WATER RESOURCES PROFILE SERIES

The Water Resources Profile Series synthesizes information on water resources, water quality, the water-related dimensions of climate change, and water governance and provides an overview of the most critical water resources challenges and stress factors within USAID Water for the World Act High Priority Countries. The profile includes: a summary of available surface and groundwater resources; analysis of surface and groundwater availability and quality challenges related to water and land use practices; discussion of climate change risks; and synthesis of governance issues affecting water resources management institutions and service providers.

Madagascar Water Resources Profile Overview

Madagascar is water abundant and is not considered water stressed at a national scale; however, there are regional water availability and water quality challenges. The total annual renewable water resources endowment per person is just over 13,000 m^3, approximately eight times higher than the Falkenmark Water Stress Index[i] threshold for water stress. Similarly, the total volume of freshwater withdrawn by major economic sectors amounts to only 11 percent[ii] of its total resource endowment. However, the south is considerably drier, and more water stressed than northern and central Madagascar. Most rivers in southern Madagascar disappear during the dry season and alternative groundwater sources are not always viable. Climate change-induced droughts also increase water stress.

Deforestation in the Central Highlands from slash and burn agriculture, logging, animal husbandry, and firewood collection contribute to some of the highest levels of erosion in the world as well as extreme flooding. Naturally high precipitation rates, especially on the northern half of the island, and the presence of steep gullies called *lavakas* throughout the western central plateau compound these risks and impact surface water quality and biodiversity.

Inadequate municipal sanitation systems, including in Antananarivo, have resulted in fecal contamination of groundwater. Additionally, small-scale gold and gemstone mining, and larger nickel, chromium, and cobalt mines have contributed to chemical contamination of groundwater.

More intense cyclones and rising sea levels caused by climate change directly threaten coastal communities and intensify flooding and erosion in coastal areas. Further, rising sea levels are contributing to increased saline intrusion in low-lying coastal alluvial aquifers.

Surface and groundwater quality and hydrometric data are not comprehensive or routinely collected, which impedes decision making for integrated water resources management (IWRM), particularly at the commune level.

Water resources management is decentralized; however, key IWRM decisions are still taken by the central government due to funding and human resources constraints within sub-national institutions.

[i]The Falkenmark Water Stress Index measures water scarcity as the amount of renewable freshwater that is available for each person each year. A country is said to be experiencing water stress when water availability is below 1,700 m^3 per person per year; below 1,000 m^3 is considered water scarcity; and below 500 m^3 is absolute or severe water scarcity.

[ii]SDG 6.4.2 measures water stress as the percentage of freshwater withdrawals against total renewable freshwater resources. The water stress thresholds are: no stress <25%, low 25%-50%, medium 50%-75%, high 75%-100%, and critical >100%.

Water Resources Availability

KEY TAKEAWAYS

- Wet and dry season precipitation patterns significantly influence water availability. Eastern Madagascar receives steady rainfall year-round. Precipitation in southern Madagascar is more erratic and rivers are not perennial, leading to seasonal water stress.
- There are five main basins and most runoff drains through the Western and Eastern slopes, including the Betsiboka on the Western slope, which is Madagascar's longest river.
- Groundwater potential is lower in the Central Highlands and much of eastern Madagascar, whereas alluvial aquifers throughout western Madagascar are extremely productive.

This section summarizes key characteristics of surface and groundwater resources. Table 1 summarizes key water resources data and Figure 1 presents key surface water resources, wetlands, and dams.

Surface Water Resources

Madagascar has five main basins and most surface waters drain from the Central Highlands across two of the basins. The Western slope drains from the Central Highlands to the Mozambique Channel and contains the largest and longest rivers, including the Betsiboka. The Western slope also features four of the five largest lakes and ten of the twenty Ramsar sites.[6] The Eastern slope is significantly steeper and drains from the Central Highlands to the Indian Ocean.[7] Major rivers in the Eastern slope include the Mananara, Mangoro, and Maningory. The Amber Mountain/Northeast slope, the Tsaratanana slope, and the Southern slope are three smaller basins that drain into the ocean and Mozambique channel.[8] Southern Madagascar is semi-arid and has no perennial surface water, although seasonal rivers such as the Onilahy, Linta, Menarandra, Manambovo, and the Mandrare are important. During the wet season these rivers can have very high flow rates and rapid changes in river stage and flood levels. Surface water is particularly scarce on the Mahafaly Plateau (between the Onilahy and Linta Rivers) and throughout the Androy Region (between the Mandrare and Menarandra Rivers). In these regions, most precipitation infiltrates quickly into the soil and the largest rivers recede greatly or dry up completely during the dry season.

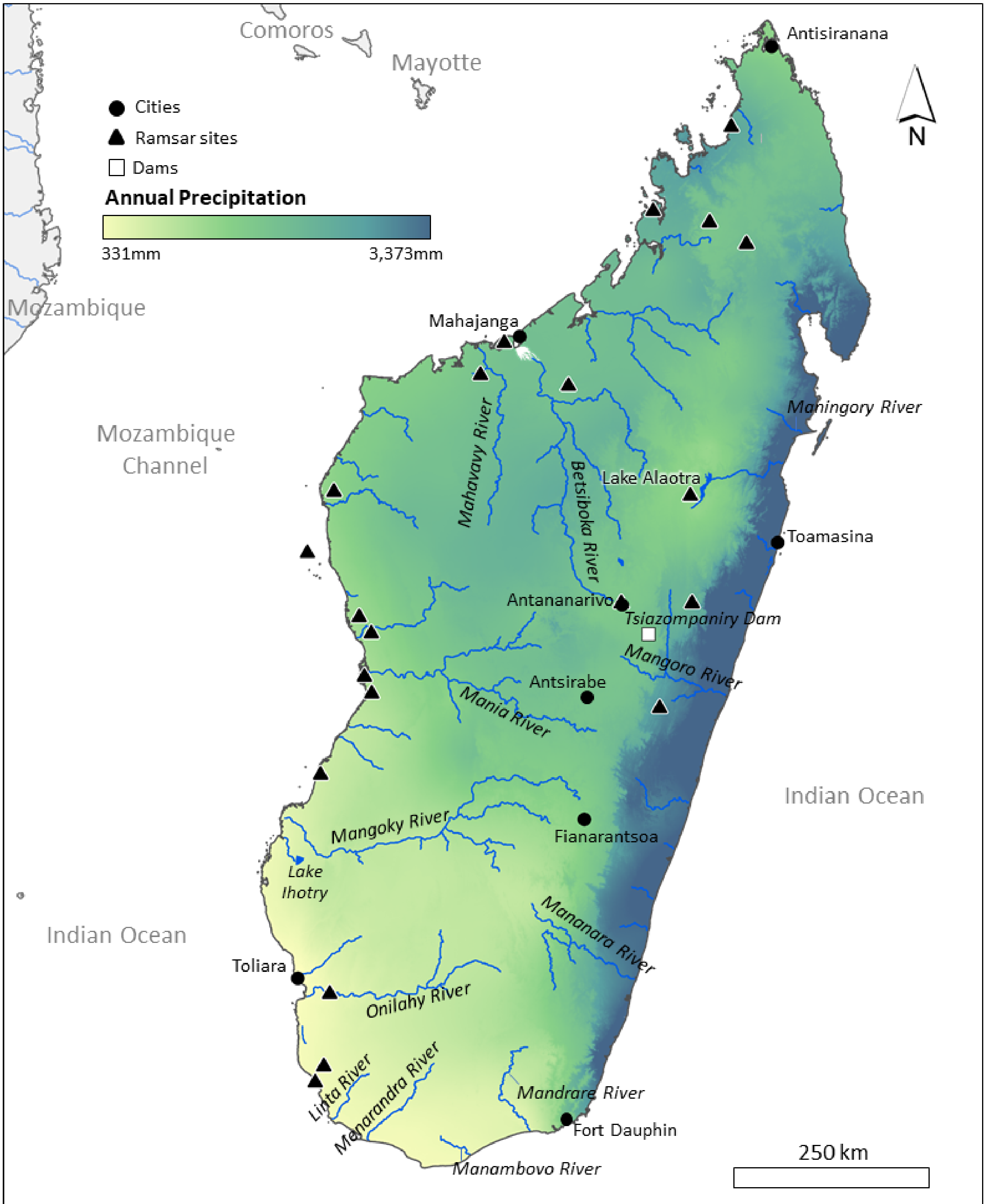
Groundwater Resources

Low to moderately productive aquifers within the crystalline basement underlie two-thirds of the country, predominantly in the Central Highlands and the east and productive sedimentary layers are found along the western coastal plains.[9] Well yields throughout the crystalline basement in central and northeastern Madagascar range between 1,800-3,600 liters per hour (L/h) with well depths less than 20 meters (m).[10] Wells depths along coastal plains and river valleys are similar or more shallow, though yields are significantly higher and range between 36,000 and 108,000 L/h.[9] Southern Madagascar's Mahafaly Plateau is considered to have moderate to high groundwater potential whereas aquifers in the Anosy Region have low potential. Groundwater recharge rates are high throughout most of Madagascar, especially along alluvial fans around rivers, although recharge rates in the Mahafly Plateau are only around 60 mm/year.[11]

TABLE 1. WATER RESOURCES DATA	Year	Madagascar	Sub-Saharan Africa (median)
Long-term average precipitation (mm/year)	2017	1,513	1,032
Total renewable freshwater resources (TRWR) (MCM/year)	2017	337,000	38,385
Falkenmark Index - TRWR per capita (m3/year)	2017	13,179	2,519
Total renewable surface water (MCM/year)	2017	332,000	36,970
Total renewable groundwater (MCM/year)	2017	55,000	7,470
Total freshwater withdrawal (TFWW) (MCM/year)	2002	13,560	649
Total dam capacity (MCM)	2015	494	1,777
Dependency ratio (%)	2017	0	22.78
Interannual variability	2013	1.4	1.55
Seasonal variability	2013	3.5	3.15
Environmental Flow Requirements (MCM/year)	2017	217,500	18,570
SDG 6.4.2 Water Stress (%)	2002	11.35	5.70

Source: FAO Aquastat

FIGURE 1: MAP OF WATER RESOURCES



Source:
Cities: World Cities – ArcGIS Hub, **Country Borders:** GADM, **Dams:** FAO Aquastat Dams Database, **Ramsar Sites:** Ramsar Sites Information Service, **Lakes and Wetlands:** WWF - GLWD (Level 1), **Rivers:** WWF – HydroRivers, **Precipitation:** WorldClim, **Flood and Drought:** WRI Aqueduct 2019

Surface Water Outlook

KEY TAKEAWAYS

- Wetland clearing for paddy rice irrigation, which accounts for most water abstractions, has impacted biodiversity and reduced water quality.
- Deforestation from slash-and-burn agriculture, logging, timber extraction for fuel, and cattle pasturage drive erosion and sedimentation of watercourses, which reduces water quality and strains ecosystems. Mangrove degradation is rampant and threatens water quality, biodiversity, and coastal livelihoods. Agriculture in and around wetlands contributes to eutrophication, which reduces oxygen levels and strains aquatic biodiversity.
- Poor sanitation systems, municipal waste disposal, and the direct discharge of untreated industrial effluent pollutes surface water with toxic and pathogenic contaminants in both rural and urban areas.

This section describes key sources of demand and uses of surface water, and associated challenges stemming from water availability and water quality challenges.

Irrigated rice cultivation in wetlands has significantly reduced natural coverage and biodiversity. Agriculture accounts for 96 percent of all freshwater withdrawals[3] and approximately 30 percent of the country's total cultivable land is irrigated.[8] Rice accounts for 70 percent of all agricultural production, of which 90 percent is irrigated in lowland areas and around prominent water bodies such as Lake Alaotra.[12,14] Madagascar is home to almost 5 percent of the world's biodiversity, with high environmental flow requirements (217,500 million cubic meters (MCM)/year) for wetlands and rivers.[8] Madagascar has lost over 80 percent of its natural wetlands due to rice irrigation and approximately 43 percent of all freshwater species are threatened, including waterbirds.[8,15–18] Few wetlands are unaffected by agriculture or other anthropogenic threats.[15]

Manufacturing and mining, primarily in the highland cities of Antananarivo and Antsirabe and in the eastern city of Toamasina, are key sources of demand.[13] Industrial abstractions are 162 MCM annually, primarily from surface water, with large-scale mining being a key water user.[3] Rio Tinto's mineral sands operations near Fort Dauphin on the south-eastern tip of Madagascar and Ambatovy in the east use significant volumes of freshwater for processing and refining nickel and cobalt.[13,19,20] Hydropower is an important non-consumptive use, as 70 percent of electricity is generated from 11 hydropower plants. However, only three plants have water storage capacity.[21]

Approximately 80 percent of the total domestic water demand depends on surface water.[13] Rivers are the primary water supply in the rainy parts of the highlands, the east coast, and in the north, while lakes and springs are used for water supply in the Central Highlands.[23] Surface water is also used during the short rainy season in the south, however, declining rainfall and more severe droughts have made surface water resources less reliable.[22,24]

Widespread erosion is degrading surface water quality and increasing flooding risks. Riverbank erosion and sedimentation of watercourses increases turbidity, reduces basin detention time, causes more severe floods, and reduces groundwater recharge and river base flow rates.[22] In the Central Highlands, erosion is caused by heavy precipitation runoff flowing down steep gullies, called lavakas.[25] Deforestation has also increased erosion and sedimentation of rivers, irrigation canals, and coral reefs.[8] Some regions have lost close to half of their forest cover in the past 40 years, largely due to agriculture, timber extraction for energy, and livestock grazing.[26] Tavy (slash-and-burn) rice farming, primarily along the Eastern slope, uses slash and burn practices to support dry rice cultivation, and 95 percent of Madagascar's population relies on timber for their energy needs.[27] In the past 20 years, 50,000 hectares/year of forest have been lost to agriculture and harvesting trees for charcoal and firewood.[28]

Clearing of coastal mangrove ecosystems have affected natural regulation of surface waters. Mangroves in northern and western Madagascar play a key role in runoff filtration, reducing sedimentation, and mitigating floods. Since 1990, 20 percent of mangroves have been cleared, largely for fuel, agriculture, and shrimp aquaculture.[29] Mangrove ecosystems have also been degraded by reduced freshwater inflows attributed to upstream irrigation and sedimentation.[27]

Agricultural runoff, decreasing water levels, and invasive species are creating hypoxic conditions in lakes and surrounding wetlands. Nitrogen and phosphorous runoff have led to algal blooms in surface water, including in Lake Ranomafana.[7,30,31] Lake Alaotra is showing signs of hypoxia as declining water levels and higher water temperatures deplete dissolved oxygen.[14] These conditions are worsened by elevated nutrient concentrations from agricultural runoff, which have increased significantly over the past few decades.[14] The proliferation of invasive species such as water hyacinths and water ferns are also exacerbating oxygen depletion.[14]

Untreated industrial wastewater and mining in the Eastern and Western slopes are contaminating surface water resources. Antananarivo and Antsirabe are centers of industrial activity in the upper catchments of the Eastern and Western slopes. Lead and chromium in rivers and lakes have been attributed to industrial effluent from textile factories and tanneries.[27] Large and small-scale mining operations have increased sedimentation and discharged toxic chemicals and heavy metals, including uranium and mercury, in surface water in the southeast, and in the Eastern, Amber Mountain/Northeast and Tsaratanana slopes.[30,32]

Limited sanitation systems drives non-point source pollution. Low access to improved sanitation, open defecation, and poor capacity for both solid waste and wastewater management are the leading sources of water pollution in urban areas and downstream surface water.[23,30] Ageing and poorly designed municipal solid waste sites and wastewater infrastructure cause localized groundwater contamination and downstream surface water pollution. Landfills are often limited in number, exceed their design capacities, have no leachate protection, and in some cases have been implicated in high concentrations of heavy metals in nearby wells.[7]

Groundwater Outlook

KEY TAKEAWAYS

- Groundwater in southern Madagascar is highly vulnerable to drought and is often the only viable water source for many communities.
- Pathogenic and nitrate contamination of groundwater is widespread in urban areas and stems from poor sanitation systems. Mining contributes to localized contamination from chemical toxins and increased salinity in coastal aquifers.

This section describes key sources of demand and uses of groundwater, and associated challenges stemming from water availability and water quality challenges.

Groundwater is the primary water source for about 20 percent of the population in rural and urban areas with annual abstractions totaling 104 MCM.[13,35] Groundwater use is high in the west where coastal, alluvial aquifers have significant potential. Groundwater is the principal water source in southern Madagascar for domestic, drinking, and agriculture uses; however, hydrogeological complexity, limited resources, and drilling capacity constrain access.[5,8,38,39]

Erratic precipitation and drought affect groundwater availability and community well-being in southern Madagascar. By the end of 2016, El Niño-driven droughts contributed to severe water and food insecurity, necessitating humanitarian assistance for over half the population in southern Madagascar (850,000 people).[40] Most wells in Tsihombe ran dry after three years of drought (2013-2016) while regional crop production was reduced by 95 percent of normal output.[39,41] Tropical storms and cyclones are also major groundwater recharge sources and can quickly influence groundwater levels, however, there is no national monitoring system to estimate fluctuations in groundwater availability.[42]

Inadequate sanitation systems contribute to widespread pathogenic and nitrate contamination of groundwater, while coastal, alluvial aquifers often have high salinity. Comprehensive studies on groundwater quality in Madagascar are limited.[23] A few groundwater quality studies in urban areas such as Antananarivo and Mahitsy City found significant nitrate contamination in groundwater, with most samples exceed WHO guidelines by a factor of 10.[43,44] Generally, nitrate concentrations were positively correlated with proximity to pit latrines, shallower water table depth, and older wells, while also having elevated chloride levels characteristic of sewage contamination. Groundwater quality testing in rural areas in northeastern coastal municipalities suggest that nitrate contamination is not widespread, although low pH, high concentrations of iron, and salinity were identified in some wells.[45] In the southeast, insecticides used to control malaria have been detected in groundwater, as well as uranium originating from Rio Tinto mines.[32,46] Iron concentrations are generally high across the highlands and throughout coastal aquifers.[47] Saline intrusion occurs naturally in coastal alluvial aquifers, rendering water unsuitable for human consumption, particularly in southern Madagascar and in the Androy Region.[5,48,49]

Water Resources and Climate

KEY TAKEAWAYS

- Precipitation intensity and flooding are expected to increase throughout Madagascar, while total rainfall is expected to decrease. Severe drought is also projected to increase, particularly in southern Madagascar.
- While the frequency of cyclones impacting Madagascar is expected to decrease, their intensity will increase.
- Rising sea levels threaten coastal communities, groundwater quality, and mangrove vitality, although the projected extent of these impacts in Madagascar is not well understood.

This section covers the climate variability and climate change, their impacts on water availability and water quality, and the risks they pose to local communities and their economies.

Madagascar is one of the world's most vulnerable countries to climate change. Flood risks, rainfall intensity, and severe drought are projected to increase. Southern Madagascar experiences water shortages due to temporal and spatial disparities in rainfall.[3] The far north and east coasts receive over 3500mm of precipitation annually whereas the drought-prone south receives just 380mm/year, with surface and groundwater shortages occurring in the dry season.[4,5] Madagascar's daily temperatures have increased since the 1950s, particularly in the dry season.[50] Average temperatures are expected to increase by 2.5°–3°C by 2100.[51] Sea levels also rising 7 to 8 mm annually.[52]

Climate change is leading to wetter, more storm-prone rainy seasons in the humid regions, and prolonged dry periods in the south. Overall precipitation is expected to decrease nationally,[51,53] however, heavy rainfall events will be more frequent and more intense, which will increase flooding.[49,53] The dry and semi-arid western and southern regions have been affected by low and variable precipitation and a marked increase in evapotranspiration rates.[22] Drought is also projected to be more frequent and severe later this century,[53] particularly in the south and southwest, which have experienced seven droughts since 1981.[24,27] As of 2021, an ongoing drought has devastated rainfed agriculture and pushed 1.3 million people into famine in the south.[54]

Cyclones will likely become less frequent but more intense. Madagascar experiences three to four cyclones annually between December and March. These storms typically strike the north and east, but often affect the entire country.[24] Between 1990 and 2013, 13 million people were affected by 65 major climate related disasters including 50 cyclones,[55] causing an estimated $1 billion in damages, affecting food security, drinking water supply, irrigation, public health systems, environmental management, and quality of life.[56] In 2017, Cyclone Enawo damaged or destroyed 250 water systems and contaminated more than 1,300 wells.[24]

Rising sea levels may increase saline intrusion of coastal aquifers and inundate mangrove ecosystems. Infrastructure, mangrove ecosystems, and coastal wells may be affected by sea level rise and coastal erosion through direct inundation and increasing salinization of water sources.

FIGURE 2: DROUGHT RISK

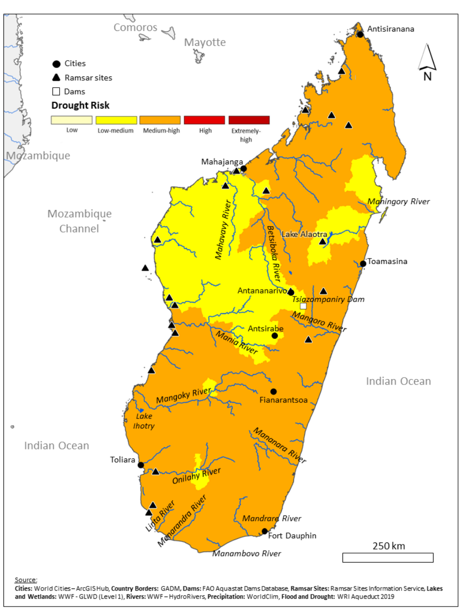
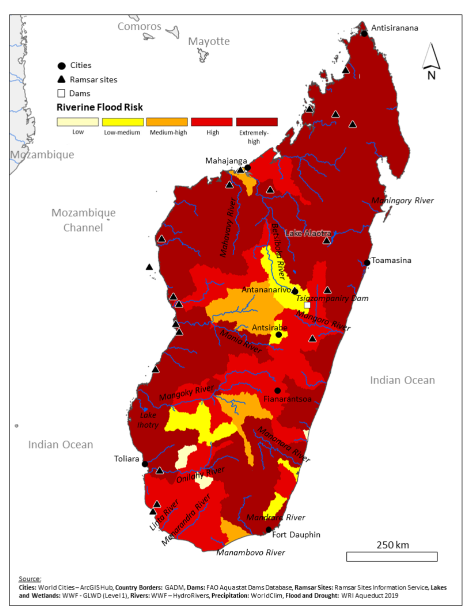


FIGURE 3. RIVERINE FLOOD RISK



Water Policy and Governance

KEY TAKEAWAYS

- IWRM planning and policy implementation is a top-down process as basin-level water management entities do not operate or lack adequate funding. Frequent water sector restructuring with the environment and energy sectors has led to inconsistent leadership and implementation of water sector policy.
- The sector remains fragmented among various stakeholders with overlapping interests and functions that are not effectively streamlined despite the National Water Code articulating roles and responsibilities.
- Constraints to human and financial resources for surface and groundwater management has allowed water use practices, such as tavy farming, development of wetlands and expanded irrigation, and industrial mining to pose continued risks to water resources namely through increased erosion and sedimentation of waterways, and exposure to chemical toxins.

This section provides an overview of key policies, institutions, and management challenges. Key laws, policies, and plans are summarized in Table 2 and the roles and responsibilities of select transboundary, national, and sub-national water management entities are summarized in Table 3.

TABLE 2. KEY LAWS, POLICIES, AND PLANS

Name	Year	Purpose
National Water Code	1999	Establishes state ownership of water, outlines responsibilities for developing water resources, sector financing strategy, and structure of the water and sanitation sector.
National Environmental Action Plan	1989	Establishes an IWRM-based framework for water source protection and water quality monitoring.

TABLE 3: WATER RESOURCES MANAGEMENT ENTITIES

Mandate	Institution	Roles and Responsibilities
National	National Authority for Water and Sanitation (ANDEA)	Effectively non-operational but is supposed to support national IWRM from within the Ministry of Water (now MEAH) by establishing IWRM policy and leading implementation. Responsible for managing sustainable IWRM finance mechanism (FNRE), establishing basin and sub-basin entities, and supporting preparation of basin management plans created by watershed agencies.
	Ministry of, Water, Sanitation, and Hygiene (MEAH)	Houses the Directorate for Water Resources Management (DGRE) and the Directorate for the Integration of the Environment (DIDE) which oversee IWRM policy implementation in the absence of ANDEA. Oversees and supports commune and regional administrations in development planning and budgeting.
Sub-national	Commune and Regional Administration	Elected administrative heads and council members develop water-sector priorities using Budget and Program by Objectives by Region process. Water sector developmental priorities are embedded within Commune Development Plans, which are integrated into Regional Development Plans and a National Development Plan, which guides national budget allocation decisions. IWRM-based budget development roles and responsibilities are not executed effectively or consistently in practice.
	Water Users Associations (WUA)	Manage, maintain, and operate irrigation infrastructure.
	Watershed agencies and committees	Manage basin resources and planning along hydrologic boundaries.

Water resources management is affected by delayed decentralization of planning and implementation mechanisms, inconsistencies in regulatory and legal frameworks as well as institutional roles and responsibilities, and funding constraints.[31] The 1999 National Water Code, which is being updated, and its subsequent decrees are the foundation of Madagascar's water policies for the management, conservation, and development of water resources.[7] Madagascar's National Environmental Action Plan, which has been renewed in phases since its inception in 1989, prioritizes IWRM planning as a framework to reduce resource degradation, promote reforestation, and improve systems for groundwater monitoring and water supply management.[8] The national budget for IWRM currently reaches only 2.35 percent of the estimated amount required to fulfill sectoral goals.[59]

Dedicated government entities and funding mechanisms for IWRM-based planning are not operational. In 2004, the National Authority for Water and Sanitation (ANDEA) was established to coordinate and regulate IWRM mechanisms and policies across the agriculture, hydropower, mining, fishing, industry, tourism, and domestic water sectors. ANDEA was tasked with managing the National Water Resources Fund (FNRE) to finance IWRM through water withdrawals and wastewater discharge fees. However, water operators and other water stakeholders contested ANDEA's regulatory oversight in court, which halted the operationalization of ANDEA and the FNRE.[31] As a result, ANDEA has not been able to collect wastewater discharge and water abstraction fees to fund the FNRE and little progress has been made in fulfilling ANDEA's objectives, including the establishment and oversight of regional and sub-regional basin agencies, management and coordination of watershed master plans, and catchment monitoring.[7,24,58,59]

Frequent changes to water sector governance structures have slowed IWRM implementation. The Ministry of Water, Sanitation, and Hygiene (MEAH) has emerged as the main institution overseeing the development and implementation of IWRM policy until issues with ANDEA are resolved. Within the MEAH, the Directorate for Water Resource Management (DGRE) and the Directorate for the Integration of the Environment (DIDE) lead the Ministry's IWRM management strategy.[60] Originally established in 2008, the MEAH has experienced several major structural changes in the last ten years, including the merger and separation of the energy, water, and the environment ministries.[31] Four different ministers have led the water sector between 2017 and 2020 alone and each round of new leadership results in new appointees and disruptions to sectoral governance, which remains highly centralized.

Incomplete decentralization and low funding have impeded basin-level management. Decentralization was prioritized in the 1992 Constitution and subsequent legislation that granted legal status and financial autonomy to decentralized territorial communities (collectivités territoriales decentralizes, or CTDs). In practice, however, most decisions on budget expenditures are taken by the central government.[49,59] Communes are supposed to request IWRM funds through a Budget and Program by Objectives by Region (BPOR) process, however, it is not consistently implemented. This process was created to help communes evaluate water sector needs, develop management strategies, and be integrated into three-year Communal Development Plans (PCD).[59] These PCDs feed into 22 Regional Development Plans (PRD) that are ultimately integrated into the Budget and Program by Objective at National Level (BPON), which informs Madagascar's National Investment Plan.[60] However, low capacity within the communes have impeded the PCD development and funding process.

Water Quality Monitoring

The Alignment of Investments with the Environment (MECIE), within the National Office for the Environment (ONE), regulates ambient water quality and industrial wastewater.[7] ONE is charged with the coordination, collection, and dissemination of environmental data including water quality information but it has experienced budget shortfalls and data management systems are limited. ONE's *Tableau de Bord Environmental de Madagascar* (TBE), an environmental data management instrument that includes water quality data, is not leveraged for IWRM purposes and lacks a real-time data capability that prevents spot-checks of environmental pollution incidents.[27,59] While the Madagascar Water and Sanitation Monitoring System (SE&AM), managed by the MEAH, offers complementary data on hydrology, hydrogeology, and water use for the water and sanitation sector, capacity constraints impede effective use of this tool for IWRM coordination.[49,59]

The MDD is mandated with regulating chemical use but the Ministry is limited in its ability to collect data on the impact of industrial, agricultural, and mining chemicals on water sources.[27] While a basic regulatory framework is in place for the MDD to control effluent discharge from these activities, the capacity to monitor compliance and enforcement is limited.[27]

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This profile was produced by USAID's Sustainable Water Partnership activity.

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