Situation Analysis Report: Maradi-Katsina Transformation Lab

Climate Adaptation and Resilience In Tropical Drylands (CLARITY)

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About CLARITY

CLimate Adaptation and Resilience In Tropical drYlands (CLARITY) seeks to identify equitable, sustainable and climate-resilient development pathways in tropical drylands. It is a 3.5-year (2023-2026) research consortium funded by the Climate Adaptation and Resilience (CLARE) Program of the Foreign, Commonwealth and Development Office (FCDO) of the British government and the International Development Research Centre (IDRC) of the Government of Canada.

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Executive Summary

In the Sahel of southern Niger and northern Nigeria, freshwater demand in cities such as Maradi and Katsina and their rural periphery is rising rapidly to meet domestic needs under high rates of population growth and to sustain the livelihoods of an increasing number of smallholder farmers employing irrigation, and transhumant herders engaged in livestock watering. This rapid rise in freshwater demand is taking place in the context of increasingly erratic seasonal rainfall and amplified rainfall extremes brought about by climate change.

In the Maradi region, groundwater drawn from a regional sandstone aquifer (Continental Hamadien) and shallow alluvial aquifer along the Rivers Goulbi Maradi and N'Kaba, is the only perennial source of freshwater. Recent research by the authors has revealed that the renewability of groundwater withdrawals depends, in part, on episodic flood discharges during the monsoon season that arise from the transboundary flow of the RGM and releases from the Jibiya dam in northern Nigeria.

In Katsina, access to freshwater occurs primarily from wells tapping a low-yielding weathered crystalline (basement) rock aquifer system and the neighboring surface water dam on the River Goulbi Maradi at Jibiya. The long-term sustainability of this conjunctive use of groundwater and surface water in the hydrological corridor connecting Maradi and Katsina is unclear. The risk of conflict between transhumant herders and irrigators who compete to abstract groundwater, is increasing.

This situational analysis aims to describe the context and key challenges, both physical and social, to the identification of equitable, sustainable and climate-resilient development pathways in the Sahelian drylands of southeastern Niger and north-central Nigeria. Such solutions need to consider explicitly rising freshwater demand among a range of different stakeholders, the transboundary and interconnected nature of surface-water and groundwater resources in the RGM basin.

1.0 The Maradi-Katsina T-Lab

The transboundary River Goulbi Maradi Basin (RGMB) is a dryland environment located in the Sahel of southeastern Niger and north-central Nigeria (Fig. 1a). It is bounded to the north by the Goulbi Kabba fossil basin and to the west by the Goulbi Bounsourou basin, situated between latitudes 13°00' and 13°48' North and longitudes 6°24' and 7°30' East (Figs. 1b, c). The River Goulbi Maradi, the only source of surface water in the Maradi region (Niger), is seasonal and flows episodically from July to October depending on local rainfall and releases from the Jibiya dam, ~50 km west of Katsina (Nigeria).

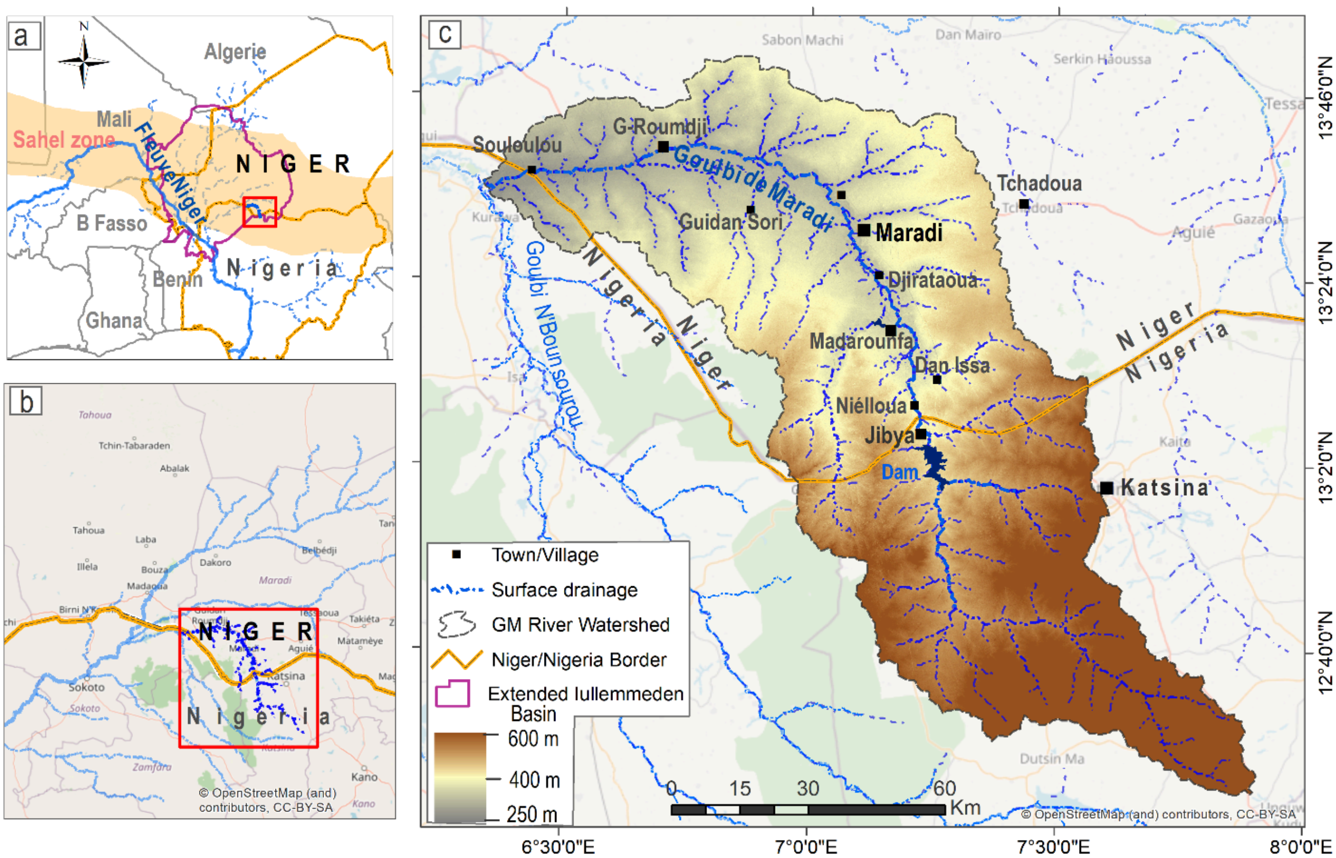

Figure 1: Map of the transboundary River Goulbi Maradi basin in Niger and Nigeria.

The region encompassing the RGMB is one of the most densely populated in the Sahel. Population densities in the Nigerien part of the RGMB (Fig. 1c) are between 81 and 105 inhabitants per km^2 (INS 2012, 2018) with a fertility rate of 7.6 children per woman that is among the highest in the world. Annual population growth is ~4% (INS, 2012). The population of the Maradi region of Niger increased from 561,000 in 1960 to just over 3.4 million in 2012. The population is young with more than half of the residents under the age of 15 years.

In Nigeria, the populations of Katsina and Jibiya have annual growth rates of 3.7% (National Population Commission, Nigeria). The fertility rate in Katsina remains high at 7.3 children per woman (Demographic Health Survey, 2018). From 2006 to 2023, Katsina's population grew from ~318,000 to ~590,000 whereas Jibiya's population rose from ~167,000 to ~311,000.

Livelihoods in the Nigerien part of this transboundary basin depend mainly on rain-fed agriculture and animal husbandry, which have recently become less productive and increasingly vulnerable to climate hazards. During drought years, declines in agricultural production have led to major food shortages and occasionally famines (Nazoumou et al., 2016). To compensate for declines in rain-fed food production and increase household incomes, residents have historically engaged in supplementary irrigated agriculture, based on flood recession and pumping of shallow groundwater.

In the Katsina-Jibiya region, residents engage in economic activities such as crop production, livestock rearing, and fishing. Further, retail activities related to agriculture that includes cross-border trade with Niger (e.g. import, export) contribute substantially to the local economy. In the Katsina-Jibiya region as with the Maradi region, people primarily rely on rain-fed farming and livestock rearing, which have been impacted by climate variability that hinders yields and increases food insecurity. To address these challenges, local communities have adopted additional irrigation farming techniques that draw from shallow groundwater in the alluvial aquifer and the Jibiya dam.

The dominant ethnicity on both sides of the Niger-Nigerian border in the RGMB is Hausa comprising two subgroups, Kastinawa and Gobirawa. Additional ethnicities include the Foulani. Maradi's regional government offices are based in Maradi City with secondary centers called "Departments" in Madarounfa and Guidan Roumdji (Fig. 1c) as well as rural communes, recognized as the local decision-making level. The administrative divisions of the Maradi regional government continue to operate in places like Nielloua (Fig. 1c) but under conditions of insecurity. In Nigeria, Katsina State has 34 Local Government Areas, including Katsina and Jibiya. Jibiya is located in the northwestern part of the state at the border with Niger; the Jibiya Dam is situated near the town of Jibiya.

Insecurity persists in the RGMB. Over the few years, banditry has created widespread insecurity in Nigeria, especially in Katsina state, which then spread to the other side of the border in Niger. As a result, the Nigerien central and the Katsina State governments have initiated security measures aimed at curbing these challenges that include the deployment of additional security forces, establishment of community watch corps, and engagement with traditional leaders and community stakeholders to reinforce local governance and promote peace-building initiatives. These strategies reflect an understanding that sustainable security solutions must incorporate the socio-political context of the affected areas, recognizing the roles that local dynamics and cross-border relations play in the broader security landscape. These strategic measures have significantly reduced the security breaches in the basin.

Farmer-herder conflict has traditionally been rooted in disputes over natural resources and it is often presented as social conflict between settled farmers and pastoralists (Oyinloye, 2020). Recent rises in the incidence of banditry have increased tensions between ethnic communities and interrupted development activities. Transhumant livestock farming has, for example, become less mobile. Continued cross-border insecurity has also led to the kidnapping and theft of animals. Further, insecurity has the corollary of the forced destocking of livestock, reorientation of transhumant circuits, break-up of pastoral families, and resettlement of breeders who have taken refuge in pastoral areas and abandonment of crop fields. Inflamed religious tensions have upset the nation's social cohesion and frightened off investors (Maigari et al., 2021), contributing to pervasive food shortages and food insecurity.

The Kano-Maradi rail project, initiated by the Nigerian government, is a key infrastructural development aimed at connecting Kano (Nigeria) to Maradi via Jibiya over a distance of ~284 km. At an estimated cost of $1.96 billion, the project is slated for completion in 2025 (Federal Ministry of Transportation/Marine & Blue Economy, 2023). This rail line is expected to boost regional trade and economic growth by easing transport of goods, reducing logistics challenges, and enhancing security across the border. It promises to stabilize the region by improving access and fostering economic resilience, potentially mitigating conflicts and enhancing social well-being in both countries. The project is also anticipated to contribute to the African Continental Free Trade Area Agreement, offering broader economic benefits.

1.1 Water Availability

1.1.1 Rainfall

The climate of the RGMB is semi-arid, featuring a single rainy season (June to early October) that is controlled by the African Monsoon (hot and humid wind), and a long dry season that occurs from November to May and is governed by the Harmattan (dry and very hot wind) arising from the Sahara desert (Issa Lélé and Lamb, 2010). Data from the Maradi Airport meteorological station indicate that the mean annual rainfall is 520 mm (1960–2021) whereas in Katsina, rainfall records from 1990 to 2015, collected by the Nigerian Meteorological Agency (NiMet) indicate average annual rainfall of 518 mm (1984-2010); mean monthly air temperatures in Maradi range between 25 and 35 °C; and mean monthly potential evapotranspiration varies between 150 and 210 mm (1984–2010). A recent report from NiMet (2022) refers to a mean annual rainfall of 716 mm for the

Katsina region that is indicative of recent rises in rainfall in the eastern Sahel following the multi-decadal Sahelian drought (1968-1993).

1.1.2 Groundwater and Surface Water Resources

The transboundary river channel of the RGMB is underlain primarily by a shallow alluvial aquifer that is exploited for drinking water as well as water for livestock and irrigation. In Niger, the shallow alluvium is, in turn, underlain by a regional sandstone (Farak-type) aquifer known as the Continental Hamadien (CH) (Dikouma, 1990; Toyin et al., 2016; Issoufou Ousmane et al., 2023a, b). Recent observations (Issoufou Ousmane et al., 2023a) suggest that the alluvial aquifer and underlying CH aquifer form an interconnected aquifer system (Fig. 2), replenished by leakage from flood discharges of the ephemeral River Goulbi Maradi (*i.e.* focused recharge) and the direct infiltration of seasonal rainfall (*i.e.* diffuse recharge). Contours of groundwater levels in the RGMB in Niger (Fig. 3) highlight the dominance of a topographically defined, regional groundwater flow regime driven by diffuse recharge that is influenced in the vicinity of the River Goulbi Maradi by contributions of focused recharge. The overall magnitude of groundwater recharge, contributions from different processes, and their relation to rainfall in the RGMB require further investigation.

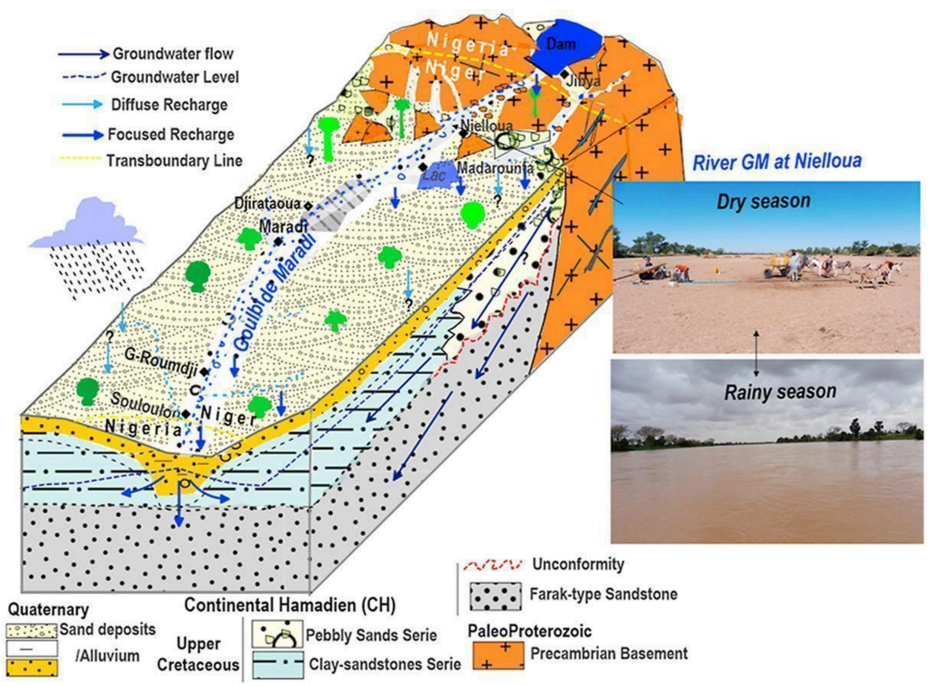

Figure 2: Block diagram outlining current conceptual model of water flows in the transboundary valley of the River Goulbi Maradi in Niger showing focused (riverine leakage) and diffuse (rainfall infiltration) recharge pathways (Issoufou Ousmane et al., 2023a).

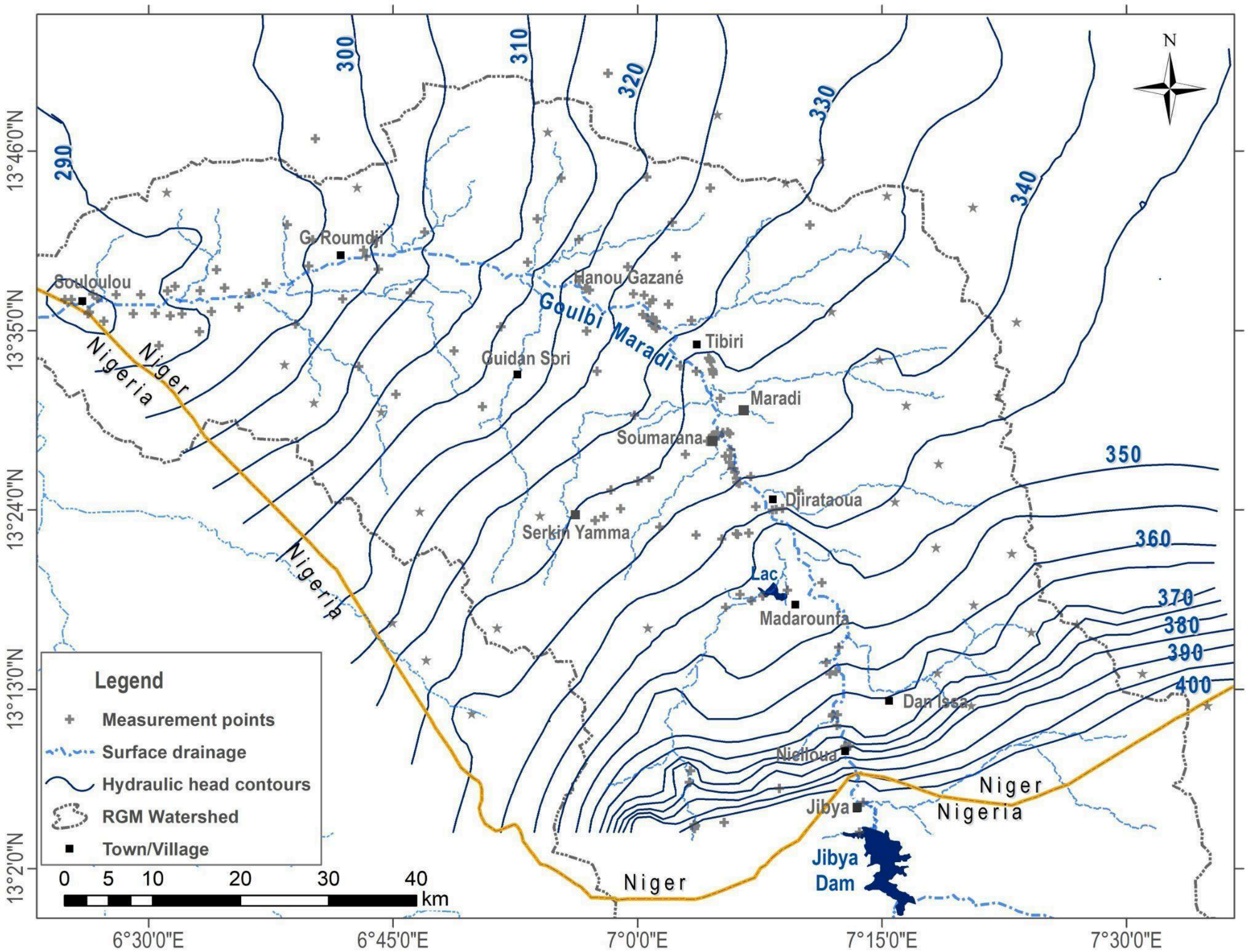

Figure 3: Map showing contours of groundwater levels (hydraulic head in m above mean sea level) recorded from 2010-2019 in the hydraulically connected Continental Hamadien regional sandstone aquifer and Quaternary alluvial aquifer in the River Goulbi Maradi Basin; interpolation was conducted by kriging in ArcGIS (Issoufou Ousmane, 2023).

In recent decades, groundwater levels in the adjacent regional sedimentary aquifer, the Continental Terminal (CT), have risen, even during The Sahelian Drought. This apparent contradiction is explained by The Sahelian Paradox in which the large-scale conversion of perennial grasslands to shallow-root crops led to a reduction in evapotranspiration (ET), enhancing groundwater recharge and river discharge (Favreau et al., 2009). The extent to which a similar increase in groundwater storage has taken place in the CH aquifer is unclear. An increasing trend in total (terrestrial) water Storage (TWS) indicated by GRACE satellite data over the last two decades (Fig. 4) is best explained by a rise in groundwater storage yet this requires further investigation from *in situ* measurements.

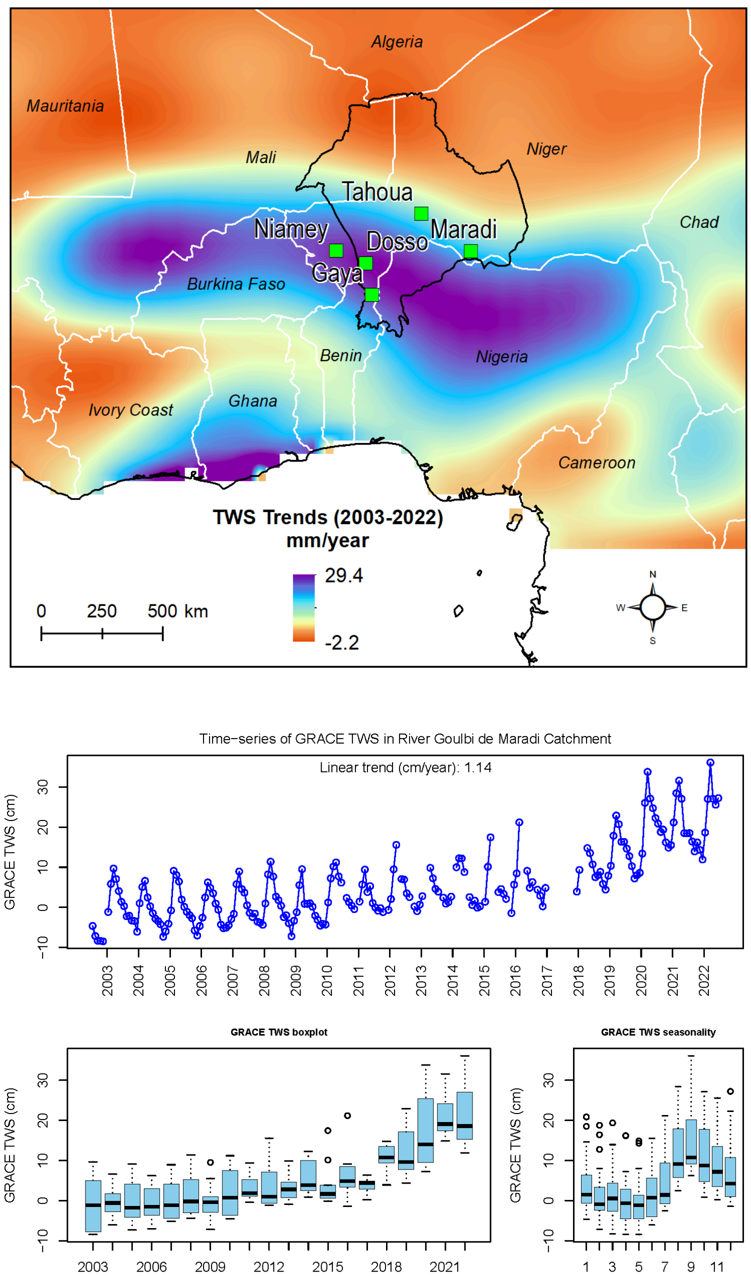

Figure 4: Changes in total terrestrial water storage ($^{\Delta}$TWS) indicated by GRACE satellite data: (a) mapped over West Africa; and (b) times series for a 'footprint' of ~ 100 000 km^2 centered on Maradi, Niger; data source: gsfc.glb_.200204_202305_rl06v2.0_obp-ice6gd_halfdeg.nc, NASA Goddard Space Flight Center (GSFC).

In Niger, surface water in the RGMB is limited in time and space so that year-round drinking-water supplies and irrigation derive primarily from groundwater (Figs. 4 and 5) flowing within the Quaternary alluvial aquifer, largely constrained to the river's floodplain, and the underlying and more extensive CH aquifer (Figs. 2) that is the predominant supply of freshwater to Maradi City. Recently, a multi-village water supply development program has been planned to increase access to drinking-water in the framework of the National Water, Hygiene and Sanitation Program of Niger (PROSEHA) (MHA, 2016); intensive pumping is proposed from deep boreholes, screened in the lower part of the CH aquifer.

Figure 5: Hand Pump well in the Maradi region of Niger (credit: Dr. Issoufou Ousmane).

Figure 6: Groundwater-fed irrigation of high-value (cash) crops (onions) in the Maradi region of Niger (credit: Dr. Issoufou Ousmane).

In northern Nigeria, the Jibiya - Katsina region is mainly underlain by weathered Precambrian crystalline (basement) rocks (Fig. 2) comprising granites, gneisses, and schists. Groundwater flows in this basement rock aquifer system comprising an unconsolidated regolith (saprolite) and underlying fissured bedrock as well as in superficial alluvial floodplain deposits along the River Goulbi Maradi (called River Gada in Nigeria). Access to freshwater from wells in basement rocks is constrained by low well yields (Fig. 7). Surface water resources include the Jibiya Dam as well as perennial and seasonal River Gada tributaries.

Figure 7: Handpumped well drawing from weathered crystalline (Basement complex) rock aquifer system in Katsina (credit: Olaniyan, 2022).

The Jibiya Dam is located just upstream of the Niger-Nigeria border along the River Goulbi Maradi (Figs. 1, 2) in Katsina State, near Jibiya town within Jibiya Local Government Area (LGA). It has a height of 23.5 m and a total length of 3660 m with a storage capacity of 142 million m^3 (Sembenelli Consulting, 1987). The dam was designed in 1987 and completed in 1989 to boost agricultural production as well as the supply of potable drinking water for the people living within and around the area. The Jibiya River channel, characterized by a narrow valley, flows consistently throughout the year. The Jibiya irrigation project (Fig. 8) is one of Nigeria's large-scale irrigation projects aimed at enhancing agricultural productivity as well as to improve standards of living for people locally through the creation of job opportunities, food production, and increased household incomes (SRRBDA, 1991).

Figure 8: Canal network of the Jibiya Dam in Katsina State (credit: Professor Ibrahim Goni).

Beyond the Jibiya dam, groundwater is accessed via well depths on the alluvial floodplain that are typically less than 10 m and used primarily for irrigation purposes but occasionally for domestic purposes. Well depths installed within the unconsolidated regolith are commonly in the range of 20 – 30 m. Deeper boreholes drilled into fractures in basement rocks and sedimentary (Gundumi, Chad) formations have depths of between 45 and 65 m (JICA, 2009). The predominant source of drinking water to Katsina City is groundwater drawn through boreholes within the deeply weathered crystalline basement complex. It is presently unclear in Katsina whether groundwater resources exist more deeply within fractured bedrock formations as has been observed rocks elsewhere in Nigeria (Abuja, Jos). Based on studies carried out in the Liptako basement region of Niger (Abdou Babaye et al., 2019), alluvial aquifers and unconsolidated regoliths are considered to be in direct hydraulic contact with the fractures and fissures in the crystalline bedrock and provide storage to sustain fracture flow. Dug wells installed into shallow zones of the regolith (within the ferricrete/laterite zone) serve small communities. The low transmissivity and limited storage of weathered and fractured crystalline rocks restricts more intensive groundwater pumping.

1.2 Water Quality

Groundwater quality in the shallow alluvial aquifer in Niger is considered generally acceptable for use in irrigation based on measures such as the Sodium Adsorption Ratio (SAR), percentage of soluble sodium (%Na), and residual sodium carbonate (RSC) but can exceed maximum guideline concentrations for manganese and occasionally fluoride (Fig. 9, Issoufou Ousmane et al., 2023b). Groundwater in the underlying CH aquifer in the upstream part of the basin, from depths of up to 100 m is also suitable for irrigation but also occasionally exceeds maximum guideline concentrations for manganese and fluoride. In downstream locations of the RGMB at depths below 60 m, excessive fluoride concentrations in groundwater from some boreholes in the CH aquifer present a potential risk to human health and are unsuitable for irrigation because of the high concentrations of sodium, chloride, sulphate, and fluoride. Better recognition of the spatial distribution of fluoride according to depth and identification of the biogeochemical conditions and lithology favoring fluoride release requires wider and depth-specific surveys of groundwater quality. The new lower maximum guideline concentration for manganese in drinking water, proposed by the World Health Organization (WHO, 2008), poses a challenge to the use of groundwater for drinking water regionally and requires further investigation.

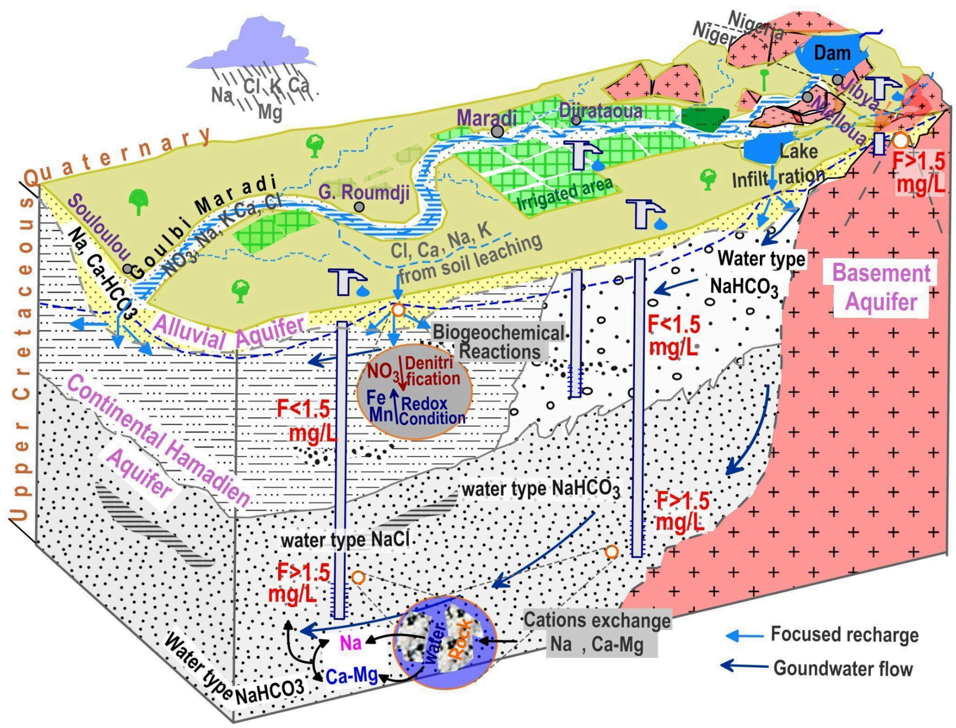

Figure 9: Conceptual model of the processes controlling groundwater mineralization in the River Goulbi Maradi Basin in Niger (Issoufou Ousmane et al., 2023b).

In waters sampled from the Jibiya Dam, Shamsuddin et al. (2018) found concentrations of lead, cadmium, nickel and iron exceeded WHO drinking-water guidelines suggesting that raw water from the Jibiya dam is unsafe for drinking. Oyewumi et al. (2019) carried out an assessment of groundwater quality sampled from 70 boreholes in Katsina State to evaluate its suitability for drinking, domestic, agricultural and industrial purposes. A suite of 11 physico-chemical parameters including pH, total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), chloride, iron, manganese, sulphate, total alkalinity, fluoride and nitrate were considered in the computation of a Water Quality Index (WQI). WQI values across Katsina State ranged from 18 to 60, indicating excellent-to-good groundwater quality for human consumption. 29 LGAs in Katsina State have mean WQI values lower than 50, representing excellent water quality whereas samples from the remaining 5 LGAs have WQI values greater than 50, denoting good water quality.

Masari et al. (2020) assessed salinity levels in irrigation water from the Jibiya, Bakori, and Mairuwa Irrigation Schemes in Katsina State. Water samples were collected during the dry season and tested for electrical conductivity (EC), total dissolved Solids (TDS) and total hardness (TH) against water quality standards for irrigation. EC values for Jibiya were <3000 μS/cm which is within the limit specified by FAO (1994) whereas those obtained from Bakori and Mairuwa were above this limit. EC values for all schemes were within the acceptable range specified for plant growth. TH values observed at Jibiya were similarly lower than that at Bakori and Mairuwa yet all were within the limit for plant growth. More recently, Sani et al. (2022) assessed the water quality for irrigation using surface waters from the Jibiya Dam. Water was sampled from the dam and main canals supplying water to irrigation fields and analysed for physical and chemical parameters (pH, EC) as well as most major ions and phosphate. Based on the FAO guidelines, the results indicate that quality of the water is suitable for irrigation purposes.

1.3 Water use in the Maradi-Katsina T-Lab

On the Nigerien side of the RGMB, agricultural activities include primarily the production of cash crops (e.g. cowpeas, nutsedge, tobacco) and cereals (millet, sorghum), as well as livestock rearing (e.g. sheep, cattle, donkeys, camels). The area of land under irrigation is unresolved but changes in intensity of irrigation activities occur along the River Goulbi Maradi. Irrigation in the valley, more developed upstream between Madarounfa and Maradi, is gradually limited and replaced by flood recession cultivation downstream from Guidan Roumdji (Figs. 1,2). This is partly linked to the accessibility to groundwater which generally deepens from upstream to downstream. In Djirataoua (Fig. 1), 512 hectares are irrigated by communities from groundwater pumping from the shallow alluvial aquifer, under the management of the National Office for Hydro-Agricultural Infrastructures (ONAHA) of Niger.

In the transboundary RGMB part in Niger, livestock husbandry is culturally and economically important, and a priority groundwater use in the arid north, as recognised by the 1993 Rural Code (Nigerien SPCR, 2018) and the 2016–2030 Sectoral Programme on Water, Hygiene and Sanitation (Nigerien MHA, 2017). Competition in water uses between transhumant herders and irrigators is prominent, especially considering policies aiming to increase irrigated land area such as the “2015 Small Irrigation Strategy of Niger (Nigerien SPIN, 2020) and 2012’s ‘Nigeriens feed Nigeriens’ (HC3N, 2012) strategies. These programs work alongside the 2017 “National Action Plan for Integrated Water Resources Management” of Niger (MHA, 2017a). The transboundary Niger Basin Authority (NBA) also plays a governance role, alongside national water, livestock and agriculture ministries and non-governmental organizations (NGOs) such as the Nigerien “National Network of Chambers of Agriculture (RECA)”.

Nigeria has, in parallel, adopted agricultural strategies, aimed at enhancing agricultural productivity and ensuring food security. One significant initiative is the “National Fadama Development Project”, which focuses on improving small-scale irrigation and increasing agricultural output among rural communities. Another pivotal strategy is the “Agricultural Transformation Agenda (ATA)”, which seeks to revitalize agriculture, reduce food imports, and boost local production across various agricultural sectors. The “Anchor Borrowers’ Programme (ABP”) plays a crucial role in providing loans to smallholder farmers to increase their access to financial support and encourage the cultivation of key commodities like rice, maize and wheat. This program aims to bridge the gap between small-scale farmers and large agro-processors, ensuring a steady supply of high-quality agricultural products for processing.

2.0 The Human Environment

2.1 Stakeholders

Stakeholders with an active stake in the equity and sustainability of water resources in the transboundary RGMB are diverse and include: water-user associations (surface water and groundwater), women's and youth groups, herders and farmers, government ministries, basin organizations, environmental organizations, locally elected officials, traditional and religious leaders, policymakers, developers, and especially actors having difficulty accessing water. Stakeholder communities, listed below, are stratified geographically and politically.

Regional institutions:

● *Niger Basin Authority* (NBA): The NBA has a mandate to promote the integrated development of the Niger Basin, focusing on sectors such as energy, water resources, agriculture, livestock, fisheries, forestry, transportation, communications, and industry. The NBA's member states, which border the Niger River, include Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, Niger, and Nigeria (African Great Lakes Inform).

● *Nigeria-Niger - Joint Commission* (NNJC): The NNJC is dedicated to fostering cooperation and development between Nigeria and Niger in various sectors such as trade, transportation, security, energy, and water resources. The NNJC's mandate includes promoting economic integration, enhancing bilateral relations, and facilitating joint initiatives for the mutual benefit of both countries.

National and Federal institutions:

● *Ministère de l'Hydraulique, de l'assainissement et de l'Environnement* (Niger)

● *Ministère de l'Agriculture et de l'Élevage* (Niger)

● *Office National des Aménagements Hydro-Agricoles* (ONAHA)

● *Federal Ministry of Water Resources*: This federal ministry is responsible for the development and management of Nigeria's water resources, focusing on areas such as water supply, irrigation, sanitation, and flood control. Its mandate includes formulating policies, coordinating water-related activities, and implementing projects to ensure sustainable water use and improve access to clean water across the country.

● *Federal Ministry of Environment*: This federal ministry is responsible for protecting and managing Nigeria's environment, focusing on areas such as pollution control, environmental conservation, climate change mitigation, and sustainable development. Its mandate includes formulating policies, enforcing environmental regulations, and implementing programs to ensure a healthy and sustainable environment for current and future generations (Federal Ministry of Environment. (n.d.).

● *Federal Ministry of Agriculture and Food Security*: The ministry is tasked with promoting agricultural development and ensuring food security in the country. Its mandate includes formulating policies, implementing programs, and supporting initiatives in areas such as crop production, livestock farming, fisheries, agricultural research, and rural development to enhance agricultural productivity and ensure a stable food supply.

● Federal Legislatures from the zone (Katsina North): They are responsible for representing the interests of their constituents in the national parliament, shaping legislation, advocating for regional development, and securing federal resources and projects to benefit their zone. Their mandate includes addressing local issues, influencing national policies, and ensuring that the needs and priorities of Katsina North are reflected in government decisions and actions (National Institute for Legislative and Democratic Studies (2022).

● *National Water Resources Institute*, Kaduna: is dedicated to the research, training, and capacity building in the field of water resources management in Nigeria. Its mandate includes conducting studies, providing education and training, and developing technologies to enhance sustainable water management, improve water supply and sanitation, and support effective utilization of water resources across the country.

State and Local Government Institutions:

● *Direction régionale de l'Agriculture et de l'élevage de Maradi* (DRHA/E)

● *Direction Régionale de l'Environnement de Maradi* (DRHE)

● *Direction Régionale du Génie Rural de Maradi* (DRGR)

● *Commission Régionale Eau Assainissement de Maradi* (CREA)

● *Conseil Régional de l'Agriculture* (CRA)

● *Katsina State Ministry of Water Resources* is responsible for managing and developing the state's water resources, ensuring adequate water supply, and implementing water-related projects to support sustainable development.

● *Katsina State Ministry of Agriculture* is focused on enhancing agricultural practices, supporting farmers, and promoting agricultural development programs to improve food security and boost the state's economy.

● *Katsina State Ministry of Environment* is tasked with environmental protection, conservation, and the implementation of policies and programs aimed at ensuring sustainable environmental management and addressing issues such as pollution and climate change.

● *Katsina State Rural Water Supply and Sanitation Agency* is responsible for providing clean water and sanitation services to rural communities in Katsina State, ensuring access to safe drinking water, improving hygiene practices, and implementing sustainable water supply and sanitation projects. While Katsina State Waterboard manages and supplies water to urban and semi-urban areas within Katsina State, overseeing the treatment, distribution, and maintenance of water infrastructure to ensure reliable and adequate water supply for residential, commercial, and industrial use.

● *Jibiya Dam Management* oversees water infrastructure for local agriculture and is responsible for the operation, maintenance, and oversight of the Jibiya Dam in Katsina State. Its mandate includes ensuring the dam's structural integrity, managing water resources for irrigation, water supply, and flood control, and supporting agricultural activities and local communities by providing a reliable water source (Federal Republic of Nigeria, 2004).

● *Agro-Climatic Resilience in Semi-Arid Landscapes* (ACReSAL): is a six-year World Bank-supported project in Northern Nigeria aimed at restoring degraded landscapes and enhancing climate resilience. It addresses environmental fragility, and poor agricultural productivity through a multi-sectoral approach led by the Federal Ministry of Environment. The project aims to implement sustainable landscape management, increase agricultural productivity, and restore one million hectares by 2028. ACReSAL seeks to reduce herder-farmer conflicts and benefit 3.4 million people directly, emphasizing ecosystem restoration, water management, and institutional strengthening for long-term sustainability (ACReSAL, 2024).

Local Non-Governmental Organizations (NGOs):

● Water-User Associations: Jibiya Farmers User Association, which represents local farmers' such as Himma-Makiyawa Farmers Association and Faru Complex Multipurpose Farmers Association

● Smallholder Irrigators NGO support: Taimakon Manoma, Karkara, Goulbi, RÉS-EAU

● Livestock rearing NGO support: ARENE (Association pour la Redynamisation de l'Elevage au Niger), Bounkassa Kiwo, DesertVit,

● WASH support in Niger: WaterAid, SAC/SPE (Structure d'Appui Conseil au Service Public de l'Eau), CARE International, Winrock International, Save the Children, Action Contre la Faim, World Vision.

In the transboundary RGMB, local administrative authorities, local elected officials and opinion leaders are essential in any research that informs the management of natural resources such as water. Different water user groups are identified based on their specific needs, uses, and the impact of their activities on water resources. Understanding the relationships among these groups is essential for effective water management and conflict resolution. Primary water user groups and a brief overview of their relationships are outlined below:

Agricultural Users: This group comprises small-scale and commercial farmers who rely predominantly on water for irrigation. They are the largest consumers of water resources, especially during the dry season when irrigation is crucial for crop cultivation. Their water usage directly impacts the availability of water for other groups. In Maradi region this group may include the National Office for Hydro-Agricultural Infrastructures (ONAHA), which manages an irrigated area of 512 ha in Djirataoua (Fig. 1).

Domestic Users: These are households and communities that use water for drinking, cooking, cleaning, and personal sanitation. In rural areas of the transboundary RGMB, domestic users often depend on boreholes, wells, and occasionally, piped water systems Maradi and Jibiya towns. The quality and quantity of water available to them are often affected by agricultural water usage and contamination.

Livestock Owners: Herders and livestock owners need water for their animals, which can be substantial depending on the size of the herds. In regions like Maradi and Jibiya, where pastoral activities are common, competition for water between herders and farmers can sometimes lead to conflicts, especially in drier months.

Fisheries: Fishing activities in the transboundary RGMB, are not prominently documented in available literature, suggesting they might not be extensive or commercial in nature. However, in general, fisheries activities in similar settings in Niger and Nigeria are predominantly artisanal. This type of fishing involves local communities using traditional methods such as nets, traps, and line fishing. Nonetheless, the Jibiya Dam may serve as a catalyst for fishing in the area.

Relationships among these groups are characterized by:

Competition: Most prominently, there is competition among agricultural, domestic, and livestock groups, especially during peak dry seasons when water shortages exacerbate conflicts over water allocations. This competition will be exacerbated by the development of smallholder irrigation by pumping groundwater.

Dependency: Maradi relies on groundwater abstracted from the CH (regional sandstone) and shallow alluvial aquifers, the replenishment of which may depend, in part, on upstream river flow.

Collaboration: There can be collaborative efforts, especially involving environmental groups and other user groups, to implement sustainable water management practices that benefit all, such as joint water conservation projects or shared water infrastructure development.

Regulation: Government bodies or local water management authorities act as mediators and regulators to balance the needs, rights, and responsibilities of different water user groups, aiming to minimize conflict and promote equitable water distribution.

2.2 Livelihoods and Gender

Common and traditional seasonal water-use practices are rooted in the conjunctive use of groundwater and surface water. Wells and boreholes are employed during the dry season. The source of water switches to surface water (rivers, ponds) during the rainy season. During the rainy season, people focus on rain-fed crops rather than market gardening. Water-user associations exist yet the participation of women is restricted due to the ‘weight’ of customs. With the establishment of the bodies of PANGIRE (National Action Plan for Integrated Water Resources Management) in Niger, participation of women is required.

Women are primarily expected to provide household water, especially in rural areas. Women’s active involvement in crop irrigation is limited and mainly conducted to enable the purchase (with their own money) and sale of market garden products at the market to generate income. It is challenging for women to own their own land yet certain NGOs support women to obtain land.

The socio-economic and gender-specific dynamics in the transboundary RGMB, particularly in relation to water security, emphasizes a stratification of roles within the community. Despite its urban administrative status, Jibiya's local socio-economic framework largely mirrors traditional rural settings where gender roles are sharply defined, particularly in terms of water usage and agricultural responsibilities. As in Maradi, women and children in Jibiya bear the primary burden of securing household water, which is a task that often reinforces their subordinate status in the socio-economic hierarchy. Their participation in water management and agriculture is heavily influenced by cultural norms that restrict their access to land and limit their roles to specific, less authoritative activities in the agricultural sector. For instance, women are actively involved in market gardening, which allows them to earn income independently, but they often face barriers when trying to access and own land, a critical asset for expanding their agricultural activities.

Understanding the current context of gender inequality and social exclusion around water management and adaptation to climate change is central and primary to the subsequent development of strategies to advance inclusion of all segments of society, particularly women and marginalized groups, in decision-making processes and benefit equally from resources and interventions.

Potential approaches to address these inequities may include:

- *Participatory Decision-Making*: Ensure that women and other marginalized groups are actively involved in water management committees and decision-making bodies. This can be achieved through quotas or other mechanisms that promote inclusive participation. Adopted Integrated Water Resources Management (IWRM) strategies include this dynamic in their implementation approach. It could thus be locally promoted, and feedback shared on both sides of the border.

● *Targeted Capacity Building*: Support training and education programs specifically requested or desired by women and vulnerable groups to enhance their understanding and skills related to water management, conservation practices, and climate adaptation technologies.

● *Gender-Sensitive Policy Frameworks*: Develop and implement policies that explicitly consider the impacts of water and climate policies on different genders. This includes analyzing how policy decisions affect men and women differently and ensuring that measures are in place to address these disparities.

● *Access to Resources*: Ensure equitable access to water resources, land rights for agriculture, and the benefits of climate resilience projects. This involves reforming land tenure systems to recognize the rights of women and marginalized communities, as well as ensuring that these groups have equal access to water-saving technologies and credit facilities.

● *Gender-Disaggregated Data*: Collect and employ gender-disaggregated data to better understand the needs, roles, and challenges faced by different genders within water and climate change projects. These data should inform all stages of project planning and implementation.

● *Awareness and Advocacy Campaigns*: Report on research progress and conduct awareness campaigns that highlight the importance of gender equality and social inclusion in water and climate change initiatives. These campaigns can help change traditional norms and promote more equitable practices.

3.0 Drivers and Impacts of Change

3.1 Drivers of Change

This section examines the drivers and impacts of change in the River Goulbi Maradi Basin. It analyzes the various factors that influence environmental and socio-economic dynamics in the region, including political instability, agricultural practices, economic developments, climate variability, and land-cover transformations. This examination highlights the complex relationships between these factors and demonstrates their cumulative impact on the challenge of transboundary water management and regional cooperation.

Politics: The coup d'état in Niger on July 26, 2023, demonstrated the impact of political instability on transboundary water management projects like those in the River Goulbi Maradi Basin. Such instability led to project delays, disruptions, and potential funding re-evaluations by international donors wary of operational and financial risks in a volatile political climate. Changes in governance bring policy and regulatory uncertainties, potentially affecting agreements critical for joint resource management with neighboring countries like Nigeria. Moreover, increased security concerns and socio-economic instability complicate on-ground project execution and strain cross-border cooperation, essential for the sustainable management of shared water resources.

Agricultural growth: In Nigeria, the Jibiya Dam is a cornerstone of the Sokoto Rima River Basin Development Authority's (SRRBDA) efforts to enhance agricultural productivity through the development of ~3,450 hectares of land for irrigation (SRRBDA, 1991). The Jibiya Dam Irrigation Project, a multipurpose project of the SRRBDA, seeks to improve farm efficiency and income through optimum water conservation and use practices. Dry season farming via irrigation is a key activity facilitated by the Jibiya Dam. With the available land, water, irrigation structures and facilities, the project cultivates an average of 1,500 to 2,000 ha each year out of the planned area of 3,450 ha. This dry-season irrigation is supported by the Federal Government in collaboration with the authorities of the Sokoto Rima River Basin Development Authority and the Katsina State Government. Despite these efforts, the full potential of the Jibiya irrigation project has yet to be realized due to several challenges that include but are not limited to insecurity.

Solar-pump revolution: The emergence of solar pumps as a potential carbon-free source of power to drive groundwater abstraction has the potential to amplify groundwater withdrawals and deplete groundwater resources. In Niger, access to solar-pump technologies is limited and hindered by insecurity. In Nigeria, especially Katsina and Jibiya, the adoption of solar-powered pumps is viewed as a water supply solution. Increased interventions by the federal and state governments, along with support from NGOs, have led to the installation of solar boreholes and hand pumps for communities and farmers. This shift from traditional petrol or diesel-powered boreholes is driven by the removal of fuel subsidies – compelled by international commitments of Nigeria to reduce carbon emissions; this action caused petrol prices to skyrocket by more than 300% and render them unaffordable for most farmers in Nigeria. Government bodies are converting existing boreholes to solar power; community members are also taking the initiative to install solar-powered pumps and boreholes, viewing them as more sustainable and easier to maintain compared to conventional systems, despite their high capital costs. This grassroots movement is complemented by legislative water interventions in the area that increasingly promote solar-powered solutions. These efforts highlight the potential of solar pumps to provide reliable water access and reduce dependency on fossil fuels, promoting both environmental sustainability and economic viability for local communities. However, the transition requires careful management to ensure groundwater resources are not over-exploited, ensuring long-term sustainability for these interventions. Further, the high capital costs, installation and maintenance of solar pumps are often beyond the reach of many smallholder farmers. Accelerated Education Programs supported by state and NGOs have sought to address technical issues with the implementation of solar-powered options and the outcomes are better.

Economics: The economy of the transboundary RGMB is strongly by cross-border trade between Niger and Nigeria; the strategic positions of Maradi and Jibiya make them important hubs for this trade. Each town's economy benefits substantially from the movement of goods and services across the border including agricultural products, textiles, and household goods. Agriculture plays a central role in the economy of Maradi and Jibiya; the area is largely agrarian as farming and livestock rearing are the primary occupations. Key agricultural products include millet, sorghum, maize, and rice, along with cattle, sheep, and goats. The agricultural sector benefits from the seasonal rainfall pattern, although it faces challenges such as the modernization of agriculture and fluctuations in rainfall amplified by climate change. High rates of demographic growth, associated with the decline in rain-fed agricultural production, can generate episodic and substantial food deficits, leading to food security and, in extreme cases, famines. Both supplementary and dry-season irrigation strategies are recognized as key pathways to increase agricultural production and improve the resilience of food production to climate variability and change. The “Small Irrigation Strategy of Niger” (SPIN, 2020) aims to increase irrigated agricultural production through the development of water and land resources in all regions of the country.

Climate Change: Studies of rainfall patterns in northern Nigeria from 1990 to 2015 indicate a trend towards wetter conditions and increased rainfall intensity, particularly towards the end of the rainy season in August and September. These trends are consistent with the region’s emergence from the multi-decadal Sahelian drought and amplification of precipitation extremes caused by global warming. Long-term rainfall data from Kano over the period of 1905 to 2000 reveals mean annual rainfall of 821 mm but also decadal-scale variations. The early 20th century experienced high precipitation levels, with peaks in the 1930s and 1950s, and a resurgence in the 1990s, aligning with the regional trend of increased precipitation after the Sahelian drought. Annual rainfall ranges from ~410 mm to 1291 mm. Such variability underscores the need for adaptable agricultural and water management strategies to accommodate extremes and ensure sustainable resource use. Recent trends towards greater rainfall have implications for local agriculture and water management in Katsina, offering benefits such as extended growing seasons but also posing challenges, especially with the amplification of rainfall extremes, through an increased risk of flooding.

Land-Cover Change: In the Jibiya and Katsina, substantial Land-Cover Change (LCC) has driven environmental and socio-economic transformations. The construction of the Jibiya Dam in the mid-1980s dramatically altered the landscape, reducing agricultural land from ~898 km^2 in 1986 to ~675 km^2 in 2010, while urban areas expanded from 6.2 km^2 to 10.1 km^2. Additionally, the dam increased the area covered by surface water from 8.9 km^2 to 35.7 km^2, impacting local hydrology and socio-economic conditions. These LCC changes highlight the need for sustainable land management to balance development and conservation efforts in the region (Funtua & Musa, 2020).

In the RGMB, as result of rapid population growth, perennial grasslands have also converted to the rainfed millet cropland. However, due to the topography of the surface geology, characterized by a relatively flat elevation, the modification of soil properties and infiltration capacities caused by clearing perennial vegetation has not led to sharp increases in surface runoff amplifying river flow and the size and number of ephemeral ponds. Thus, widespread connectivity of surface waters to aquifers has not been established. The magnitude and characteristics of LCC in the Nigerien side of the RGMB remain unclear (Fig. 10). The conversion of perennial grasslands to shallow root crops in western Niger from 1980 to 2000 led to an increase in surface runoff and groundwater levels through reductions in ET (Favreau et al., 2009). Field observations and anecdotal evidence from the RGMB indicate an increased erosive power of river discharge, possibly due to an increased intensity of flood discharges.

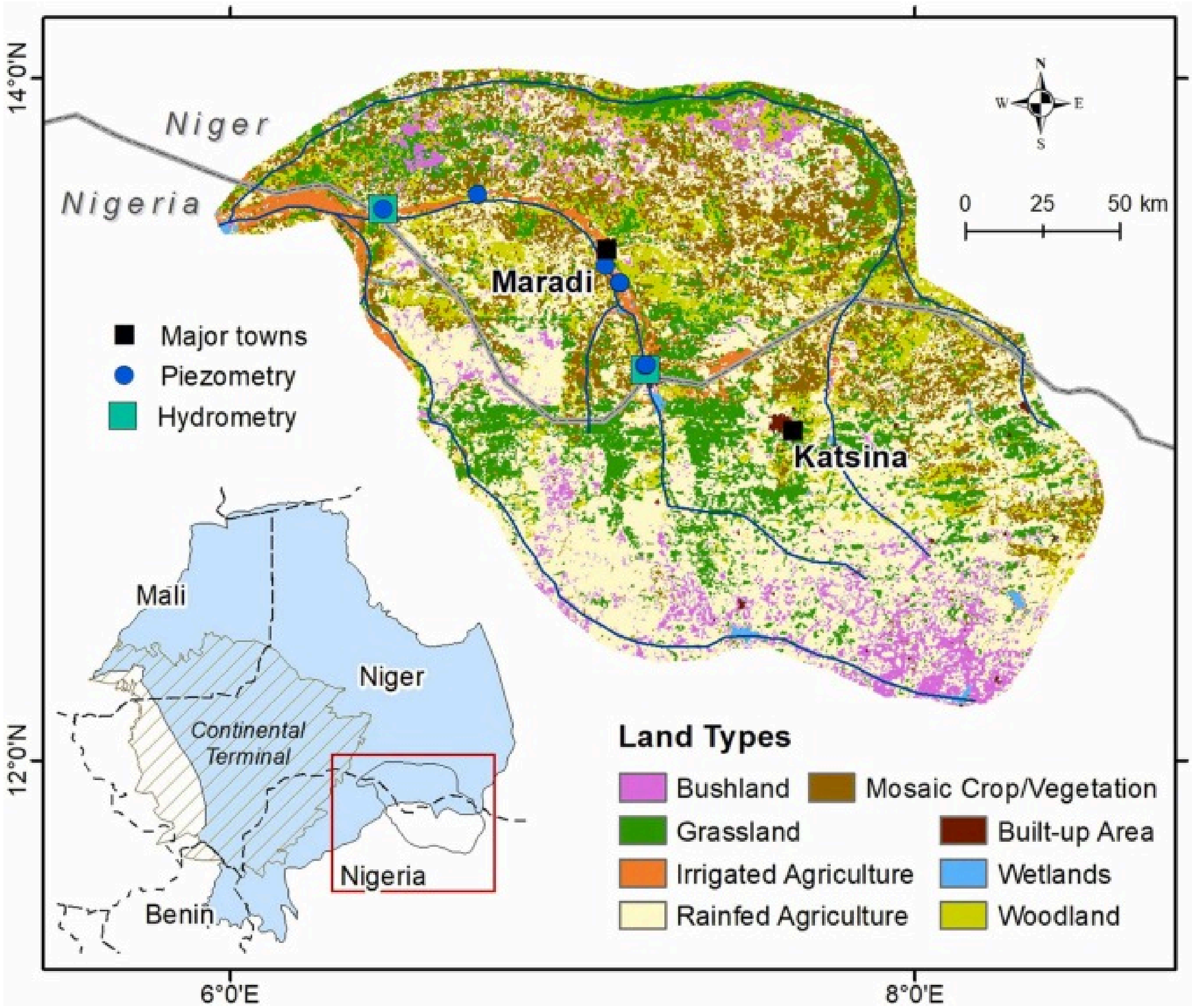

Figure 10: Map of land cover in the Iullemmeden observatory of southeastern Niger (Chandrasekharan et al., 2021); the position of this sub-catchment area (35,793 km^2) within the Iullemmeden Basin is indicated in the inset drainage map.

3.2 Impacts of Change

Political instability: Political instability, as exemplified by the recent coup d'état in Niger, presents significant challenges to transboundary water management in the River Goulbi Maradi Basin. Such instability can destabilize longstanding cooperative frameworks and disrupt the continuity of joint water management projects between nations. New administrations may revise or overhaul existing policies and regulations. Such shifts can lead to uncertainty regarding the continuity of agreements essential for managing shared water resources. These changes can affect everything from legal frameworks to operational guidelines, which are foundational for collaborative and efficient water use and conservation efforts across borders.

Agricultural growth: The promotion and projected adoption of irrigation by smallholder farmers in the RGMB in Niger and Nigeria increases water demand. Further, the intensification of agricultural production through the use of fertilizers and pesticides carries unclear consequences for water quality. Current access to water on valley floors via shallow alluvial aquifers is at risk from groundwater depletion and contamination. The sustainability and climate resilience of safe water and food systems requires investigation and clear policies to protect water access.

The development of irrigated crops desired by the Niger authorities will increase water needs. As a Sahelian country, the demand for water will be greater access to groundwater which suffers from the vagaries of climate change. Easy access to water in the valleys and especially the alluvial aquifer will not be without risk linked to exhaustion and their quality. It is therefore important to estimate the needs and transit time of water in order to rationalize pumping and minimize the risk of pollution due to fertilizers and pesticides. However, concentrations of iron and manganese exceeding the guideline value of the World Health Organization(WHO, 2022) respectively from 325 to 2870 µg/L and 80 µg/L were observed in the alluvial aquifer (Issoufou Ousmane et al., 2023). High concentrations of these two elements appear to be associated with redox reactions of groundwater under anoxic conditions at a pH ranging from 6 to 7, consistent with irrigation activities practiced in the area. This could pose threats to the drinking water supply of populations. However, health consequences of excess Mn and Fe have not yet been reported in the region.

Climate change: Climate change is manifesting in the River Goulbi Maradi Basin through increasingly episodic river discharges and more frequent and intense flood events, necessitating the development of enhanced systems for capturing and storing floodwaters to bolster water security during dry periods. Altered rainfall patterns, especially during the monsoon season, are escalating the need for supplementary irrigation to support agriculture, highlighting the importance of utilizing shallow groundwater resources as a supplementary water source. Integrating strategies such as rainwater harvesting, greywater recycling, and artificial recharge zones are expected to be critical to ensuring the climate resilience of water supplies that can adapt to increased variability in rainfall and sustain safe water supplies in the basin.

Land-Cover Change: Rising groundwater levels in regional aquifer systems such as the Continental Terminal of western Niger have been attributed to land-cover conversion from grasslands to short-root crop (Figs. 4, 10) that occurred during the Sahelian drought (The Sahelian Paradox, Favreau et al., 2009). Rises in river discharge (and groundwater levels) observed in western Niger in response to LCC (The Sahelian Paradox, Favreau et al., 2009) are not apparent in the RGMB, despite the decrease in vegetation cover observed in the area, following the gradual extension of rain-fed cultivation zones.

4. Water Governance

This section explores the governance structures and policy frameworks that underpin the management of water resources in the transboundary RGMB. The evolution of these frameworks reflects a dynamic shift from local, uncoordinated efforts toward integrated, cooperative management strategies across national boundaries. This transformation is essential for promoting sustainable water use, equitable resource distribution, and the mitigation of conflicts in the basin. By examining both formal and informal governance mechanisms at various levels—from local to national and transboundary—this section aims to delineate the complexities and strategic approaches that characterize effective water resource management in this region.

4.1 Governance structures

The governance and policy framework for water resource management in the River Goulbi Maradi Basin, spanning Niger and Nigeria, has evolved to address the complex challenges posed by a transboundary water system. Historically, the policies have transitioned from uncoordinated local management practices to more integrated and cooperative transboundary approaches. This shift aims to ensure sustainable water use, equitable resource distribution, and conflict mitigation.

Both countries operate under a mix of formal legislation and informal, customary laws that govern land and water use. Formal laws include national water laws and international treaties on transboundary waters. Informal practices often guide local water distribution and conflict resolution, especially in rural areas where traditional norms are strong.

Transboundary institutions:

The Niger Basin Authority (NBA) plays a crucial role in coordinating water management efforts across member states, including Niger and Nigeria (Fig. 11). While the NBA applies to both countries, federal and state ministries of water resources oversee the implementation of water policies at local levels, often integrating traditional practices with formal strategies.

The Iullemmenden Aquifer System (IAS) Consultation Mechanism is a consultation framework between Niger, Nigeria and Mali, through which the 3 countries have engaged in a process of concerted management of water resources. Through this process, they plan to cancel, if not reduce, these risks that threaten the quantity and quality of groundwater in the IAS.

Nigeria-Niger - Joint Bilateral Commission (NNJC) is responsible for "promoting and coordinating joint research program projects aimed at developing the water resources of the two contracting parties". The Commission enabled the identification of two priority projects relating to water transfer, including the transfer of water to Niger from the Jibiya Dam (Nigeria).

Figure 11: Niger-Nigeria water summit in Niamey of transboundary organizations under *GroFutures*.

National Level:

● The Minister of Hydraulics, Sanitation and the Environment of Niger is responsible for the design, development, implementation, monitoring and evaluation of the national water policy. water and sanitation As such, it defines, designs and implements policies, strategies, development projects and programs in the areas of water, hygiene, sanitation and sanitation. the environment.
● The Ministry of Agriculture and Livestock of Niger is responsible for the design, development, implementation, monitoring and evaluation of the national policy on the development of agriculture and livestock, in accordance with the guidelines defined by the government.
● Federal Ministry of Water Resources (Nigeria): This body is responsible for formulating and implementing policies related to water resources management throughout Nigeria, including transboundary water bodies.● Nigeria Hydrological Services Agency (NIHSA): Manages hydrological and hydrogeological data that are crucial for planning and

development purposes in regions like Jibiya.
● National Office for Hydro-Agricultural Infrastructures (Office National des Aménagements Hydro-Agricoles, ONAHA) in Niger has the mission of ensuring delegated irrigated project management, monitoring and the provision of engineering support and services for public irrigated areas.

State and Local Level:

● The Regional Directorates of Hydraulics, Environment, Agriculture, Livestock, and Rural Engineering of Maradi are the local representations of the Technical Ministries of Niger in the Maradi region. They carry out the sovereign missions of their respective supervisory ministries.
● Katsina State Ministry of Water Resources: Works on the implementation of water projects and policies at the state level, often coordinating with federal and local agencies.
● Local Government Authorities in Jibiya: These are involved in the direct implementation of projects and the day-to-day management of water resources, which includes dealing with local water supply and sanitation issues.

Strategic Frameworks:

● Conjunctive groundwater and surface water management
● Agriculture/Irrigation/Food Security
● Poverty Reduction
● Environmental Conservation
● Energy Production including hydroelectric projects
● Land Use Planning: Policies to coordinate land and water use, preventing conflicts and optimizing use of resources

Key policy entry points

● Engage Ministries of Hydraulics, Sanitation, Environment, Agriculture and Livestock in Niger and both federal and state Ministries of Water Resources, Environment and Agriculture in Nigeria.

● Enhance the capacity and authority of the Niger Basin Authority (NBA) to enforce water management policies and ensure compliance across both countries. This could include clearer mandates, better resource allocation, and more robust enforcement mechanisms.

● Align national laws and regulations concerning water use, environmental protection, and land use with international treaties and agreements to which both countries are signatories. This will reduce conflicts and streamline management processes.

● Increase local community involvement in water management decisions through participatory approaches. This should include empowering local governments and community groups with the knowledge and resources to manage their water needs effectively.

● Implement IWRM strategies that consider the interconnections between water, land, and people. This includes cross-sectoral planning that incorporates agriculture, urban development, and industry needs, focusing on sustainability and efficiency.

● Develop and integrate climate change adaptation strategies into water management policies to address the variability in water availability due to changing climate patterns. This could involve investing in climate-resilient infrastructure and technologies.

● Improve water-related infrastructure to enhance water storage, delivery, and irrigation systems. This includes repairing and upgrading existing facilities like dams and canals, as well as developing new infrastructure where necessary.

● Establish and maintain comprehensive monitoring systems to assess water quantity and quality. Encourage data sharing between Niger and Nigeria to improve water management decisions based on accurate and timely information.

These policy entry points aim to foster a more cooperative and integrated approach to managing the transboundary water resources of the River Goulbi Maradi Basin, enhancing the socio-economic well-being of the populations in both Niger and Nigeria.

4.2 Potential collaborators and “change makers”

Below is a list of potential sources of information, collaborators and change makers with whom the research team will partner. Identifying and engaging with 'champions' or 'change makers' is a critical strategy for effectively disseminating research findings and influencing policy and practice. the following champions and change makers are identified:

Sector Expertise: Look for individuals who are respected experts in water management, agriculture, climate change, and related fields. These might include academicians, researchers, and professionals who have a deep understanding of the issues and are recognized as thought leaders.

Government Officials: Target high-ranking officials in relevant government departments such as the national (in Niger), federal and state Ministry of hydraulics, Water Resources, Ministry of Environment, and Ministry of Agriculture. These individuals have direct influence over policy decisions and can champion initiatives within government circles. Federal and state legislatures

NGO and Civil Society Leaders: Leaders of prominent NGOs and civil society organizations often have networks and platforms to amplify messages and mobilize community support. They can be instrumental in advocating for policy changes and ensuring community buy-in.

Industry Representatives: Include representatives from the agricultural sector, water management companies, and related industries who can provide a practical perspective and drive adoption of recommendations within their practices.

Local Community Leaders: Engage leaders from local communities who are directly affected by the issues being studied. These may include mayors of local communities in Niger, traditional customary leaders, heads of local water user associations, village heads, and influential local figures who can sway public opinion and encourage grassroots support.

Media structures and Personalities: local communities radio leaders, Journalists and media personalities who specialize in environmental, agricultural, or policy-related reporting can help disseminate information widely and shape public discourse around the project's themes.

International Development Partners: Representatives from international bodies such as the World Bank, United Nations, or regional development banks, representatives of bilateral cooperation who are involved in funding or advising on similar projects and program can provide valuable support and international leverage.

Academic Institutions: Collaborators from universities and research institutes can help in vetting the research findings and providing the necessary academic rigor to ensure the recommendations are informed by science.

Policy Think Tanks: Experts from think tanks that focus on policy analysis and advocacy in the relevant sectors can offer insights into how best to navigate policy environments and influence decision-makers.

Identified ‘champions’ will be engaged through tailored communication, showing how the research findings and recommendations align with their interests and goals. Regular updates, involvement in key meetings, workshops, and public forums will be essential to keep them engaged and motivated to support the initiative. This approach not only facilitates the sharing of findings with decision-makers but also enhances the likelihood of meaningful impact on policy and practice.

5. Identifying Solutions

5.1 Evolving freshwater demand

Historically, in rural areas like Jibiya and the broader Katsina State, freshwater demand has been primarily for agricultural purposes, reflecting the region's agrarian economy. This includes irrigation for crops and livestock watering. In urban areas, the demand has been more diversified, including domestic use, sanitation, and industrial needs, driven by a growing urban population and economic activities.

Currently, water demand has escalated due to population growth and economic development in both rural and urban settings. Recent trends have shown a significant rise in water needs due to the influx of people displaced by conflicts in surrounding rural areas seeking refuge in Jibiya and Katsina. This migration from rural zones, where conflict has uprooted communities, to urban centers increases the strain on existing water infrastructure. As such, the urban and peri-urban areas of Jibiya face critical challenges in managing and sustaining water supplies for an increasingly diverse population that includes both long-term residents and newcomers displaced by rural conflicts. This situation highlights the need for enhanced water management strategies that can adapt to the dynamic demographic shifts and ensure reliable water access for all segments of the population.

Projections of freshwater demand indicate a continued rise across both rural and urban areas. Urban demand is expected to grow significantly as cities expand and industrial activities increase. Rural areas will also see increased demand, particularly for irrigation as agricultural practices intensify to meet food security needs and increase the resilience to climate change of traditional rain-fed agriculture.

5.2 What needs to change?

● There is a critical need for better management strategies to address the increasing demand and variability in water availability. This involves more efficient water use in agriculture, industry, and domestic contexts.

● Significant investments are needed to upgrade and expand water infrastructure, including storage facilities, distribution networks, and treatment plants. This will ensure reliable potable water supply systems that can meet growing demands.

● Adoption of sustainable water practices is crucial. In rural areas, this could include low-intensity irrigation methods such as drip irrigation that conserve water. In urban areas, water recycling and reuse systems can significantly reduce freshwater demand.

● Strengthening policies that govern water use, promoting equitable distribution of water, enforcing regulations on water quality, and encouraging investments in water-related infrastructure are essential steps.

● Educating communities about water conservation and management can lead to more sustainable practices at the local level. Community involvement in water management decisions can also ensure that solutions are tailored to meet local needs effectively.

These changes are essential to ensure that water demand in rural and urban areas of Jibiya and Katsina town respectively is managed in a sustainable manner, balancing growth and development with conservation and equitable access to water resources.

5.3 How does the research address these needs?

Approaches to identify and characterize equitable, sustainable and climate-resilient development pathways in the Maradi-Katsina T-Lab are expected to engage with some or all of the following innovative strategies and policy recommendations:

Co-development of Knowledge and Innovation: The research advocates for a collaborative approach to knowledge generation, involving local communities, policymakers, and researchers. This co-creation of knowledge fosters a better policy environment and co-solutions that are culturally appropriate and technically feasible. By integrating local insights with scientific research, the solutions become more adaptive to the specific challenges faced by these regions.

Improving Smart Agriculture: The research underscores the importance of smart agricultural practices such as precision farming, which utilizes advanced technologies to optimize water use and crop yields. By recommending policies that support the adoption of such technologies, the research aligns with goals to enhance agricultural productivity while conserving water.

Optimizing Water Supply and Utilization: Highlighting the need to optimize water resources, the research supports the development of more efficient water supply systems. This includes the improvement of infrastructure to tap into underutilized water sources like the regional CH aquifer, which could significantly enhance water availability, especially for irrigation purposes remote from the River Goulbi Maradi.

Identifying and Strengthening Local Strategies: The research calls for identifying and bolstering local strategies that promote inclusive and sustainable water usage. This involves supporting traditional practices that have been effective while integrating them with modern technologies and approaches to ensure they meet current and future demands.

Increasing Drinking Water Supply and Supporting Livestock Husbandry: By focusing on enhancing drinking water supply and supporting sectors like livestock husbandry through the use of shallow groundwater for seasonal irrigation, the research connects these actions with expected increases in water demand. These sectors are critical for the livelihoods in Jibiya and Katsina, and their sustainable development is crucial for economic stability.

Policy Linkages: The research makes a strong case for linking these practical solutions to policy initiatives. This includes advocating for policy frameworks that support sustainable water management practices, such as the expansion of infrastructure, adoption of water-saving technologies, and the enforcement of water quality regulations.

6. Key documents and data

6.1 Policy documents

- PNUD / MHE/LCD (2002) : Etude du cadre juridique et institutionnel relatif aux unités de gestion des eaux (UGE), pp. 80-110.
- PNUD / MHE/LCD (1997) : Schéma directeur de mise en valeur et de gestion des ressources en eau, « le référentiel » du secteur de l'eau et de l'assainissement au Niger, 315p.
- Haut-Commissariat à l'Initiative 3N (2012) : Initiative 3N, pour la Sécurité Alimentaire, Nutritionnelle et le Développement Agricole Durable, « Les Nigériens Nourrissent les Nigériens », Cadre stratégique et coût estimatif 2012-2015, 18 avril 2012, 59 p.
- Ministère de l'Agriculture (2013) : Stratégie de la Petite Irrigation au Niger (SPIN), Partie 1, Version provisoire, septembre 2013, 83 p.
- Ministère de l'Elevage (2013) : Stratégie de développement durable de l'Elevage (SDDEL 2013-2035), mai 2013, 77 p.
- Ministère de l'Environnement et de la Lutte contre la Désertification (2007) : Stratégie de Développement de la Pêche et de l'Aquaculture, mars 2007, 48 p.
- Ministère de l'Hydraulique et de l'Assainissement (2014) : Document de «Stratégie Nationale de l'Hydraulique Pastorale (SNHP)», 4 juillet 2014, 116 p.
- Ministère de l'Hydraulique et de l'Assainissement (2014) : Document de « Stratégie Opérationnelle de Promotion de l'Hygiène et de l'Assainissement au Niger 2014-2018», juillet 2014, 44 p.
- Ministère de l'Hydraulique et de l'Assainissement (2016) : programme sectoriel de l'eau et de l'assainissement (PROSEHA) 2016-2030
- Ministère de l'Hydraulique et de l'Assainissement (2017) : Plan d'Action National de la Gestion Intégrée des Ressources en Eau (PANGIRE), mai 2017, 158 p
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- Ministère de l'Hydraulique et de l'Environnement (2001) : Politique et stratégies pour l'Eau et l'Assainissement : de l'eau pour un développement durable, mai 2001, 54 p.

- Ministère de l'Intérieur, de la Sécurité Publique, de la Décentralisation et des Affaires religieuses (2012) : Document-Cadre de politique nationale de la décentralisation 2012-2022, Version finale, mars 2012, 48 p.
- Ministère du Développement agricole (2005) : Stratégie Nationale de Développement de l'Irrigation et de collecte des Eaux de ruissellement (SNDI/CER), juillet 2005, 84 p.
- Ministère du Plan, de L'Aménagement du Territoire et du Développement communautaire (2015) : Plan Développement Economique et Social (PDES) 2012-2015, 276 p.
- National Water Resources Bill
- Nigeria's National Water Resources Master Plan
- Nigeria's National Policy on Environment
- State Water Policies
- Transboundary Water Agreements
- Erosion and Watershed Management Project (NEWMAP) Documents: Specific projects like NEWMAP that address water management and environmental challenges through funding and strategic interventions.
- Development Plans from International Donors and Development Banks: For instance, World Bank projects related to water management and sanitation that provide both financial and technical support.
- Reports and Studies from Local Universities and Research Institutes
- Nigeria's National Policy on Climate Change
- Nigeria's Intended Nationally Determined Contribution (INDC)
- National Adaptation Strategy and Plan of Action on Climate Change for Nigeria (NASPA-CCN)
- Sectoral Policies in Agriculture, Energy, and Urban Development: These policies often intersect with water management under climate change, as they address issues like irrigation needs, energy production from hydroelectric sources, and water supply for growing urban centers under shifting climatic conditions.

6.2 Hydroclimatological monitoring

Groundwater-level measurements: The first piezometric measurements in the River Goulbi Maradi Basin were initiated in the 1970s by the Office Des Eaux de Sous-Sol (OFEDES). These measurements were carried out using 30 cement dug wells. The data available for these dug wells include 1 piezometer in the Continental Hamadien and 6 within the alluvial aquifer (Fig. 12, purple cube), which were measured in June, July, September, November, and December 1977. For some of these piezometers, measurements continued until 2018. From 1991 to 2000, as part of the Programme Hydraulique Niger Suisse (PHNS), piezometric measurements were taken every 15 days during the rainy season and once a month during the dry season.

From 2000 to 2010, piezometric measurements were taken from 17 piezometers installed by the Agence Nigérienne de Promotion de Petite Irrigation (ANPIP), which later became the Programme de Petite Irrigation (2003-2005) (PIP2). More recently, in 2015, as part of the Plan d'Action Nationale de Gestion Intégrée des Ressources en Eau (PANGIRE), a larger network of 65 monitoring wells comprising 26 piezometers, 38 cemented dug wells and 1 hand-dug borehole was established; 10 of these piezometers (Fig. 12, green cube) were equipped with Global Logger 16 (WL16) automatic loggers (Global Water Instrumentation, Inc.) with a twelve-hour (12 h) measurement interval between two measurements, and 3 other piezometers were equipped with automated water-level dataloggers. In addition, all these piezometers were levelled using a ProMark2 differential GPS. Data available for these piezometers are from 2015 to 2020. Under *GroFutures*, 10 new piezometers were realized (Figure 12, red cube), including 8 in the Nigerien part and 2 piezometers, produced for the first time in Jibiya, in the Nigerian part of the basin. Data available for these sites are from 2017 to 2022.

River discharge measurements: Hydrometric measurements on the River Goulbi Maradi began in the 1960s. Between 1960 and 1980, there were six stream-gauging stations (Figure 12). Currently, two stations are operational (Nielloua, Souloulou). River flow data are available from 1960 to 2004; river stage data from 1985 to 2022. Figure 13 shows the estimated annual discharge at Niélloua from 1961 to 2004. The flow ranges from 40 to 650 Mm^3/year, with a standard deviation of 135 Mm^3/year and an interannual mean of 200 Mm^3/year; the three lowest annual flows are recorded in the last decade of this time series (1994, 1997, 2003). Rises in river discharge (and groundwater levels) observed in western Niger in response to LCC (The Sahelian Paradox, Favreau et al., 2009) are not apparent in the RGMB, despite the decrease in vegetation cover observed in the area, following the gradual extension of rain-fed cultivation zones. The transition towards greater variability in river discharges and lower low-flow years is a matter of concern.

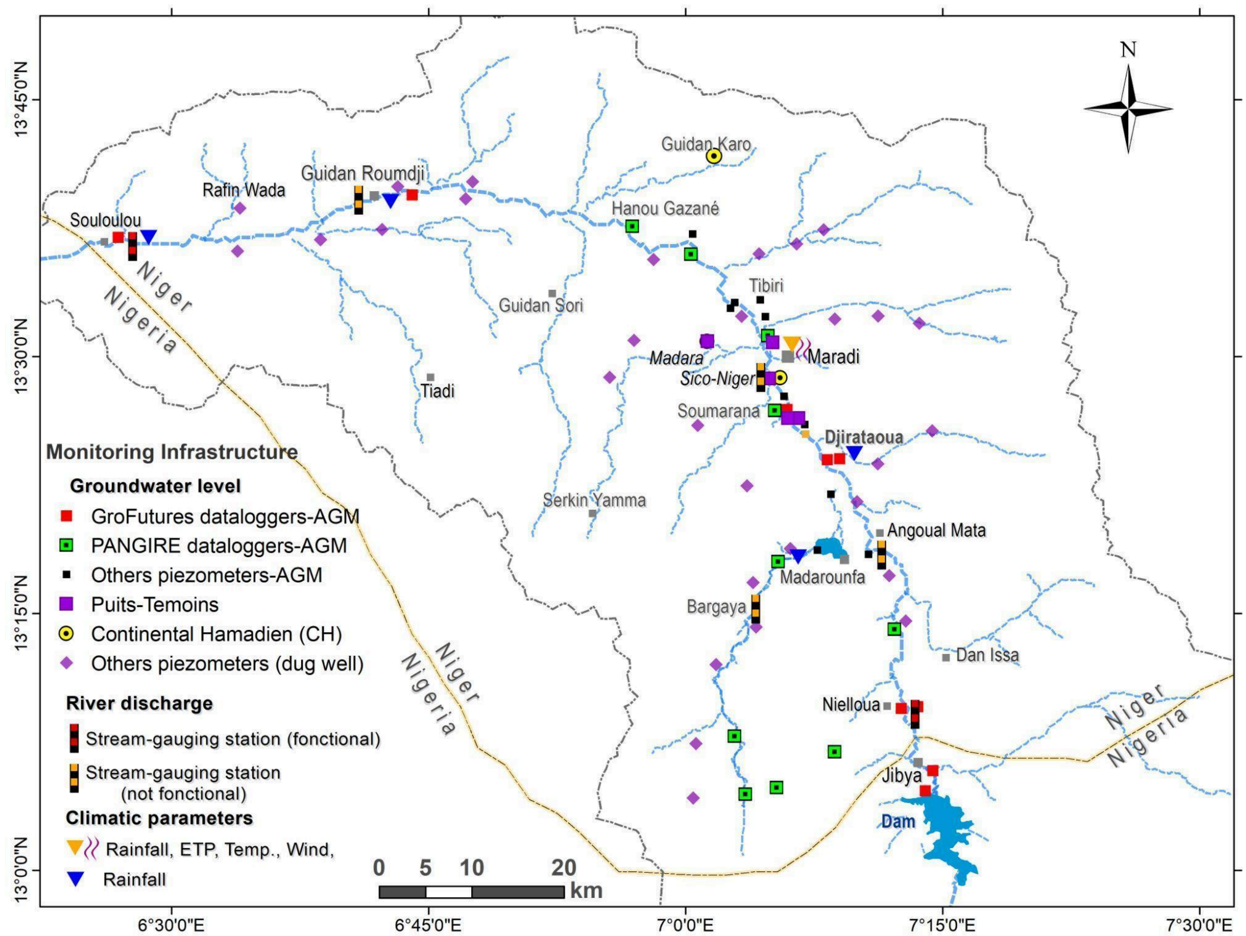

Figure 12: Map showing hydroclimatological monitoring infrastructure of the River Goulbi Maradi Basin. (AGM : Alluvium Goulbi Maradi).

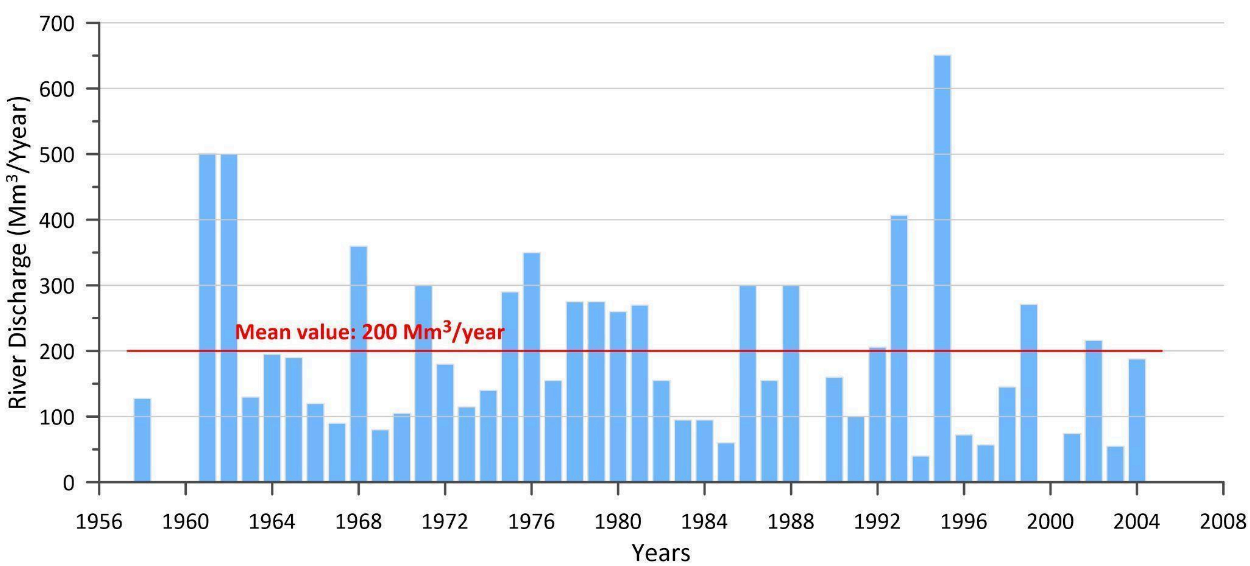

Figure 13: Annual discharge of the River Goulbi Maradi observed at Nielloua (Fig. 12); years without values represent data gaps, not zero discharge.

Rainfall measurements: Rainfall data are measured by the Direction de la Météorologie Nationale (DMN) at the synoptic station of Maradi airport and on the rain gauge of Madarounfa Djirataoua and Guidan Roumdji located in Figure 12. For rain gauges, annual data exist from 1953 to 2021 for Madarounfa and from 1961 to 2021 for Guidan Roumdji. For the synoptic station of Maradi, monthly data were collected from 1960 to 2021.

The rainfall pattern in Jibiya-Katsina, is characterized by a seasonal distribution with the majority of the rainfall occurring between July and September, and minimal to no rainfall from November to April. Historical data from 1971 to 2010 show an overall increase in rainfall, particularly during the later months of the rainy season, aligning with a shift towards wetter conditions identified in regional climate trends. From 1990 to 2015, the average annual rainfall was approximately 518 mm, reflecting a consistent pattern across these decades. The typical annual rainfall in more recent years has been around 716 mm, indicating a potential increase in total annual rainfall. This information suggests significant implications for water management and agriculture in Jibiya, necessitating adjustments to accommodate the increased rainfall and mitigate potential impacts of flooding, especially given the area's positioning in the Sahel, a region known for its distinct wet and dry seasons (Suleiman et al., 2020).

Potential Evapotranspiration and Air Temperature: Data on potential evapotranspiration and temperature are measured specifically at the synoptic station of Maradi. Data available are mean monthly air temperature from 1950 to 2014, air humidity from 2009-2017, and potential evapotranspiration from 1984 to 2003.

7. Summary

In the complex, adaptive socio-hydrological system that exists in the eastern Sahel of Niger and Nigeria along the Maradi-Katsina/Jibiya corridor, connected by the River Goulbi Maradi, the challenge of identifying equitable, sustainable and climate-resilient solutions to meet rapidly growing freshwater demand is considerable. Notwithstanding observed trends towards higher rainfall totals following the termination of the multi-decadal Sahelian drought, the amplification of rainfall extremes from daily to seasonal timescales requires strategies that can better capture flood discharges and improve the resilience of safe water supplies to more frequent and prolonged drought conditions. Competition for scarce water resources under drought conditions heightens the potential for conflict among irrigators, transhumant herders, industry and public (municipal) water supplies not only within communities but also between communities upstream and downstream of the border between Niger and Nigeria along the River Goulbi Maradi. Insecurity and the increased frequency of rainfall extremes continue to inhibit growth in agricultural production.

A critical concern is how seasonal or episodic water scarcity impacts less-powerful stakeholders and the extent to which the views and aspirations of historically marginalized communities including women are considered not only in water governance but also national and regional government policies seeking to increase food production. Under conditions of inadequate water governance, there is also growing concern and evidence that efforts to intensify food production through use of fertilizers and pesticides are jeopardizing the availability of safe water for drinking and irrigation.

Considerable uncertainty persists around the viability of potential supply-side solutions seeking to exploit deeper groundwater within the weathered crystalline basement complex in northern Nigeria and a regional sandstone aquifer, the Continental Hamadien, underlying the Maradi region of Niger. Indeed, questions persist around the dimensions of these sources and their renewability, both in terms of the pathways to replenishment and their magnitude. Opportunities for collaborative, conjunctive use of groundwater and surface water in the hydrological corridor connecting Maradi and Katsina remain unexplored.

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