaptation measure in coastal areas, where salinization threatens agricultural productivity and food security. By selecting and cultivating these crops, farmers can maintain or even increase yields on land that would otherwise become unproductive due to salinity.

The Gambian government can promote the use of salt-resilient crops by implementing demonstration farms or pilot projects in coastal and estuarine regions of The Gambia to test and showcase the performance of salt-tolerant crops under local conditions. This approach can help identify the most

suitable species and varieties, build local capacity, and encourage adoption among farmers – the Gambian Ministry of Agriculture has apparently instigated some initial actions in this direction.

Pollution Control



Effective pollution control in The Gambia requires a multi-pronged approach, targeting agricultural runoff, industrial waste, and sewage to protect water resources and aquatic ecosystems. Stricter regulations, combined with best management practices, can significantly reduce the introduction of pollutants into rivers, estuaries, and groundwater systems.

Especially the management of dump sites in relation to the siting of abstraction wells needs to be regulated more strictly in order to protect drinking water quality. Adequate separation between borehole locations and potential sources of pollution, such as residential sewage soak-aways, should be ensured. This can be achieved through comprehensive land use planning, informed by scientific studies, to strategically separate polluting activities from (potential future) water abstraction points. Furthermore, existing well fields require robust protection measures. Achieving this goal necessitates coordinated, cross-ministerial collaboration involving agencies responsible for land, geology, and water resources to ensure the sustainable management and safety of water supplies.

Finally, enforcement is a critical component of effective pollution control, as regulations and policies alone are insufficient without consistent and visible implementation. Concrete enforcement actions-such as regular inspections, fines for breaches, and collaboration with relevant (local) authorities-are essential to ensure polluters are held accountable and pollution reduction targets are met.

Wetland Conservation



Conservation of wetlands to maintain or improve their ecosystem services. This can be realised through legal measures such as enforcing regulations and designating protected areas. Buffer zones with land use restrictions are considered international best practice. These measures ensure the long-term health of wetlands, benefiting biodiversity, water quality, flood control, and carbon sequestration.

Again, enforcement is crucial. For example, regulations should require permits for any development or alteration within wetland boundaries, with regular monitoring and penalties for violations. The experience of countries implementing the Ramsar Convention demonstrates that legal frameworks, when actively enforced, can prevent harmful interventions and maintain wetland integrity.

Wastewater Treatment & TSE Reuse



Expanding and upgrading wastewater treatment facilities is vital for public health and environmental protection in The Gambia. Currently, key urban areas like Banjul and Kotu have ageing and inadequate wastewater infrastructure, with some systems lacking any treatment capacity. Untreated or poorly treated wastewater can contaminate rivers and coastal waters, increasing the risk of waterborne diseases and degrading water quality. Upgraded treatment plants remove pathogens, organic matter, and pollutants, ensuring that water released back into the environment is safe

and supports healthy aquatic ecosystems

In addition, if water is treated to a safe standard the effluent can be reused for non-potable purposes such as irrigation, landscaping, or industrial processes. This approach – also referred to as Treated Sewer Effluent (TSE) reuse - conserves freshwater resources, reduces pressure on groundwater and surface water, and provides a reliable water source for agriculture and green spaces, especially in water-stressed regions.

7.2.3 Infrastructure development

Regulate well drilling



The absence of effective regulation for groundwater extraction has resulted in poor management and unsustainable use of this critical resource. Currently, the ease with which individuals can drill boreholes—often without oversight—exacerbates over-extraction, leading to declining groundwater levels and increased risk of contamination. To address these challenges, robust legislation is required to govern borehole drilling, set clear abstraction limits, and enforce water quality standards. The implementation of such regulations depends heavily on strong political will, as well as the establishment of institutional frameworks that assign clear responsibilities for tasks such as aquifer mapping and ongoing monitoring.

Promulgation of a National Water Act would play a pivotal role in this context, enabling authorities to register water bottling companies, manage borehole drilling activities, and regulate all aspects related to natural water resources. By empowering national institutions to monitor, assess, and control water use – embedded into a National Water Act – groundwater would no longer be treated as a private commodity but as a shared resource subject to sustainable management principles. Assigning institutional responsibility for aquifer mapping and monitoring is essential to provide the data and oversight needed for informed decision-making and long-term resource protection.

The same holds for water abstractions in general – i.e. from any other source than groundwater. Any abstraction from a shared public resource should be recorded and regulated by the government – so that the sustainability of the resource can be ensured. This specifically relates to abstractions from groundwater and from the Gambia River.

Infrastructure Development



Investing in robust water infrastructure to ensure reliable access to clean water. This supports economic development and improves the quality of life for residents. Also, the reduction of water losses through maintenance of infrastructure, monitoring and repair of leaks is key to improving water efficiency.

As an example, maintaining existing infrastructure, monitoring water distribution systems, and promptly repairing leaks are key to reducing water losses and improving efficiency. Simple steps like fixing leaks, installing water-saving fixtures, and upgrading aging pipes can significantly decrease non-revenue water and ensure more water reaches end users. For example, systematic leak detection campaigns and the use of smart water meters can help utilities identify and address water losses quickly.

Climate-Resilient Infrastructure



Designing and constructing water infrastructure systems that can withstand extreme acute weather events and chronic climate changes ensures continuous water supply and reduces vulnerability to climate impacts.

These measures are crucial for ensuring sustainable water management in The Gambia, addressing both the challenges posed by climate change and the pressures of population growth. By adopting these strategies, The Gambia can protect its water resources, support biodiversity, and improve the well-being of its communities.

This approach includes proper risk assessment and siting. That is, infrastructure should be planned using risk and vulnerability assessments to identify areas prone to flooding, drought, or salinity intrusion. This ensures that investments are targeted in a climate-robust manner and that facilities are sited away from known hazards.

7.3 Risks & adaptation measures matrix

In order to provide an overview of which measures can be applied to which risks, an overview matrix is provided below.

				Main Risks			
Adaptation Measure	Description	Icon	Reduced freshwater availability in irrigated agriculture due to saltwater intrusion up the Gambia River as a consequence of sea level rise	Reduced water availability for domestic and industrial use due to over-abstraction and saltwater intrusion in the aquifers (GBA)	Degradation of ecosystem services in wetlands due to encroachment, land-use changes and increasing evaporation rates	Reduced navigation possibilities during droughts	
Water Availability	Transboundary Water Management	Implement IWRM to optimize water use across regions, including initiatives like the Sambangalou dam ⁵⁸ .		✓	✓		✓
	Decision Support System (DSS)	Develop plans for managing water shortages, prioritizing users, and integrating data for informed decision-making.		✓	✓	✓	✓
	Water Efficiency	Promote water-saving technologies in agriculture, industry, and households to reduce consumption and waste.		✓	✓		
	Relocate Water-Intensive Activities	Move water-intensive industries and agriculture upstream to reduce pressure on coastal groundwater resources.		✓	✓		
	Rainwater Harvesting	Implement systems to collect and store rainwater for agricultural and domestic use.		✓	✓		
	Managed Aquifer Recharge (MAR)	Intentionally recharge and store water underground for subsequent recovery and use.		✓	✓		
	Sustainable Deep Aquifer Exploitation	Explore and utilize climate-robust deeper aquifers as an alternative water source.		✓	✓		

	Adaptation Measure	Description	Icon	Main Risks			
				Reduced freshwater availability in irrigated agriculture due to saltwater intrusion up the Gambia River as a consequence of sea level rise	Reduced water availability for domestic and industrial use due to over-abstraction and saltwater intrusion in the aquifers (GBA)	Degradation of ecosystem services in wetlands due to encroachment, land-use changes and increasing evaporation rates	Reduced navigation possibilities during droughts
Water Quality	Mangrove Reforestation	Protect coastal water sources from saltwater intrusion and erosion.		✓	✓	✓	
	Salt-Resilient Crops	Introduce crops that can thrive in soils with high salinity levels.		✓			
	Pollution Control	Implement stricter regulations to reduce pollution from various sources.		✓	✓	✓	
	Wetland Conservation	Maintain wetlands through legal measures and buffer zones to preserve ecosystem services.			✓	✓	
	Wastewater Treatment & TSE Reuse	Expand and upgrade facilities to improve water quality, reduce waterborne diseases and reuse the treated sewer effluent (TSE)		✓	✓	✓	
Infrastructure	Regulate well drilling	Groundwater extraction requires robust regulation, clear responsibilities, and enforcement under the National Water Act.		✓	✓		
	Infrastructure Development	Invest in robust water infrastructure for reliable access to clean water.			✓		
	Climate-Resilient Infrastructure	Design and construct water systems to withstand extreme weather events and chronic climate changes.			✓		

8. REFERENCES

- Africa FMM. (2020). *The Gambia Country Overview*. Africa Finance Minister' Meeting .
- African Development Bank. (2013). *The Gambia, Transport Sector Diagnostic Study*. Abidjan, Côte d'Ivoire: AfDB.
- Aikins, E. R. (2024, 06 30). *Gambia*. Retrieved from ISS African Futures (International Monetary Fund World Economic Outlook database): <https://futures.issafrica.org/geographic/countries/gambia/>
- Allen, R. G., & Luis S. Perrera, D. R. (1998). *Crop evapotranspiration - Guidelines for computing crop water requirements - ANNEX 1*. Rome: FAO.
- AMCOW. (2018). *Water fact sheet Gambia 2016*.
- Bagbohouna, M., Yaffa, & Bah. (2018). *The Impacts of Saline-Water Intrusion on the Lives and Livelihoods of Gambian Rice Growing Farmers*.
- Boussouga, Y. A., Sacher, F., & Schäfer, A. I. (2023). *Water quality of The Gambia River: A prospective drinking water supply*. *Science of the Total Environment*, 878, 162794.
- Copernicus. (2024). Sentinel-2 MSI. Retrieved 3 2024, from https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S2_SR_HARMONIZED
- Copernicus Climate Change Service. (2024). Climate Data Store. *ERA5-land post-processed daily-statistics from 1950 to present*. doi:<https://doi.org/10.24381/cds.e9c9c792>
- Degeorges, A. &. (2007). Eco-politics of dams on the Gambia river. *Water Resources Development* 23(4), 641-657.
- Edwards, D., & McKee, T. (1997). *Characteristics of 20th Century Drought in the United States at Multiple Time Scales*.
- FAO. (1986). *Irrigation Water Management: Irrigation Water Needs*. Rome: FAO.
- FAO. (2005). *AQUASTAT Country Profile – Gambia*. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).
- FAO. (2018). *Climate-Smart Agriculture in The Gambia*. Retrieved from <https://openknowledge.fao.org/server/api/core/bitstreams/8e02d0c5-ad86-4234-8cee-ece99b0b665c/content>
- FAO. (2024, 6 30). *Gambia*. Retrieved from ISS African Futures (Food and Agriculture Organization Food Balance Sheets): <https://futures.issafrica.org/geographic/countries/gambia/>
- Ferguson, G. A., & Gleeson, T. (2012). *Vulnerability of coastal aquifers to groundwater use and climate change*.
- Gambia Bureau of Statistics. (2024). *The Gambia 2024 Population and Housing Census*.
- GEF-LDCF Project . (2021). *Improving Water Availability in The Gambia's Rural and Peri-Urban Areas*. Retrieved from https://www.thegef.org/sites/default/files/web-documents/10199_LDCF_Gambia_PIF.pdf
- Global Water Partnership. (2010). *Implementing Water Sector Reform in The Gambia*. Retrieved from <https://www.gwp.org/globalassets/global/activities/impact-stories/implementing-water-sector-reform-in-the-gambia.pdf>
- GNAIP. (2015). *Republic of the Gambia National Agricultural Investment Plan (GNAIP)*. Retrieved from <https://www.gafspfund.org/gafspmapcountry/>
- Government of The Gambia (GOTB). (2020). *Third National Communication under the .* Banjul: Ministry of Climate Change environment and Natural Resources (MECCNAR).
- Haskoning. (2004). *Greater Banjul Area Water Supply Project*.
- IGRAC. (2023). *Groundwater monitoring data (the Gambia)*. Retrieved from [ggis.un-igrac.org: https://ggis.un-igrac.org/catalogue/#/dataset/2347](https://ggis.un-igrac.org/catalogue/#/dataset/2347)

- IMF. (2024). *Technical Assistance Report: The Gambia*.
- Kaicun, W., Pucal, W., Li, Z., Cribb, M., & Sparrow, M. (2007). *A simple method to estimate actual evapotranspiration from a combination of net radiation, vegetation index, and temperature*. American Geophysical Union.
- Kendall, M. G. (1975). *Rank Correlation Methods*.
- NIRAS. (2013). *Assessment of Groundwater Monitoring Procedures and Network Design*. Ministry of Fisheries and Water Resources.
- NIRAS. (2015). *National Water Resources Assessment and Management Strategy*. Ministry of Environment, Climate Change, Water Resources, Parks and Wildlife (Republic of The Gambia).
- Njie, M. (2002). Second Assessment of Climate Change induced vulnerability in the Gambian Water Resources. *Consultancy Report for National cleat Committee (The Gambia)*, 71p.
- Njie, M. (2009). *IWRM roadmap for the Gambia*. Banjul: Consultancy Report prepared for the UCC-Water/DHI .
- OMVG OMVS. (2020). *SMAB Deliverabe 5: Report on Capacity Assessment*.
- ONEC. (2014). *MULTINATIONAL: OMVG ENERGY PROJECT: ESIA Summary of the Sambangalou Dam Construction*. Retrieved from <https://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/ADF-BD-IF-2008-151-EN-MULTINATIONAL-OMVG-ENERGY-PROJECT-ESIA.PDF>
- RAMSAR. (2025). *Country Profile Gambia*. Retrieved from Ramsar.org: <https://www.ramsar.org/country-profile/gambia>
- Rijkswaterstaat. (2025). *Verdeling water bij droogte*. Retrieved from rijkswaterstaat: <https://www.rijkswaterstaat.nl/water/waterbeheer/droogte-en-watertekort/verdeling-water-bij-droogte>
- Sanitation and Water for All. (2022). *Gambia 2022 SMM Country Overview*. UNICEF.
- Séne, S. M. (2024). Assessment of current and future trends in water resources in the Gambia River Basin in a context of climate change. *Environmental Sciences Europe*, 36(1), 32.
- SNC Lavalin International, GAMECS. (n.d.). *Gambia Water Supply and Sanitation Study: Final Feasibility Study Report*.
- Trading Economics. (2025). *Gambia - People Using At Least Basic Drinking Water Services (% Of Population) - 2025 Data 2026 Forecast 2000-2022 Historical*. Retrieved from tradingeconomics: <https://tradingeconomics.com/gambia/people-using-basic-drinking-water-services-percent-of-population-wb-data.html>
- UN Water. (2017). *UN-Water Country Brief The Gambia*. Food and Agriculture Organization of the United Nations (FAO).
- UNESCO. (2015). *National Integrated Water Resources Management Roadmap for The Gambia*. Retrieved from <http://unesdoc.unesco.org/images/0022/002257/225741E.pdf>
- UNICEF. (2018). *Multiple indicator cluster survey*.
- Water Action Hub UN Global Compact. (n.d.). *The Gambia Water Indicators Country Overview*. Retrieved from https://wateractionhubfrontdoor-d6dwaqhbqwebcfcg2.z01.azurefd.net/media/files/2020/08/19/Country_Profile_80.pdf
- Waternet. (2025). *Amsterdamse Waterleidingduinen*. Retrieved from Waternet.nl: <https://www.waternet.nl/en/service-and-contact/tap-water/where-does-our-tap-water-come-from/amsterdamse-waterleidingduinen/>
- Weatherspark. (2025). *Country GM*. Retrieved from Weatherspark: <https://weatherspark.com/countries/GM>
- World Bank. (2021). *Climate Change Knowledge Portal - Gambia*. Retrieved from Climate Knowledge Portal: <https://climateknowledgeportal.worldbank.org/country/gambia/climate-data-projections>

Xuehui Han, K. K. (2024). Climate Change Vulnerabilities and Strategies: The Gambia. *International Monetary Fund*.

ANNEX A – WATER BALANCE COMPONENTS – GAMBIA RIVER BASIN

Table 8-1: The annual fluxes of discharge, precipitation, evapotranspiration and change in storage in km³ within the GRB. The ΔV fraction is provided as a ratio of total volume change compared to the total precipitation [-].

Year	Discharge (Q) [km ³]	Precipitation (P) [km ³]	Evapotranspiration (ET) [km ³]	Storage (ΔV) [km ³]	$\Delta V/P$
1995	6.88	57.09	-52.85	-2.65	-0.05
1996	8.53	62.31	-51.1	2.68	0.04
1997	3.39	50.03	-50.4	-3.76	-0.08
1998	3.63	45.42	-42.33	-0.54	-0.01
1999	7.44	63.92	-50.07	6.4	0.1
2000	6.28	56.7	-50.62	-0.2	0
2001	4.12	48.79	-45.71	-1.04	-0.02
2002	1.97	38.9	-38.86	-1.93	-0.05
2003	6.41	58.34	-46.1	5.83	0.1
2004	3.03	44.34	-44.04	-2.73	-0.06
2005	2.59	45.88	-41.67	1.62	0.04
2006	2.11	40.62	-38.3	0.2	0.01
2007	4.14	45.97	-39.07	2.76	0.06
2008	5.53	58.74	-48.3	4.91	0.08
2009	5.35	53.97	-46.58	2.04	0.04
2010	7.12	60.45	-48.31	5.02	0.08
2011	3.44	44.61	-43.45	-2.28	-0.05
2012	5.86	59.04	-46.95	6.23	0.11
2013	3.86	48.3	-44.73	-0.28	-0.01
2014	1.9	40.17	-40.52	-2.24	-0.06
2015	5.87	54.37	-43.4	5.1	0.09
2016	6.09	53.43	-44.72	2.62	0.05
2017	4.52	49.59	-45.89	-0.82	-0.02
2018	9.68	57.32	-42.89	4.75	0.08
2019	6.4	52.27	-44.36	1.51	0.03
2020	11.59	68.34	-50.94	5.82	0.09
2021	3.71	46.58	-46.07	-3.21	-0.07
2022	4.88	53.63	-46.79	1.95	0.04
2023	2.97	43.2	-41.69	-1.45	-0.03
2024*	7.16	62.35	-36.48	18.7	0.3

* Data availability for GloFAS data for 2024 was not completely available when analysis was done. This year will be left out of the long-term average calculations

ANNEX B – WATER BALANCE COMPONENTS – THE GAMBIA

Table 8-2: The annual fluxes of river inflow, precipitation, evapotranspiration and TRWR in km³ within The Gambia country boundaries. The recharge/TRWR and inflow/TRWR fractions are provided as well.

Year	Inflow [km ³]	Precipitation [km ³]	Evapotranspiration [km ³]	Recharge [km ³]	TRWR [km ³]	recharge/TRWR [-]	inflow/TRWR [-]
1995	6.54	8.64	-8.04	0.60	7.14	0.08	0.92
1996	8.04	8.67	-7.99	0.68	8.71	0.08	0.92
1997	3.36	6.94	-7.96	-1.02	2.35	-0.43	1.43
1998	3.63	5.76	-6.57	-0.81	2.82	-0.29	1.29
1999	7.01	8.74	-7.47	1.27	8.28	0.15	0.85
2000	6.24	7.64	-7.78	-0.14	6.10	-0.02	1.02
2001	4.08	6.98	-7.33	-0.35	3.73	-0.09	1.09
2002	1.98	4.81	-6.21	-1.40	0.59	-2.39	3.39
2003	6.31	7.74	-6.93	0.81	7.11	0.11	0.89
2004	3.03	5.55	-6.63	-1.07	1.95	-0.55	1.55
2005	2.57	6.58	-6.63	-0.05	2.52	-0.02	1.02
2006	2.11	6.06	-6.41	-0.35	1.76	-0.20	1.20
2007	4.14	5.27	-5.83	-0.55	3.59	-0.15	1.15
2008	5.21	8.49	-7.27	1.22	6.43	0.19	0.81
2009	5.00	7.86	-7.39	0.47	5.47	0.09	0.91
2010	6.52	8.80	-7.49	1.31	7.83	0.17	0.83
2011	3.42	6.02	-7.11	-1.09	2.33	-0.47	1.47
2012	5.64	8.67	-7.49	1.18	6.82	0.17	0.83
2013	3.54	8.35	-7.54	0.82	4.35	0.19	0.81
2014	1.89	5.75	-7.00	-1.25	0.65	-1.93	2.93
2015	5.81	7.39	-6.97	0.42	6.22	0.07	0.93
2016	5.92	6.96	-6.92	0.04	5.96	0.01	0.99
2017	4.47	6.59	-7.10	-0.51	3.96	-0.13	1.13
2018	9.32	7.49	-6.77	0.72	10.04	0.07	0.93
2019	6.24	6.74	-6.74	0.00	6.24	0.00	1.00
2020	10.53	9.61	-7.50	2.10	12.63	0.17	0.83
2021	3.44	7.47	-7.54	-0.07	3.38	-0.02	1.02
2022	4.63	9.18	-7.99	1.19	5.82	0.20	0.80
2023	2.92	6.63	-7.43	-0.80	2.12	-0.38	1.38
2024*	7.11	9.88	-5.93	3.95	11.06	0.36	0.64

* Data availability for GloFAS data for 2024 was not completely available when analysis was done. This year will be left out of the long-term average calculations

ANNEX C – ENVIRONMENTAL WATER DEMAND

The assumption is that the evapotranspiration of the environment can be estimated by assessing the ‘greenness’ of the surface area in combination with the net radiation and the surface temperature. The yearly evapotranspiration of the environmental areas then is assumed to present a proxy for the environmental water demand.

The actual evapotranspiration of the environmental areas is assessed using a method that establishes a relation between actual evapotranspiration and net radiation (R_n), surface temperature (T) and the vegetation index (VI) (Kaicun, Pucai, Li, Cribb, & Sparrow, 2007). This relation is shown below.

$$ET = R_n * (0.1505 + 0.45VI + 0.004T)$$

Net radiation data as well as surface temperature data is obtained from the ERA5-Land Daily Aggregated satellite (Copernicus Climate Change Service, 2024). The average vegetation index over the years 2022 - 2024 is calculated using Sentinel-2 MSI data (Copernicus, 2024).

The used method yields evapotranspiration in W/m^2 . Using conversion factors provided by the FAO (Allen & Luis S. Perraera, 1998), the results are converted to water demand in millimetres and aggregated per land cover type. For the environmental demand, the following land cover types (based on ESA landcover classes) are assumed to be part of the environmental demand: Tree cover, Shrubland, Grassland, Bare - sparse vegetation, Herbaceous wetland and Mangroves. Cropland, permanent water bodies and built-up areas are not considered to be part of the environmental demand. The resulting environmental water demand is presented in Table 8-3.

Table 8-3 - Aggregated environmental water demand

Land cover	Area (km ²)	Area (% of total surface area in the Gambia)	Water demand (mm)	Water demand (km ³)
Tree cover	16067	14.4	1364.6	2.19
Shrubland	3387	30.4	1420.2	4.81
Grassland	1185	10.6	1243.8	1.47
Bare - sparse vegetation	45	0.4	-	-0.00
Herbaceous wetland	629	5.7	1083.9	0.68
Mangroves	711	6.4	864.8	0.61
TOTAL	22024	67.9	n.a.	9.76

To get an impression of the variation of the environment water demand over a year, the data per month and per land use category are aggregated. In Figure 8-1, the results per month and per land use category are displayed. A small peak in water demand in March/April, and a high peak in October and November is observed. The main land use types that consume water are tree cover, shrubland and grassland.

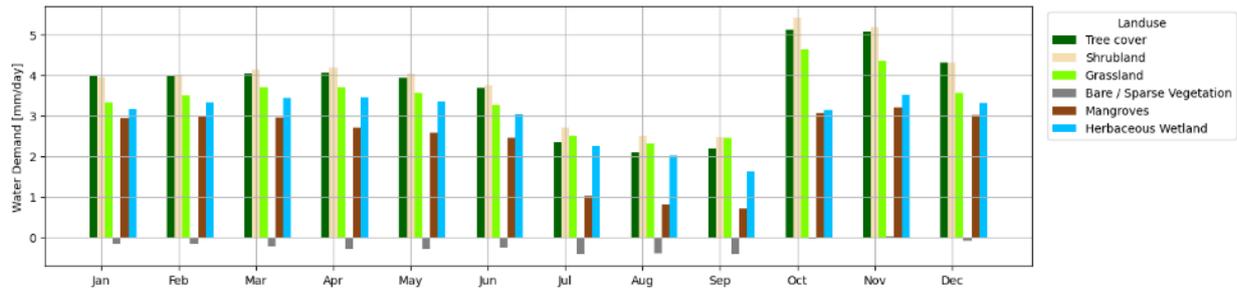


Figure 8-1: Water demand per month per land cover type

To validate our analysis, the environmental water demand with the bare soil evaporation product and the potential evaporation product of the ERA5 mission (Copernicus Climate Change Service, 2024) are compared. It is expected that the calculated evapotranspiration is high than the bare soil evaporation and higher than the potential evaporation, which is also observed - see Figure 8-2. This indicates that the proposed methodology is within the right range.

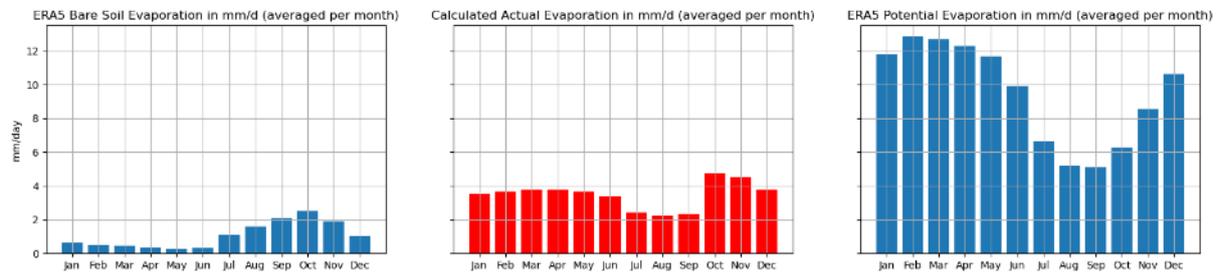


Figure 8-2 - Comparison between ERA5 bare soil evaporation values and calculated actual evaporation values

However, there are some observations that limit the viability of the proposed methodology to estimate the environmental demand:

- Firstly, some of the calculated demand may be supplied by seawater. The mangroves for example will also transpire seawater, which attribute to the demand presented in this analysis. However, this part of the demand will not restrain the freshwater availability. The presented values may therefore overestimate the freshwater demand.
- Taking into account that the yearly averaged precipitation in the Gambia is about 9 km^3 and the yearly averaged evapotranspiration about 7.17 km^3 the total environmental demand of 9.76 km^3 seems to be overestimated. Since the calculated environmental demand of 9.76 km^3 is always higher than the actual evapotranspiration rates – which also include open water evaporation and demand from agriculture – it is concluded that the presented method overestimates the environmental demand.
- The presented analysis uses the NDVI averages of 2022 – 2024. However, if a ‘wetter’ year had been considered, the estimated environmental demand would be higher. In other words, the environmental assets will always take more water if it is supplied. Therefore, what the environmental demand should depend on what natural assets are required to be preserved.

ANNEX D – PRECIPITATION TREND PLOTS

Data from All Stations Over Time

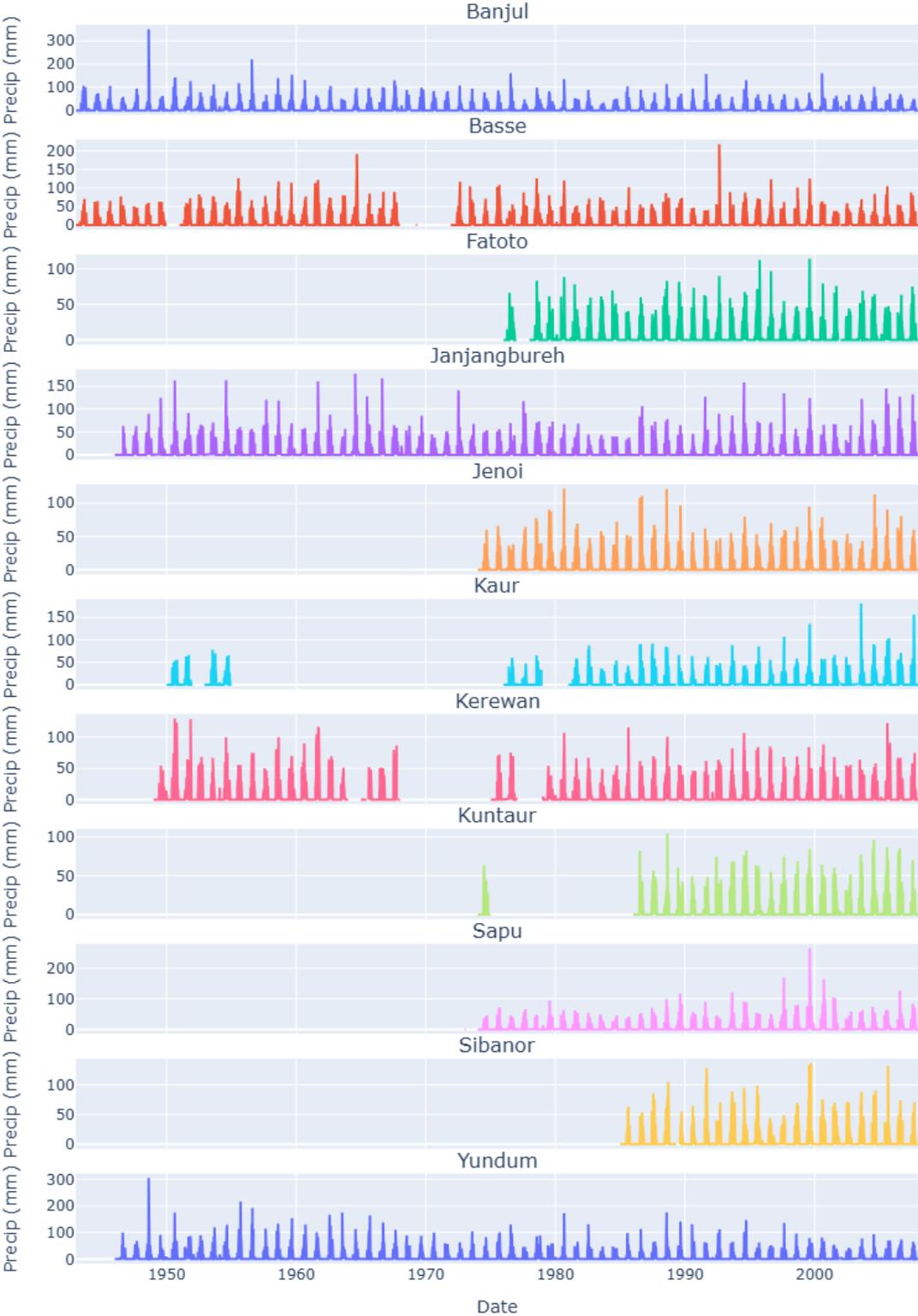


Figure 8-3: Raw data plots – daily precipitation sums.

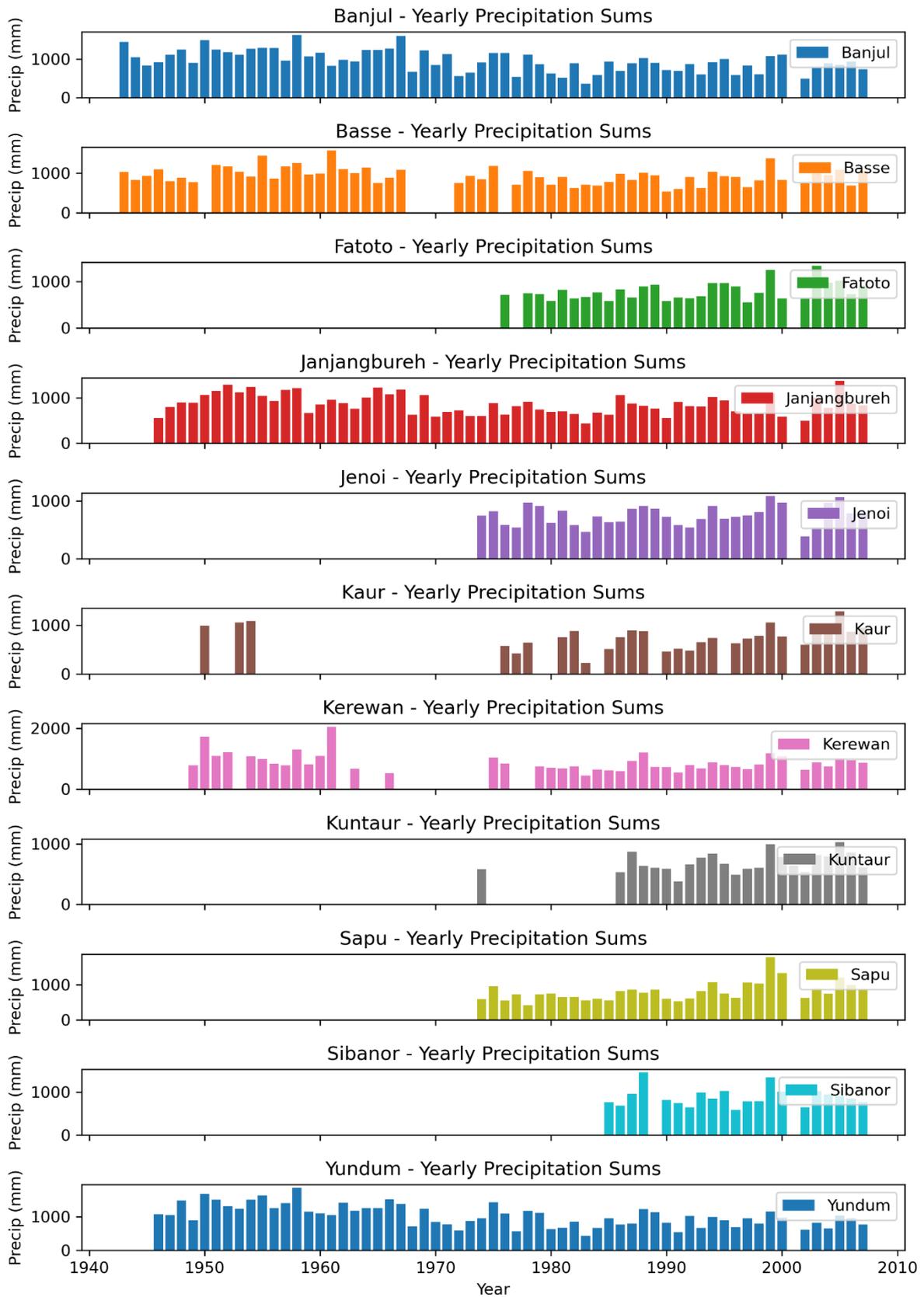
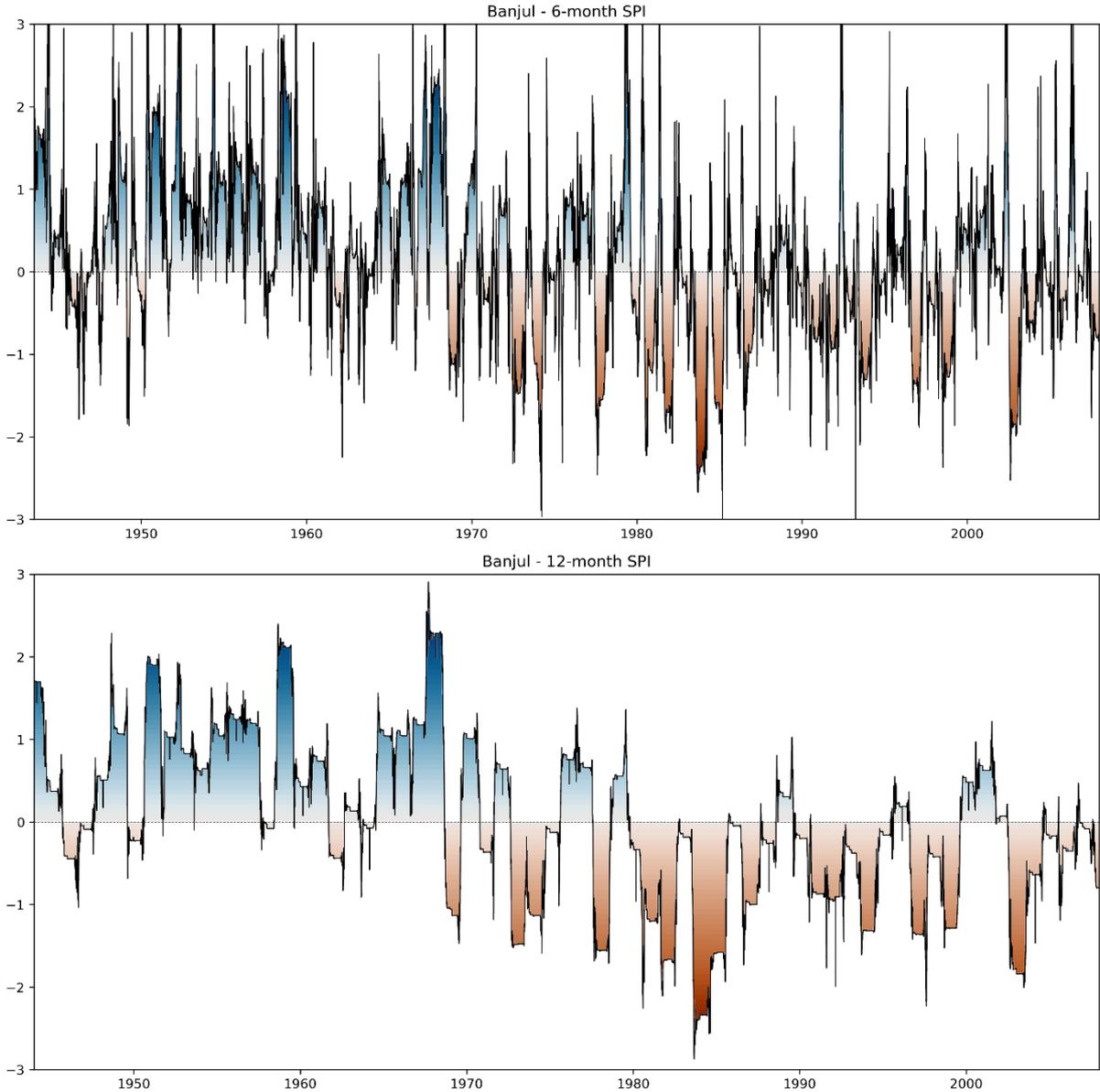
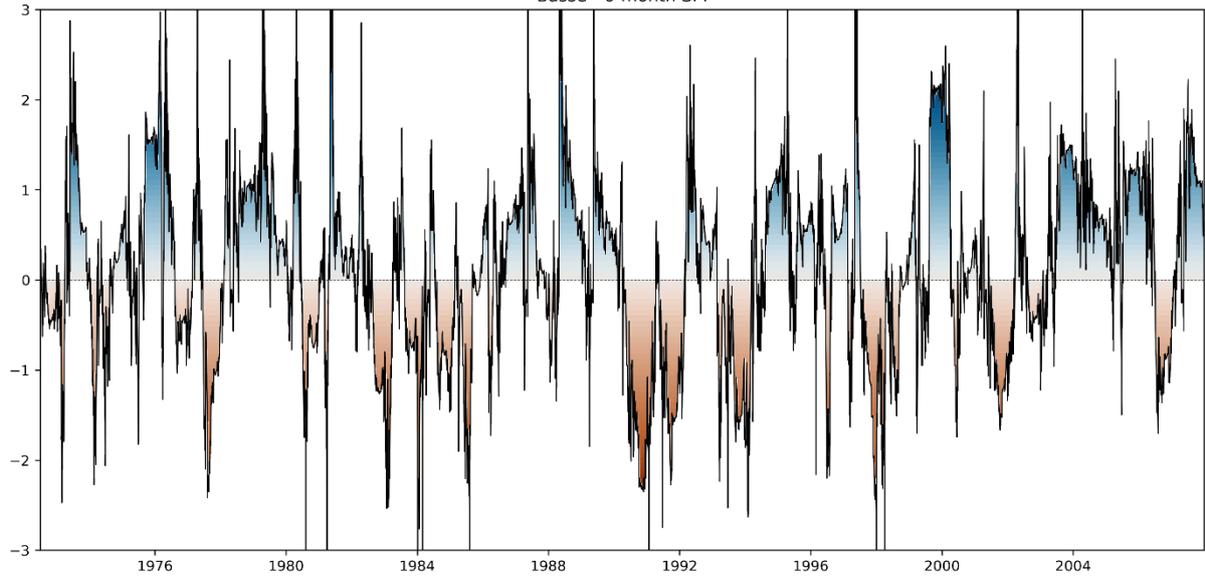


Figure 8-4: Yearly precipitation sums for valid years (max 10 missing values).

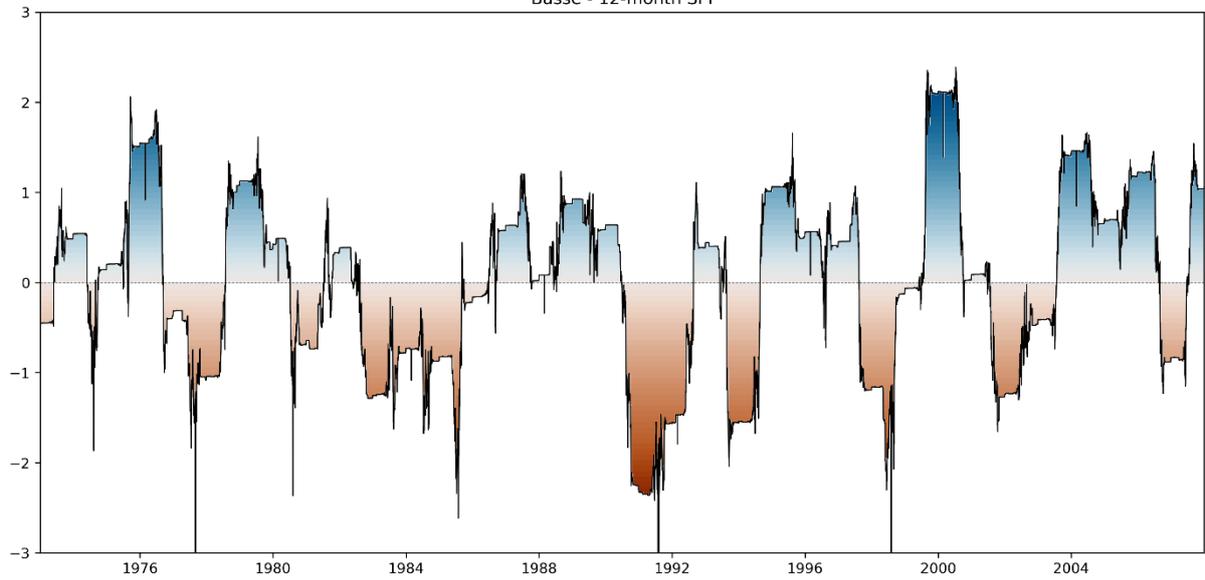
Figure 8-5: SPI graphs for all available data after validation for all meteo stations



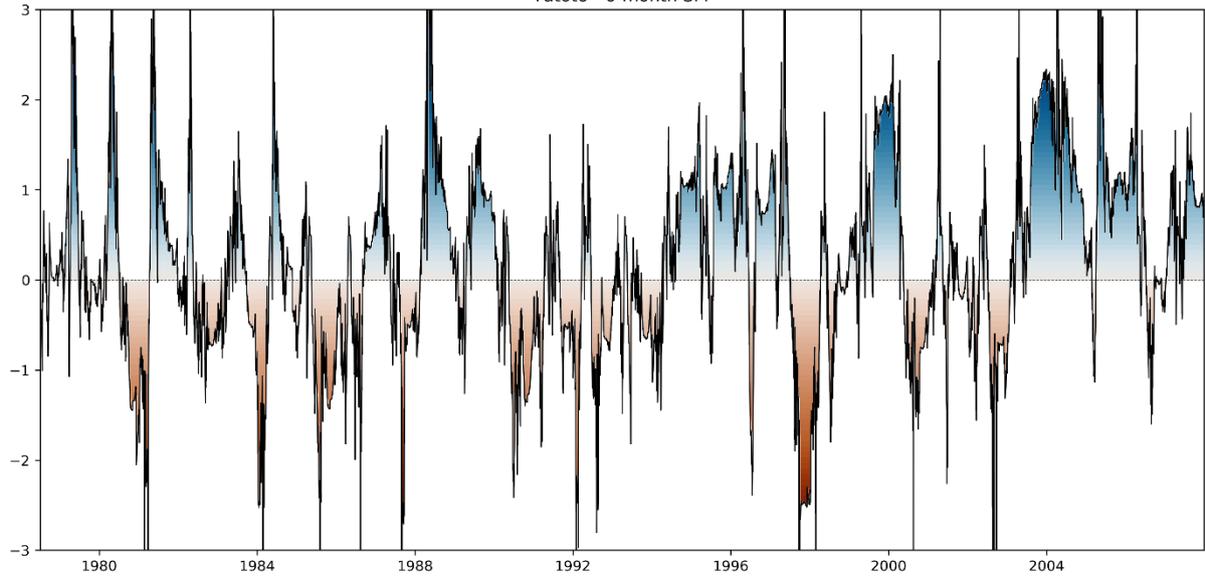
Basse - 6-month SPI



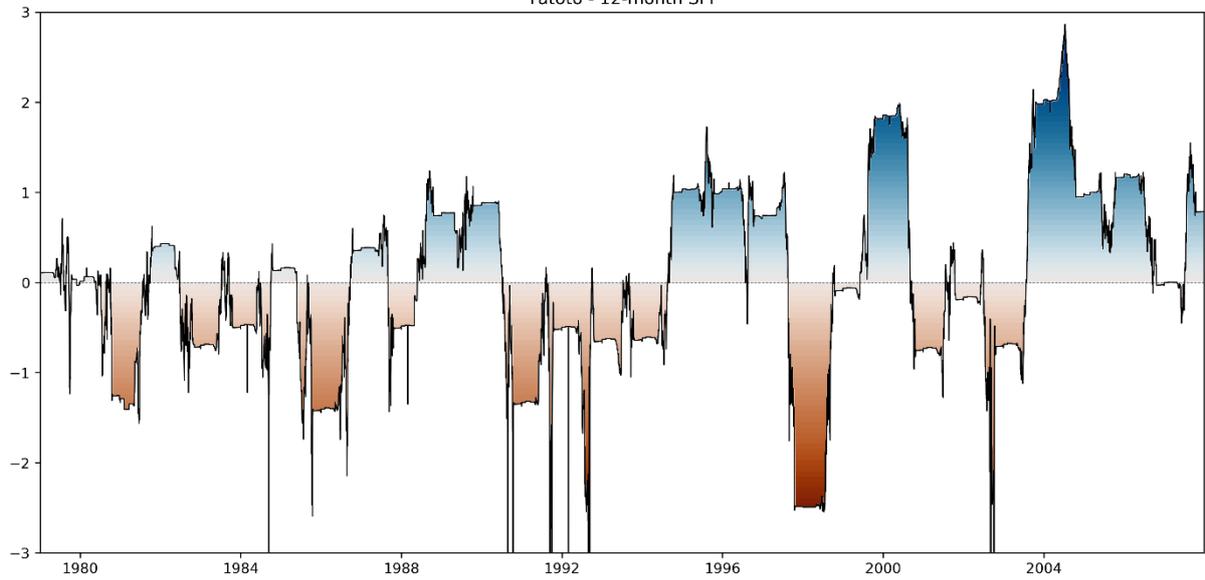
Basse - 12-month SPI

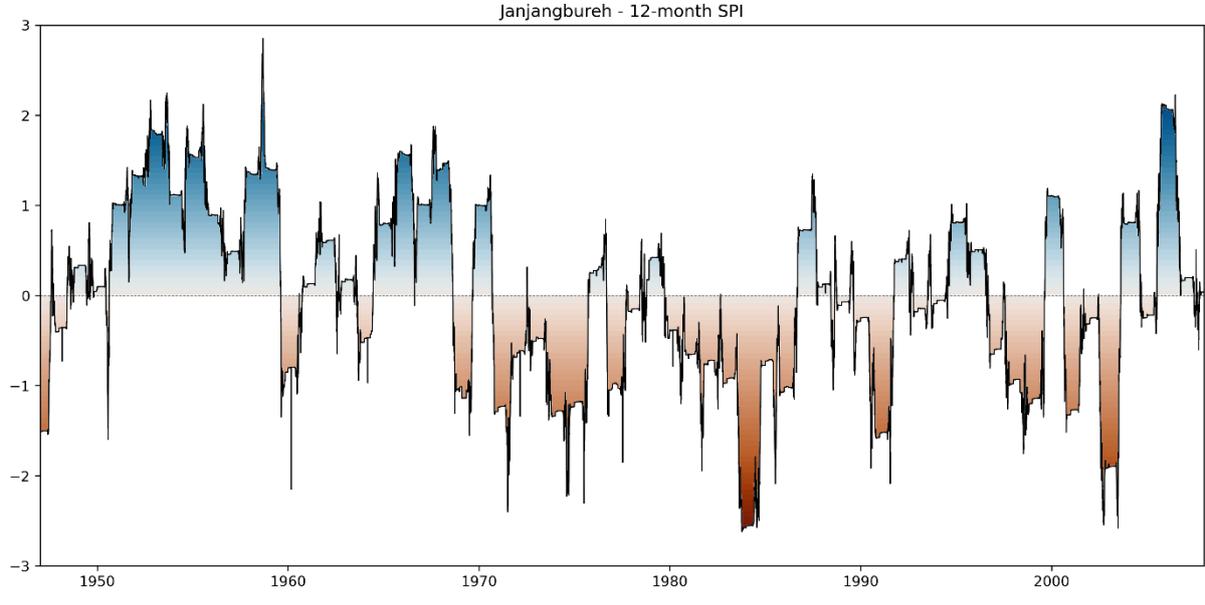
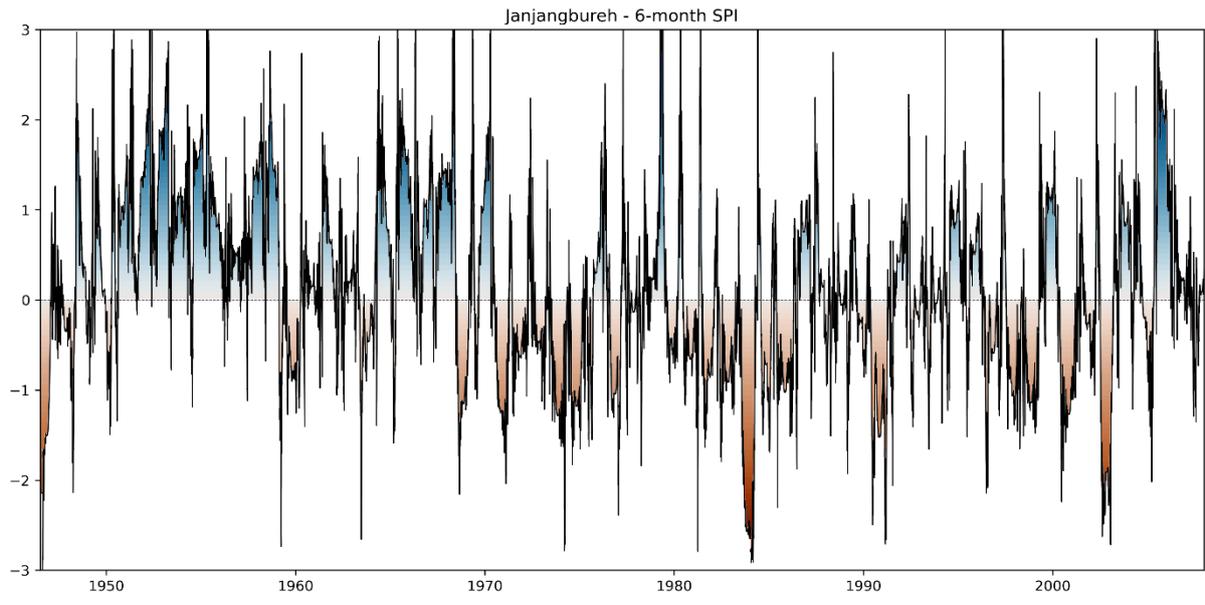


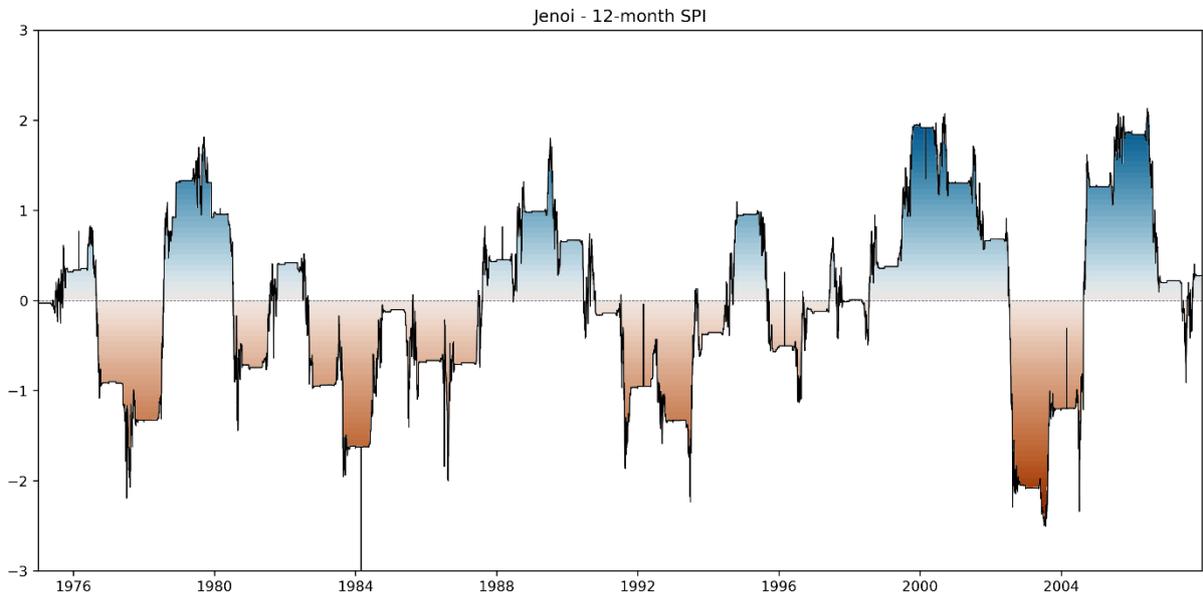
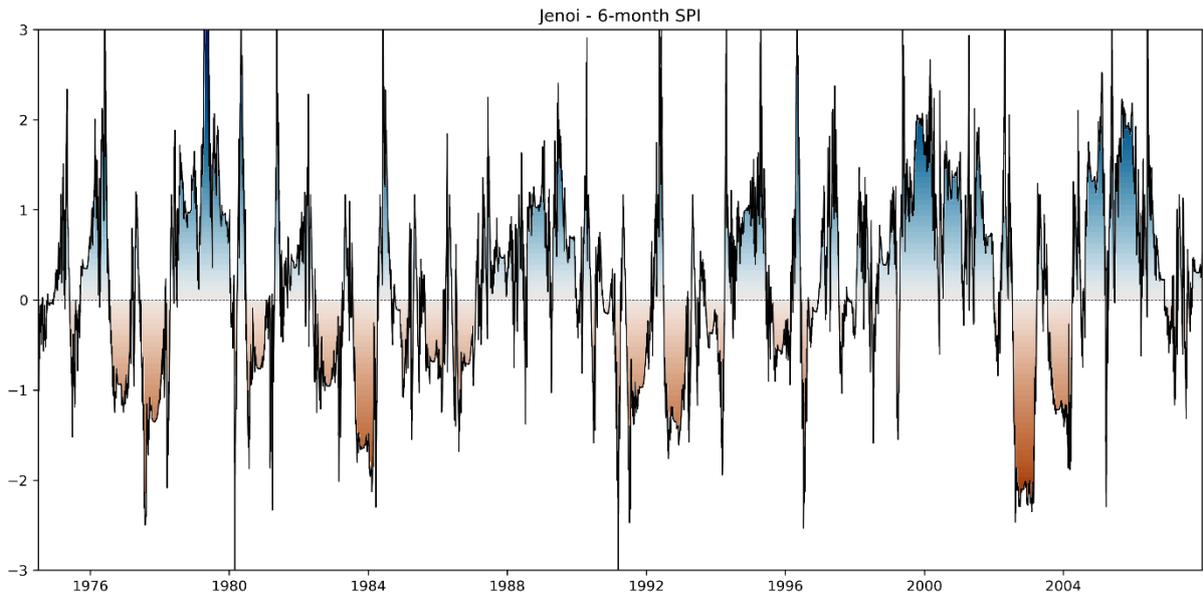
Fatoto - 6-month SPI

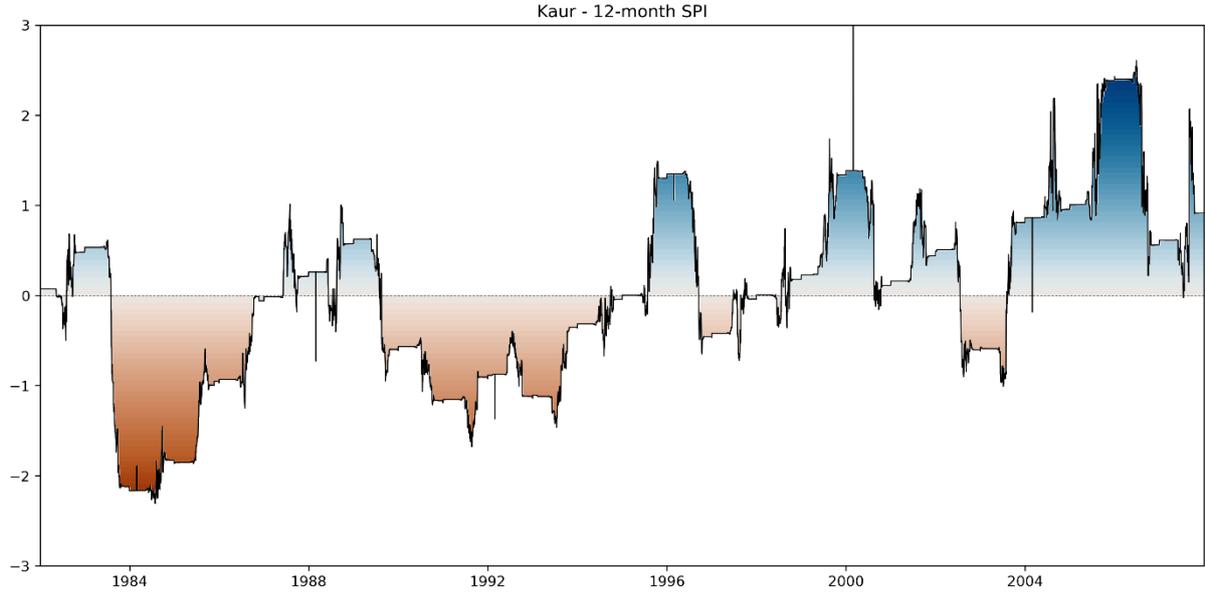
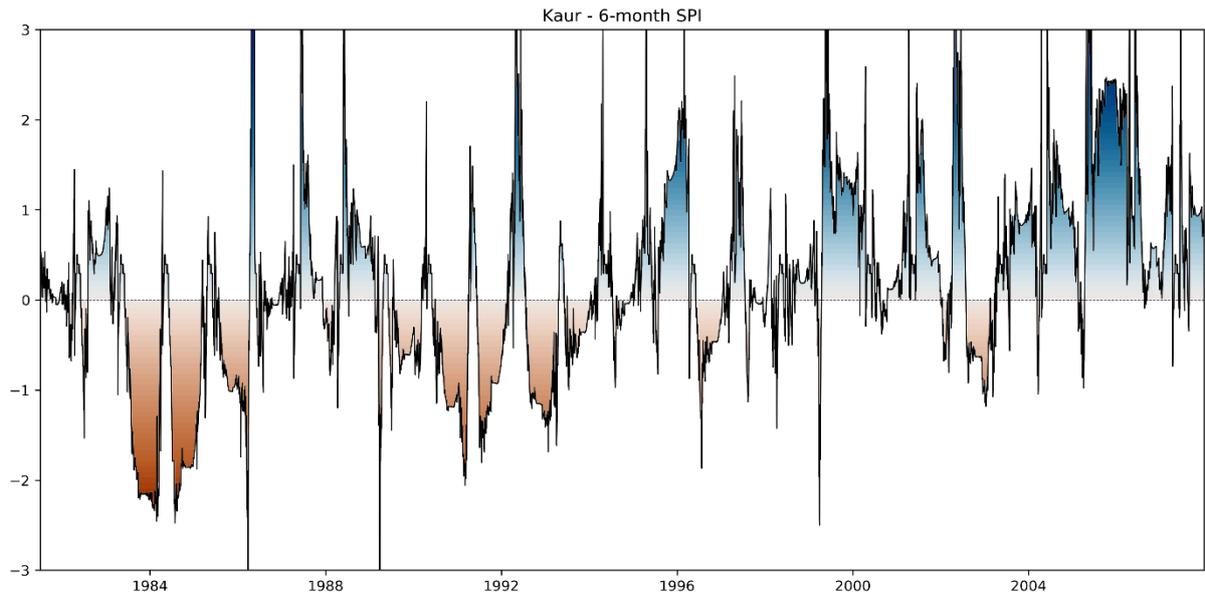


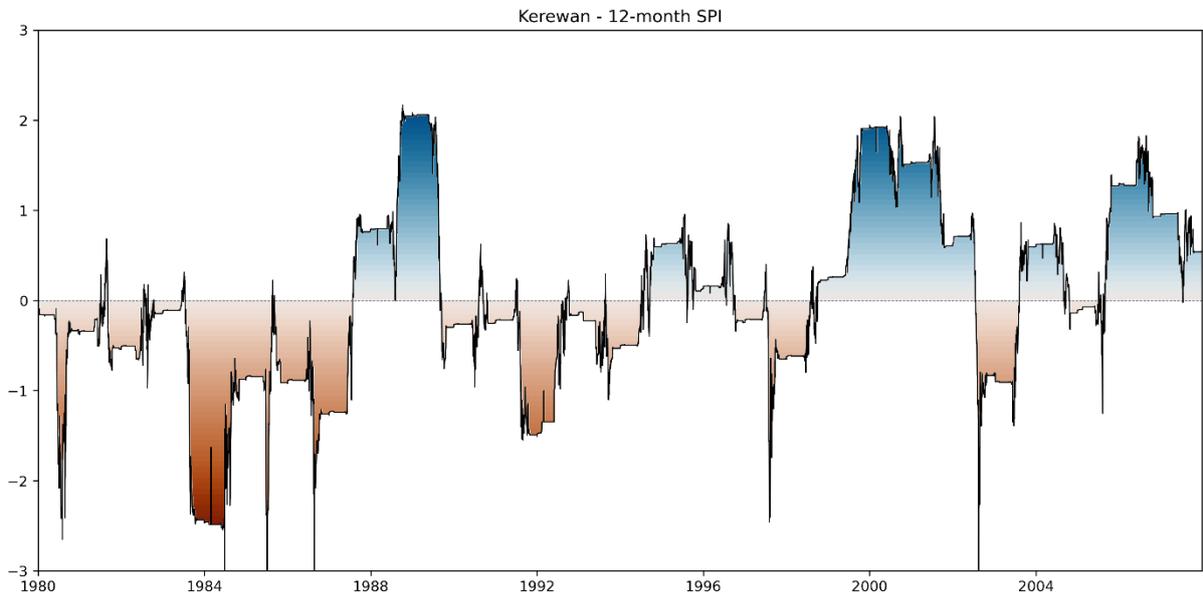
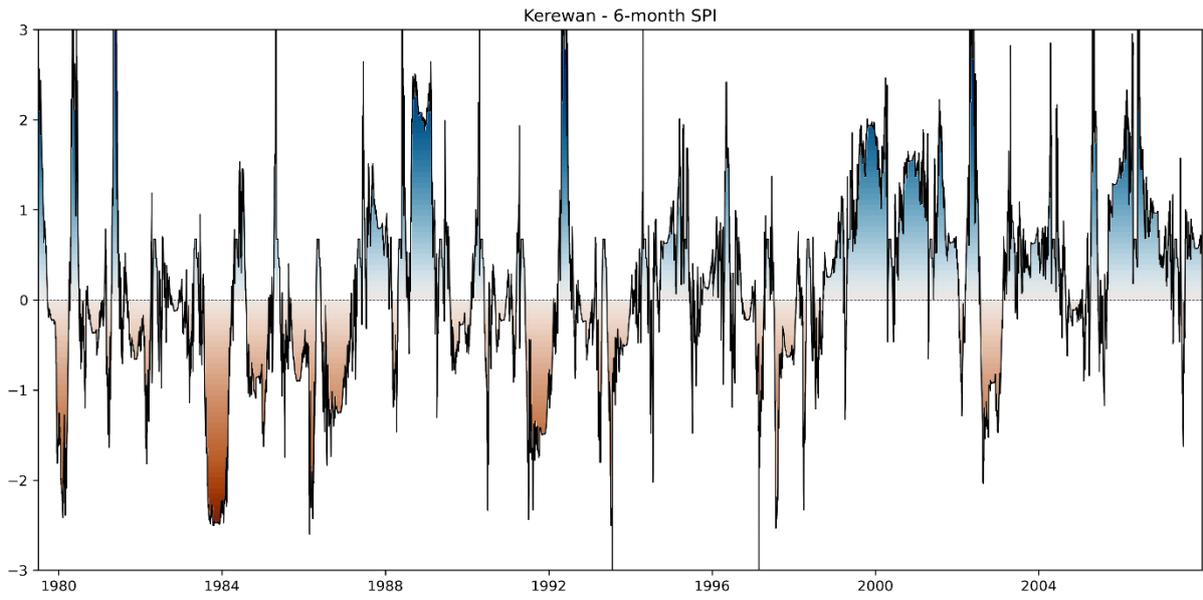
Fatoto - 12-month SPI



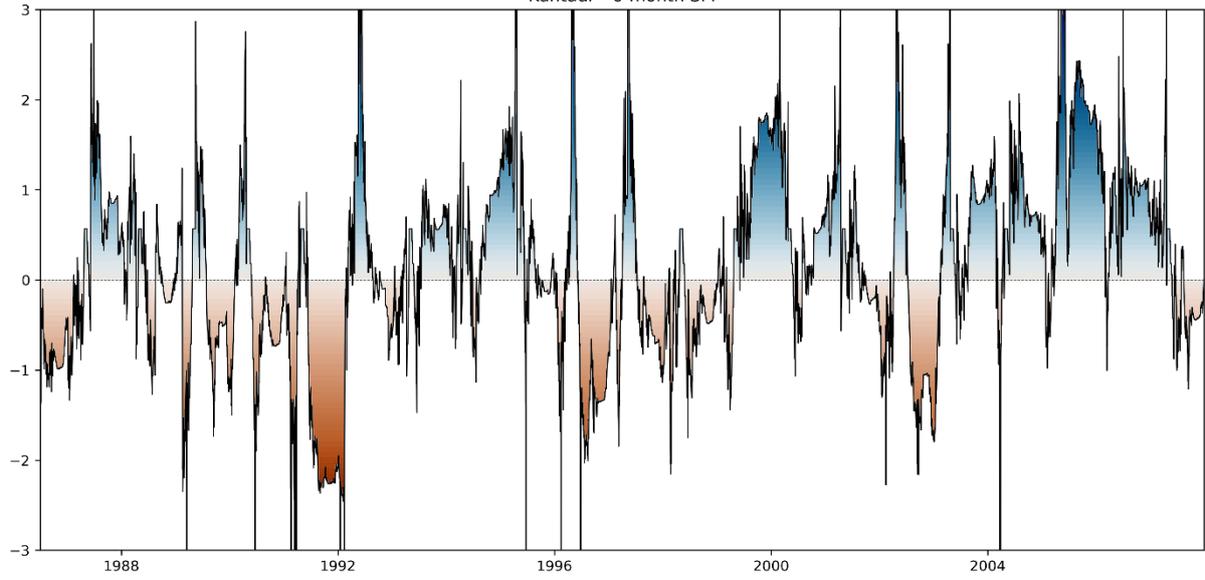




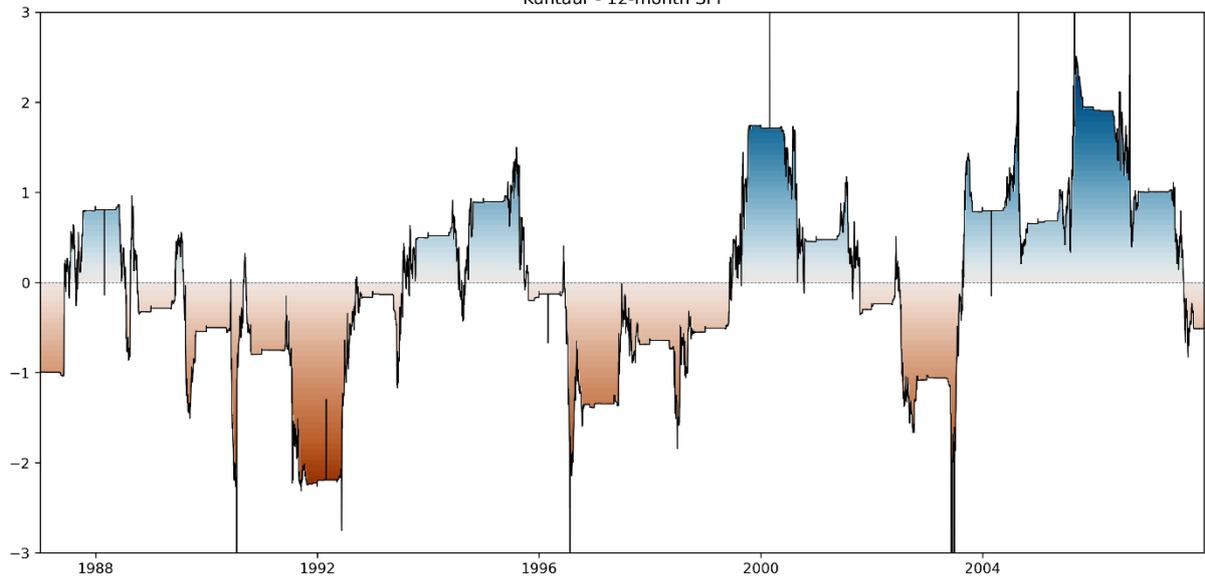


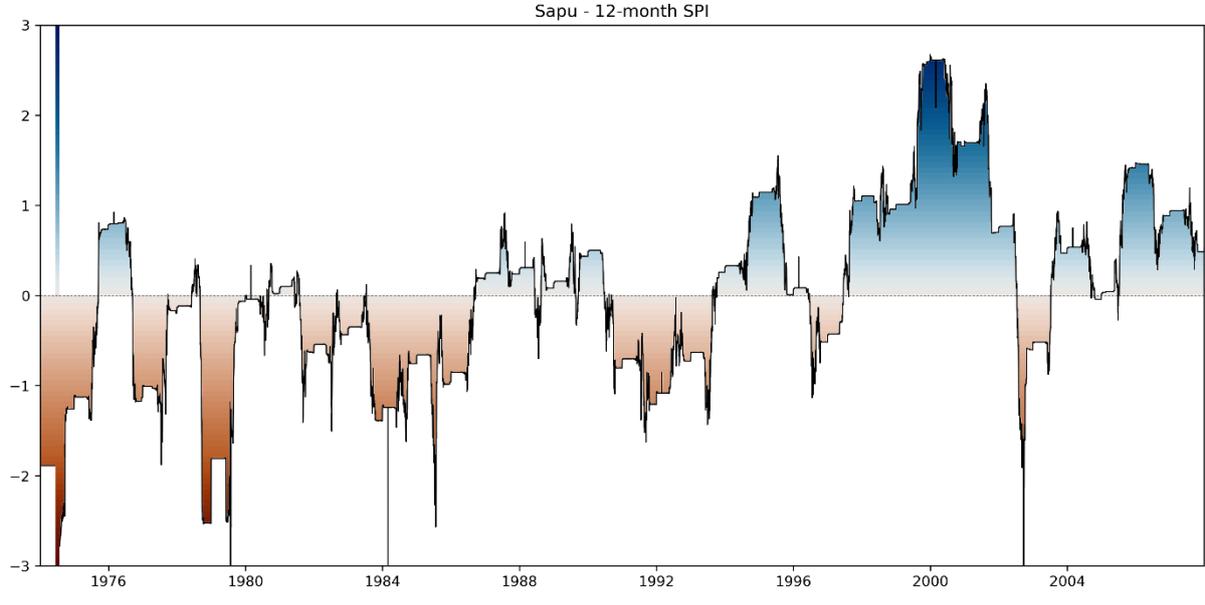
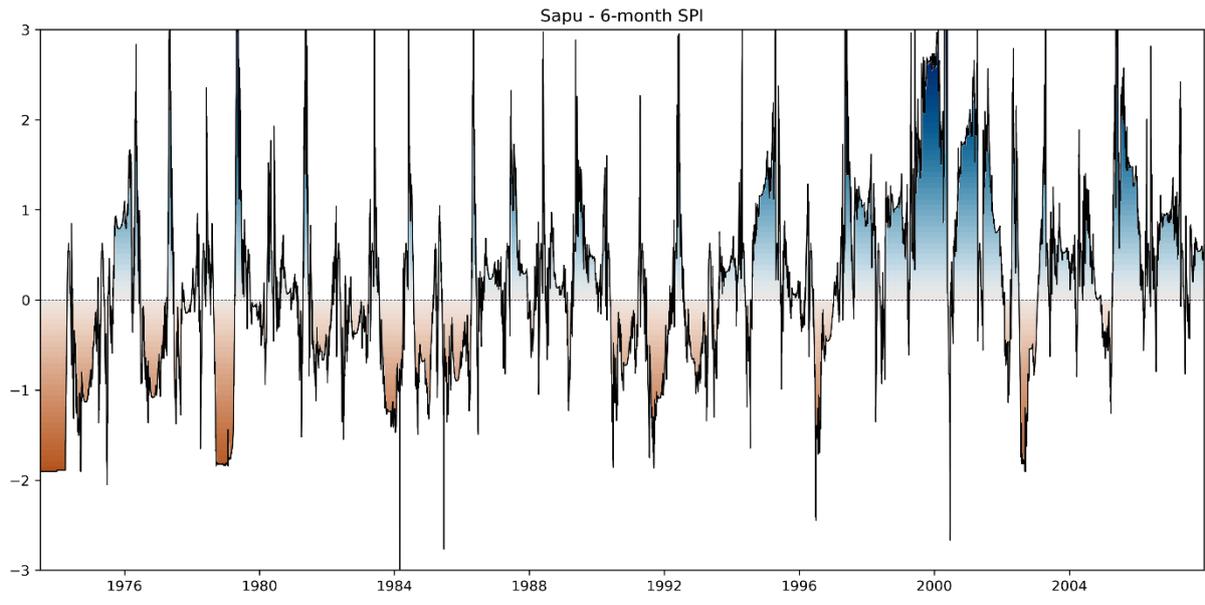


Kuntaur - 6-month SPI

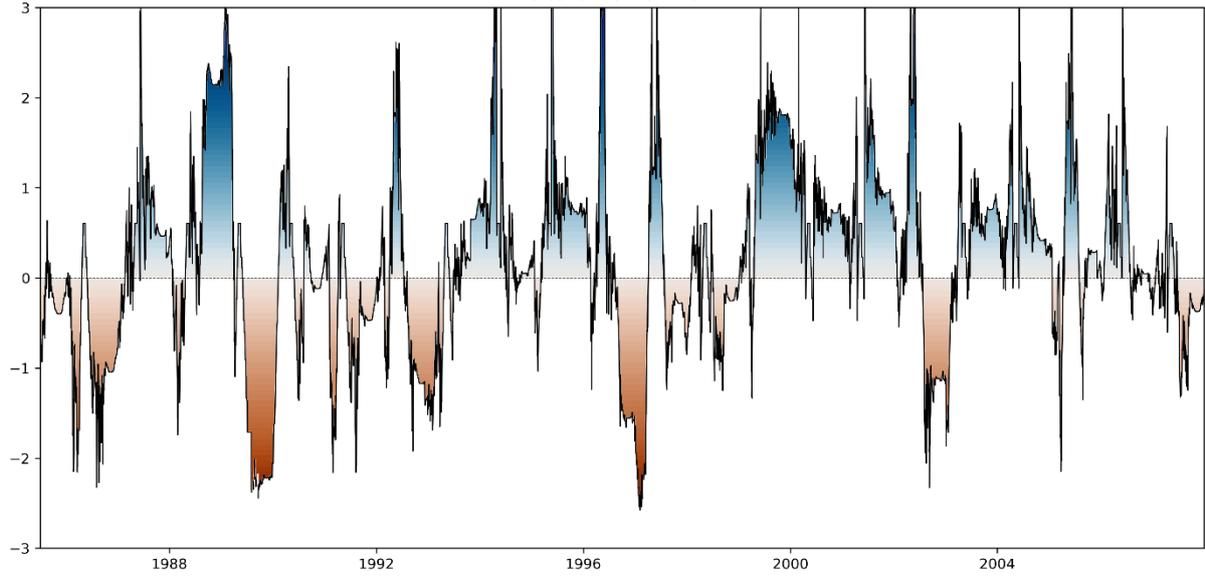


Kuntaur - 12-month SPI

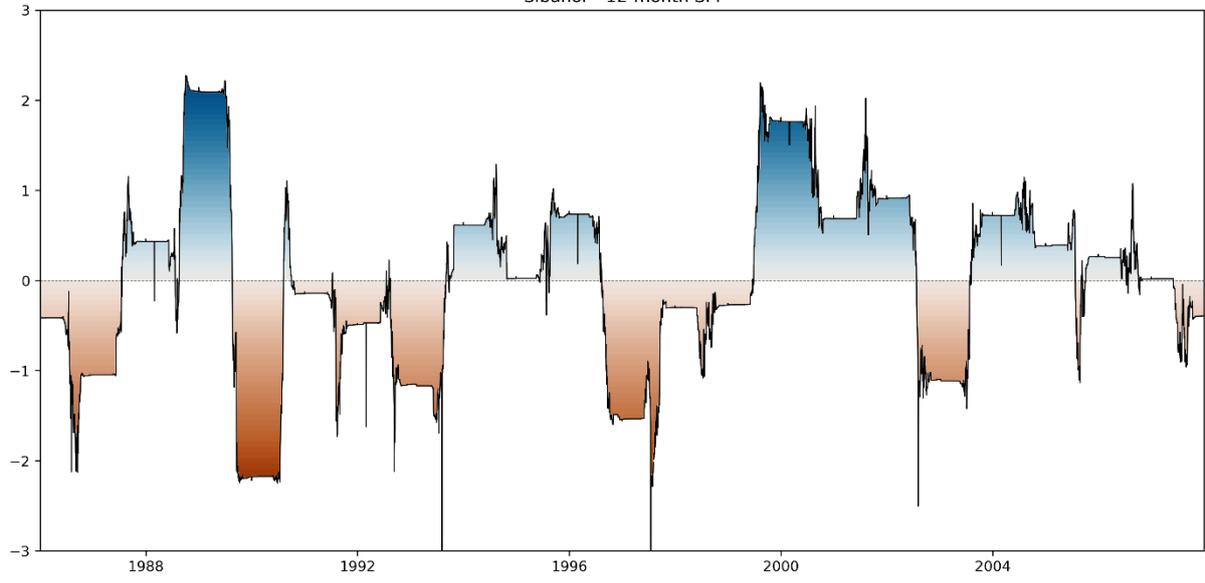




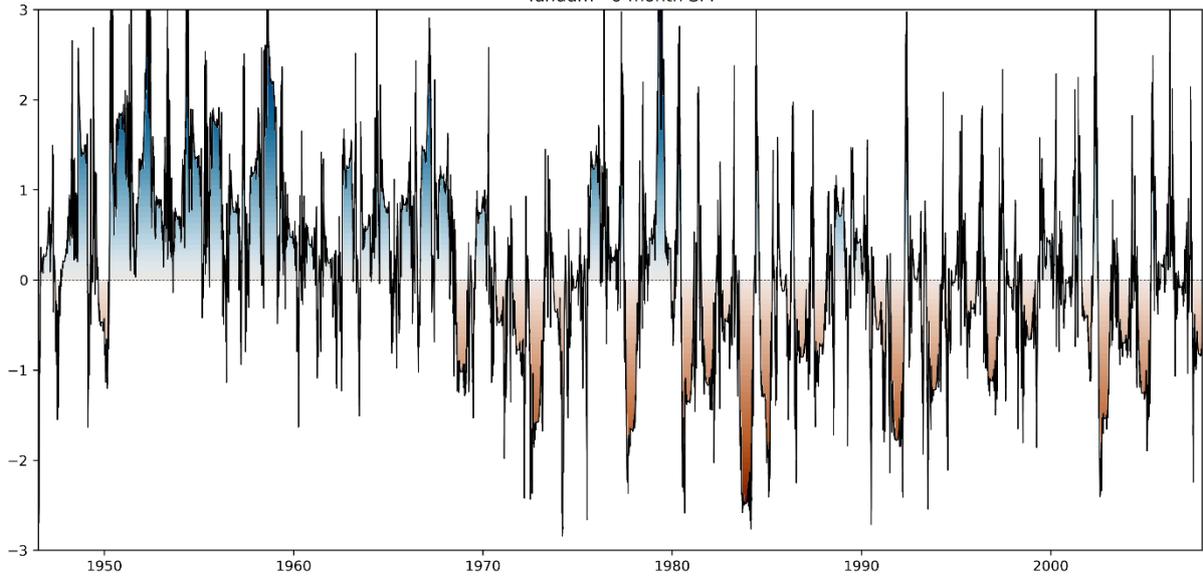
Sibanor - 6-month SPI



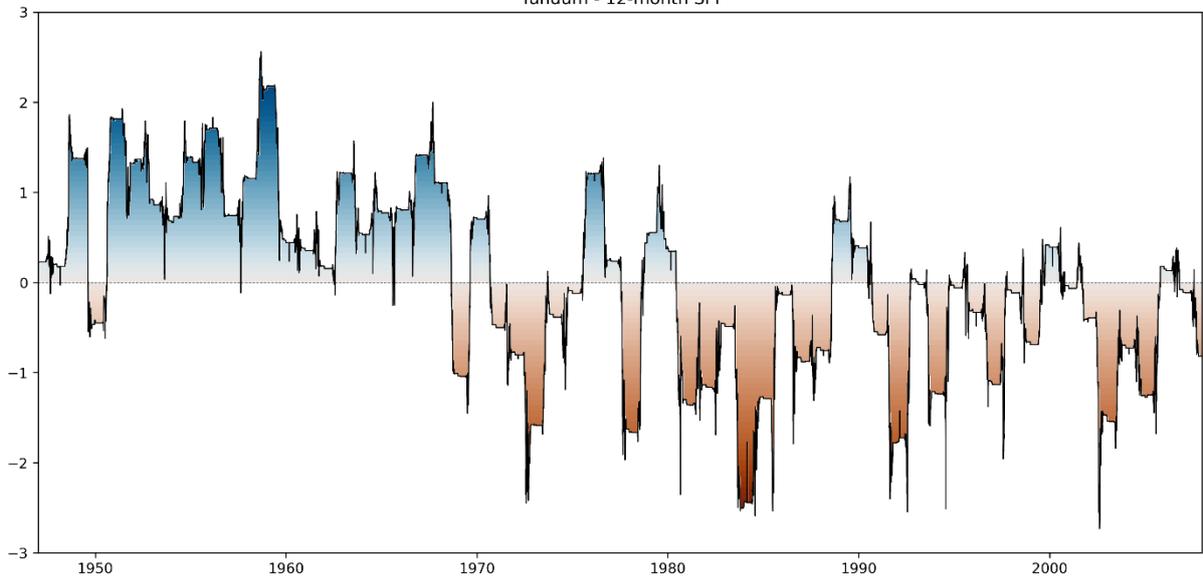
Sibanor - 12-month SPI



Yundum - 6-month SPI



Yundum - 12-month SPI



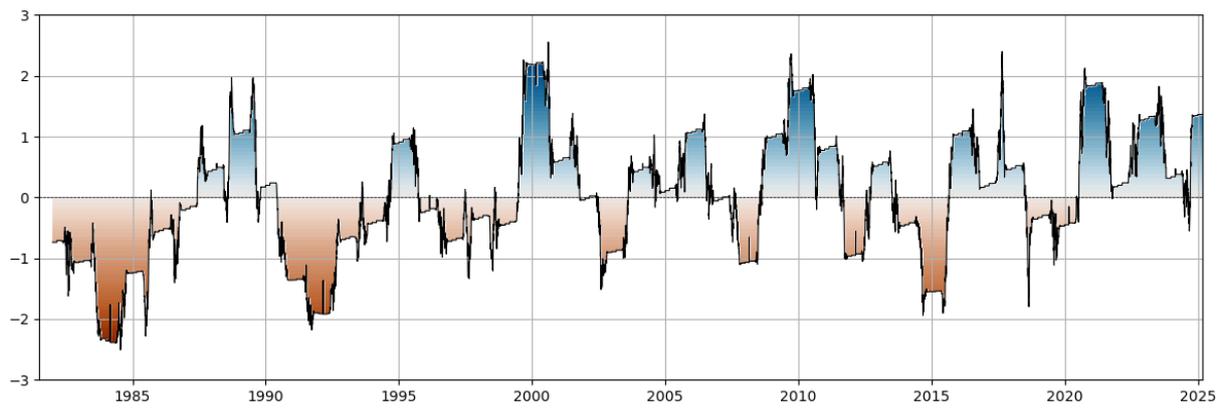


Figure 8-6: SPI-12 for the CHIRPS country averaged daily precipitation sums



GLOBAL
CENTER ON
ADAPTATION

ANTOINE PLATEKADE 1006
3072 ME ROTTERDAM
THE NETHERLANDS
+31(0)88-088-6800
WWW.GCA.ORG