VITALITY & VULNERABILITY

OF WATER RESOURCES IN MADAGASCAR

Lovy Hervet RASOLOFOMANANA
Country Representative of WaterAid in Madagascar

AKADEMIA MALAGASY

WaterAid

about

This document was elaborated during the Month of the Malagasy Language by the Akademia Malagasy, celebrated under the theme **“Water and Habitat”:**

« Teny malagasy loharano tovozin-tsy ritra, antoky ny toeram-ponenana soa sy madio »

“The Malagasy Language, an infinite source, guaranteeing a healthy and pleasant home”.

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Summary

Abstract

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Ny tahirindrano dia sady sarobidy no saropady. Misy fasamihafana be ny fitsinjarana ny tahirindrano eto Madagasikara.
Ny mampifanindran-dalana ireo fampiasana ny rano, izay mazana saika mifanohitra. Isan'ny olana politika goavana ny tsy fahampian-drano sy ny tsy fahazoan'ny olona rano. Manomboka hita taratra ireo fambara mahakasika ny faharatsian'ny kalitao sy fihenan'ny fatran'ny rano miendrika faharitran'ny rano sy fahaloton'ny rano. Ny tondradrano sy ny haitany dia zary efa mahazatra fa eo ihany koa ny fiovan'ny toetrandro izay isan'ny olana atrehina.

Maro ireo irika fanararaotra mahakasika ny fambolena, ny jono, ny fitanterana, ny angovo, ary ny toekarena amin'ny ankapobeny. Ahafahan'i Madagasikara mamaly ny filan'ny mponina, ny biby, ny zavamaniry, ny fampivoarana ny toekareny sy ny fanatsarana ny tontolo iainan'ny mponina ao aminy ny fitantanana an-tsakany sy an-davany ny tahirindrano.

Les ressources en eau sont vitales et très vulnérables. Il y a une hétérogénéité dans la répartition et le potentiel de ses ressources en eau à Madagascar. Il est souvent difficile de concilier les divers usages parfois conflictuels. La pénurie en eau et la difficulté d'accès à l'eau potable constituent un problème hautement politique. Des signes de détérioration des ressources en eau sont visibles comme le tarissement et la pollution des ressources en eau. Les inondations et la sècheresse sont déjà des phénomènes chroniques pour certaines régions et le changement climatique affecte aussi le pays.

Les potentialités d'utilisation des ressources en eau à Madagascar pour l'agriculture, la pêche, les transports fluviaux, l'énergie et l'économie en général sont énormes.
La gestion rationnelle des ressources en eau permettra à Madagascar de répondre aux besoins humains, des faunes et des flores, du développement de son économie et l'amélioration des conditions de vie de sa population.

Water resources are vital and highly sensitive.
The potential and distribution of water resources vary throughout Madagascar. Often, it is difficult to reconcile its various conflicting uses. Water scarcity and difficulty of access to drinking water are a highly political issue. Signs of water resources degeneration are observed, including water resources depletion and pollution. Floods and droughts are already a chronic phenomenon in some regions and climate change also affects the country.

The potential for the Madagascar water resources to be used in agriculture, fishing, river transport, energy and the economy in general is enormous. Rational water resources management will help Madagascar meet its human, fauna and flora needs, develop economically and improve the living standards of its population.

Keywords : Water resources – surface water – groundwater – watershed – drinking water – environment – Integrated water resource management.

I. Introduction

Appearing about 3 to 4 billion years ago, water is almost as old as the Earth. Since then, its volume has generally remained stable. The same water circulates and is continuously transformed in the atmosphere, on the surface and in the subsoil of the Earth. Water is highly abundant on our planet. When seen from space, Earth looks blue as oceans cover nearly three-quarters of its surface (70%). The total volume of water on Earth is about 1.4 billion km3, available in the liquid, solid or gaseous forms. However, most (97%) is contained in the oceans and is salty, making it unusable by humans. Freshwater only represents 3% of the total water on Earth, and consists of:

- Mountain snow-caps and ice sheets in Greenland and Antarctica (nearly 2%);
- Underground freshwater (less than 1%, not all groundwater are freshwater, most are salty);
- Surface water (rivers, frozen soils, swamps and freshwater lakes: 0.03%);
- The atmosphere (0.001%);
- Living organisms.

La Half of this water is freshwater suitable for human use, which only makes up 0.3% or 4 million km3 of water volume in the world. This water is available in different natural resources such as rivers, shallow aquifers or lakes[1].

[1] http://www.eau-poitou-charentes.org/IMG/pdf/Cycle_naturel_eau.pdf

Without water, life on earth is unimaginable or even impossible. Water is the main constituent of the human body, with an average percentage of 65% for an adult. On earth, water is a mobile, renewable and indestructible resource that is sometimes subject to multiple conflicting uses as has been observed throughout the history of mankind. Today, the uneven distribution of water resources on planet earth is a source of conflicts and issues relating to water shortage.

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In Madagascar, renewable water resources are estimated at 337 km^3/year. Renewable surface water resources are estimated at 332 km^3/year and groundwater at 55 km^3/year, with a shared part between surface waters and groundwater at 50 km^3/year (table below). Main rivers drain off to about 335,405 km^2 of watersheds or 57 percent of the country's total surface. The 13 largest reservoirs have a total capacity of about 493 million m3, of which 108 million are for irrigation and 385 million for hydropower generation[2].

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Its plan is consistent with the Akademia Malagasy policy on journals and communications.

This paper aims to highlight the vitality and vulnerability of water resources in Madagascar while providing food-for-thought for its rational use for sustainable development.

An overview of water resources in Madagascar will be provided prior to the laws and regulations governing water resources, related challenges, their potential uses and finally alternative solutions will also be provided.

[2] http://www.fao.org/nr/water/aquastat/countries_regions/mdg/indexfra.stm

Table: Water Resources in Madagascar

Renewable Water Resources		
Average rainfall	1,513	mm/an
	888	$10^9 m^3$/an
Domestic renewable water resources	337	$10^9 m^3$/an
Total actual renewable water resources	337	$10^9 m^3$/an
Dependency ratio	0	%
Per capita renewable water resources 2004	18,826	m^3/an
Total capacity of dams 2002	493	10^6 m^3

2. Method

This study is a documentary research on available water resources literatures in Madagascar, as well as related challenges and proposed solutions, enriched by personal archives.

The following documents have been particularly analysed throughout this study:

- **Water Resources in Madagascar by the Food and Agriculture Organization of the United Nations (FAO)**
- **Feedback on Integrated Water Resources Management by CITE: Ran'Eau and PS'Eau.**
- **Rivers and streams of Madagascar**

This document is not intended to conduct a thorough analysis of water resources in Madagascar. It is limited to informing the current situation and providing food for thoughts. Written in the form of collection, this document is intended for students or people who want to have a basic knowledge of water resources, particularly those of Madagascar.

3. Findings

Carte des rivières de Madagascar

© Crédit Photo : Lovy Hervet Rasolofomanana

3.1. Overview of Water Resources in Madagascar[3]

The potentials and distribution of water resources in Madagascar is very disparate. Some areas seem to not adequately use the resources available to them, while others do not have enough.

Although no systematic study to evaluate the water resources of the country has been conducted to date, a summary of the main aquatic potential of Madagascar will be outlined in the following paragraphs.

3.1.1. Quantitative Aspects

a. Surface Water

In terms of waterways, Madagascar has more than 3,000 km of rivers and streams. Waterways are naturally divided into five sections of unequal size. The country has five watersheds:

- The Watersheds of the Ambre Mountain 11,200 km², whose main rivers are Irodo, Saharenana and Besokatra;
- The Watersheds of Tsaratanàna 20,000 km², whose main river is Mahavavy du Nord 160 km and 3,345 km² with its tributary of Antsiatsia 60 km; Sambirano 124 km and 2,980 km²; Maevarano 203 km and 5,408 km² and Bemarivo 140 km and 4,779 km²;
- The Eastern Watersheds 150,000 km² whose main rivers are Maningory 260 km and 12,646 km2, Sandratsio 125 km, Ivondro 150 km and 3,513 km², Rianila 134 km and 7,594 km², Mangoro 300 km and 17,704 km², Mananjary 212 km and 7,002 km², Namorana 103 km and 2,079 km², Faraony 150 km and 2,761 km², Mananara 323 km from Sahambano and 17,230 km²;
- The Western Watershed 365,000 km² whose main rivers are Sofia 328 km and 28,295 km² with the following tributaries: Mangarahara, Anjobony 200 km and Bemarivo 265 km; Betsiboka 605 km from Jabo and 48,879 km² whose main tributary is Ikopa 485 km; Mahajamba 298 km and 14,883 km²; Mahavavy du Sud 410 km and 19,459 km²; Manambolo 370 km and 14,351 km²; Tsiribihina 525 km and 47,797 km2 whose main tributaries are Sakeny 170 km and Mahajilo-Kitsamby 260 km; Mangoky 714 km from Matsiatra and 55,884 km² and Onilahy 400 km and 32,225 km² whose main tributary is Imaloto-Lalana 242 km;
- The Southern Watershed 48,750 km² whose main rivers and streams are Mandrare 270 km and 12,547 km², Manambovo 165 km and 4,765 km², Menarandra 235 km and 8,624 km² and Linta 173 km and 5,437 km².

Aerial view of Mantasoa Lake

[3] Cette section était extraite en intégralité du document téléchargé du siteweb suivant : http://www.google.mg/url?sa=t&rct=j&q=&esrc=s&source=web&cd=51&ved=0ahUKEwjp--KS8NjLAhWDeA8KHbttB_I4MhAWCBkwAA&url=http%3A%2F%2Fwww.doc-developpement-durable.org%2Ffile%2Feau%2Fcultures-en-conditions-arides%2FRESSOURCES%2520EN%2520EAU%2520de%2520MADAGASCAR.doc&usg=AFQjCNHpk0fD6mHXLQCne7Aqy0Eh-QPzrlQ

N.B : The surface areas pertain to the watershed surface
Source : *Rivers and Streams of Madagascar, ORSTOM 1993.*

The aquatic environments and wetlands of Madagascar mainly consist of lakes that cover about 2,000 km², which are composed of:

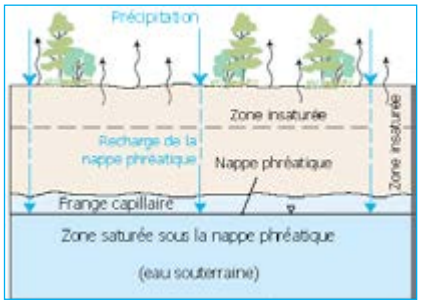
- Natural water bodies: lakes and lagoons, as well as artificial water bodies
- Dams
- Coastal canals and mangroves

b. Groundwater

Given that no information is known about the country's groundwater resources, various studies and work have provided results that can shed light on such resources per region:

1. Sedimentary Watershed in the Far South

There are deep aquifers at a great depth underground (50-170 m), usable at a very low flow rate (< 3m³/h). There are also shallow aquifers contained in sands, white sands and alluvium, located at depths of less than 20 m underground and also usable at very low flow rates (1 to 4 m3 / h).



Example of groundwater

2. Crystalline are in the South with low rainfall

These fractured rock aquifers offer some water supply perspectives for the South. Drilling has been made since 1980, but flows are low at 15 to 20 m underground. They are higher (10 m³/h) at 50-70 m deep.

3. Sedimentary Watershed of Toliara

These are different types of groundwater (limestone, shallow sands, beach sands ...) which are already being used for the water supply of several localities more or less satisfactorily. Their flow is up to 3,000 m³/h (for the Eocene limestone groundwater which ensures the water supply of Toliara)

4. Sedimentary Watershed of Morondava

The main aquifers are now well-known and used (Dabaraha, Isalo, Morondava) for water supply and irrigation.

5. Sedimentary Watershed of Mahajanga

The water supply of Mahajanga, Ambato-Boeni and Antsohihy are ensured by the main aquifers (Eocene limestone and sandstone).

6. Sedimentary Watershed of the Eastern Coast

This alluvial aquifer is used via underflow catchments in Sambava and Antalaha, via wells and boreholes in Fénérive Est and via sand and beach dune aquifers and wells in Mahanoro, Vatomandry, Mananjary and Vohémar.

7. Central Highlands

These alluvial aquifers yield a rate of 25 m3/h/m in Maevatanàna, Mampikony and Fenoarivo Be, while regolith aquifers have a very low flow rate of 0.1 to 0.2 m³/h/m. Fractured rock aquifers are still not well-known.

8. Sedimentary Watershed of Antsiranana (North)

Known aquifers are sandy beach (10 to 12 m³/h) and volcanic formation aquifers (25m³/h).

Regolith and fractured rock aquifers are significant because they are sources of runoff in Madagascar. In fact, they could ensure the water supply of cities and rural places, as well as their agriculture or livestock farming.

c. Estimated Resources

1. Rainfall

The primary source of freshwater is rainfall. In Madagascar, annual rainfall significantly varies from 3,800 mm in the Antongil Bay in the northeast part of the country to 380 mm in the extreme southwest part. It is similar and varies from 2,500 to 3,500 mm between the coast and the first reliefs of the eastern coast; and gradually decreases from 1,760 mm to 380 mm on the west coast, from north (Analalava) to south (Faux-Cap). From east to west, mean annual rainfall also generally decreases from the highlands. Abundant rainfall are observed north of the Tsaratanàna Mountain 2,500 mm, in the northwestern part near Mahajanga and Maevatanàna 1,500 mm to 2,000 mm and central Mountains of Ankaratra and Andringitra 2,500 mm. The most pronounced contrast is found south of Fort Dauphin in Ambovombe where average annual

rainfall changes from 1,500 mm to less than 500 mm over several dozens of kilometers.

2. Evaporation and Evapotranspiration

— Evaporation

In general, average annual evaporation from open water is approximately:

2,000 mm in the northwestern
1,600 mm in the south
1,400 mm in the southwest
1,000 à 1,100 mm in the highlands
700 mm on the western watershed

— Evapotranspiration

On the eastern watershed and the northwest coast, evapotranspiration ranges between 1,000 and 1,300 mm. On the east, between the eastern watershed and the Highlands, and in the northwestern part of the country (from Nosy Be to Morondava) it is between 800 and 1,000 mm, while on the Highlands 700 to 800 mm and down to less than 400 mm in the south and southwest coasts.

3. Water Table

Annual available water resources (flow) are made of rainfall minus evapotranspiration losses, deep infiltration and natural plant absorption (flow deficit). But this amount is distributed unevenly throughout the year.

The estimated annual renewable water resources in Madagascar are 40 km^3 or 3,120 m^3 per capital (WRI 1992). However, this amount is not always evenly distributed across the territory. Also, ensuring the sound management of resources for optimum utilization of available water is necessary.

3.1.2. Qualitative Aspects

Water quality issues should be taken very seriously because it also determines the availability of usable water resources for human needs. The degradation of water resources quality is linked to natural environmental factors such as erosion, indirect human-induced factors such as deforestation and poor management of spaces or direct human-induced factors such as pollution.

a. Freshwater Physical and Chemical Quality

— General Characteristics

Following the wearing of suspended minerals torn from the base, freshwaters are very rich in iron, particularly surface water and groundwater on recent lands. This phenomenon is also the reason for two physical characteristics of the water, which are turbidity and colour. It is mainly due to erosion of the watersheds.

In general, freshwater in sedimentary watersheds (coastal areas) are more mineralised than those of the highlands (crystalline basement) but overall, Malagasy waters are lightly mineralised.

b. Water treatment

— Water Drinkability

Drinking water intended for consumption are subject to rigorous standards set by the Ministry of Water, Sanitation and Hygiene, which are based on WHO recommendations:

Organoleptic and physical characteristics

Odourless, colourless, without unpleasant taste
Recommended temperature: 15 °
Turbidity < 25 mastic drops
Resistivity at 180°C : 1,000 to 10,000 Ohm/cm
Basic pH 6.5 to 8.5
No radioactive elements

Chemical Characteristics

Existence of a number of minerals (normal elements) at desirable levels
Content in abnormal elements (chemical pollution index) whose variation is to be monitored
Content in toxic elements (responsible for a nuisance on health) very low or even zero.

Bacteriological Quality

Drinking water must be free of pathogens from human or animal faeces or sewage, which can contaminate a community water supply. Tests consist of a germ-test for faecal contamination, whose presence indicates that there are health risks. These germs include:

Total coliforms
Heat tolerant coliforms, where Escherichia coli is the most significant species for faecal contamination
Faecal streptococci
Sulphite-reducing anaerobic spores
Pathogenic staphylococci in bottled water and swimming pool water.
Industrial water

There are very specific quality guidelines for boiler or cooling water in terms of mineral content (low), but for process water, only a few industries are subject to guidelines (breweries, paper mills, dairy firms).

— Disposal of pollutants

In Madagascar, industrial effluents are regulated by the MECIE Decree (Decree No. 99-954 of December 15, 1999 amended by Decree No. 2004-167 of February 3, 2004 on the compatibility of investments with the environment). Pressure from neighbouring population generally obliges the facilities to treat effluents.

Amboasary Sud, one of the semi-arid areas of Madagascar

An example of optimal use of water resources in agriculture area in Moramanga

4. Legal Framework

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Currently, Law No. 98-029 of January 20, 1999 on the Water Code, published in the Official Journal of 27.01.99 No. 2557 E.S., p. 735, governs the water resources in Madagascar. A Water, Sanitation and Hygiene Code is currently being developed. This Code has been developed in consideration of the following key elements:

a) **Water is a common national heritage,**
b) **Water is an essential natural element,**
c) **Unevenly distributed, it causes economic, social and health issues.**

This Code includes five Titles and 84 articles, where **Title II** is exclusively dedicated to water resources management. **Title II** deals with the quantitative and qualitative protection of water, conservation of water resources, environmental protection, development of water resources, drinking water supply and collective sanitation of domestic wastewater. Other Titles, namely **Title I** on the Public Ownership of Water, **Title III** on water monitoring and policing, **Title IV** on the financing of the water and sanitation sector, **Title V** on the organisation of the water and sanitation sector, and **Title VI** on transitional and final provisions are also closely related to water resources management. The Water Code highlights the following principles:

- Strengthening of water protection measures, especially for drinking water;
- Liberalisation of the water sector;
- The non-free water principle;
- The necessary management transfer of the facilities to the communities;
- Empowerment of rural and urban communities and suburban areas;
- Regulating the water supply and sanitation services;
- Strengthening the fight against water pollution;
- Setting the rules for protecting and enhancing water resources and environmental standards;
- The polluter pays principle.

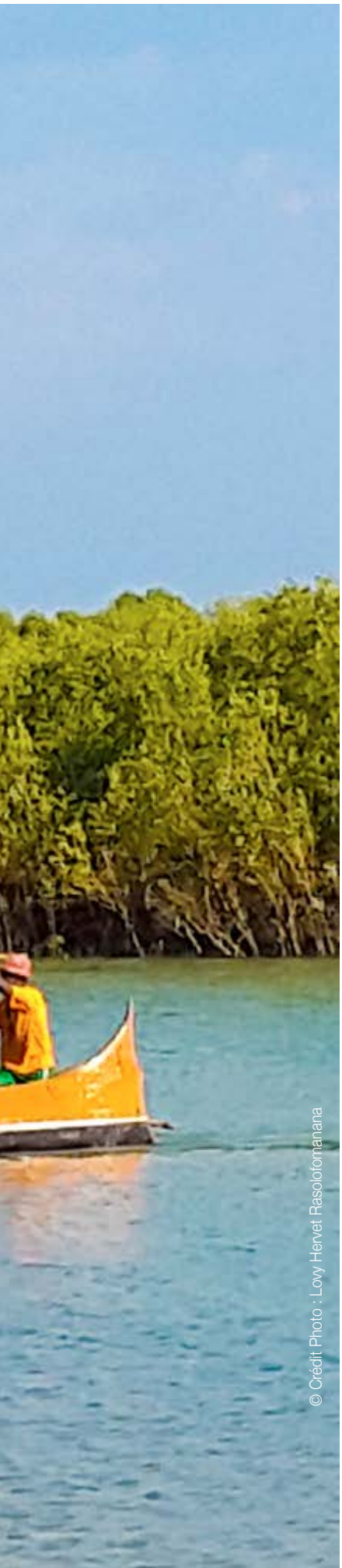
The legal and regulatory framework governing water resources management adheres to the Integrated Water Resources Management (IWRM) approach that was initiated internationally in the 90s. This approach aims for the optimal distribution of water resources between different users and the implementation of means to preserve the quantity and quality of these resources[4].

Implementing Decrees of the Water Code

- Organisation, powers and operation of Watershed Agencies
- Organisation, powers and operation of the National Authority for Water and Sanitation (ANDEA)
- Organisation of public drinking water, sanitation and wastewater services
- Price regulation of public water and sanitation services
- Catchment and disposal fees
- Procedures for granting water catchment permits
- Organization, powers, operation and financing of the Regulating Agency of Public Water and Sanitation Services (SOREA)
- Protection Perimeters
- Water Use for Hydropower
- Administrative organisation of water and skills transfer between decentralised communities
- Water monitoring, drinking water control and priorities of access to water resources
- Reclassification of streams, a section of this stream or a lake in the public domain

[4] http://www.pseau.org/outils/ouvrages/cite_pseau_gire_madagascar_2014.pdf

5. Challenges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5.1. Freshwater resources are distributed unevenly

Rainfall varies throughout Madagascar from 3,500 mm per year in the East Coast, to 1,400 mm in the capital and less than 300 mm per year in the Southern Region. This could be explained by the differences in altitude and the prevailing wind[5].

There are eight types of climates in Madagascar:

— the North and Northwest equatorial/ monsoon climate with heavy rainfall of about 2,000 mm per year;

— the Northeast, the East Coast and Southeast equatorial/humid climate with rainfall of over 3,000 mm per year,

— the Western savannah climate with oscillating rainfall between 1,000 and 2,000 mm per year,

— the highlands with rainfall of 1,200 mm per year;

— lthe South arid climate with scarce rainfall and,

— the Southeast region with both dry and hot climate.

These differences in climates result in the uneven distribution and the irregular temporal variability of water resources. The inequitable distribution of water resources between regions creates transregional and interethnic conflicts. The use of upstream water, including containment systems, has an impact on downstream quality. Other elements such as customs and traditions also come into play and could result in conflicts related to trans-regional water resources management[6].

[5] https://fr.wikipedia.org/wiki/G%C3%A9ographie_de_Madagascar

[6] http://cite_pseau.org/outils/ouvrages/cite_ps_eau_gire_madagascar_2014.pdf

5.2. Conciliation of different contrasting uses

Given that water resources are for multiple uses, their allocation and distribution could lead to conflicting relationships between various users (agriculture, energy, process, waterway transport, drinking water...). These conflicts could be due to several factors such as insufficient amount for downstream users, deteriorating water quality or excess water resulting in floods[7].

In southern Madagascar, conflicts between drinking water and livestock farming water are more significant than those about drinking water supply, industries, tourism and energy.

Management of various divergent social, economic and environmental interests is inherently a major challenge for water resources management.

[7] IWRM Tools and Uses, their Importance and the Impact of Climate Change, Dr Alain J. Andriamaherisoa, November 2011

5.3. Water scarcity and difficulty accessing drinking water

It is so tough to get access to safe water in Androndra area of Antananarivo

Despite the immensity of water resources, access to water remains a luxury for over half of Madagascar according to the statistics of the WHO-UNICEF Joint Monitoring Programme published in 2014. People in the arid regions of Madagascar settle for muddy puddles for their drinking water and shower after a rare rain. Due to low rainfall, there is no water for agriculture and livestock farming. This situation is cyclical and worsens every year. People also have to fetch water by walking kilometers in often difficult conditions. Even some large cities in Madagascar are suffering from water shortage based on the long queue at public standpipes. Waiting time at standpipes could be several hours before a household has its daily ration[8]. However, people who have access to water are wasteful on domestic and agricultural water (including irrigated rice).

[8] http://www.mg-planet.com/ http://agir.avec.madagascar.over-blog.com/2015/06/gachis-des-ressources-en-eau-a-madagascar.html

5.4. Deterioration of Water Resources

In Madagascar, a degradation of water resources in specific areas starts to be noticed and is sometimes in the form of resource depletion[9]. Some human activities such as deforestation, slash and burn agriculture and bushfires result in erosion which in turn causes runoff. This has a negative impact on groundwater recharge and amplifies floods during the rainy season and drought during the dry season. Demographic growth, urbanisation, agricultural expansion and climate change also induce pressure on water resources.

Given the industrial growth in some areas of Madagascar, pollution is feared if the MECIE Decree standards (Decree No. 99-954 of December 15, 1999 amended by Decree No. 2004-167 of February 3, 2004 on the compatibility of investments with the environment) are not met. As of the time of writing, use of organic or inorganic pesticides and fertilisers is still minimal and so is the risk of groundwater contamination[10].

Some studies on water resources sustainability (conducted by UNICEF, WaterAid or JICA) has also shown that Madagascar is facing a drying up of water resources in some areas. This phenomenon is caused by the degradation of plant covers and overexploitation of water resources. In terms of quality, excessive exploitation of groundwater through dense drilling networks, especially in the south of Madagascar, result in groundwater drawdown and increased groundwater salinity[11].

- Flood, drought and climate change

Madagascar is regularly affected by cyclones, floods and droughts due to its geographical position, the irrational use of its water resources, the degradation of the conditions of its infrastructure and most recently climate change. In the three arid regions of Madagascar (comprised of 104 municipalities), the population is facing a cyclical drought that generates food insecurity repeatedly affecting between 1/3 and 2/3 of the local population. High temperature (20-25°C), low rainfall and high winds in these regions aggravate poor harvests. The hot and arid climate prevents crop diversification, and the water and forest resources appear to be amongst the most degraded in Madagascar. The Atsimo Andrefana region is also prone to locust invasions, which regularly devour their corn crops.

[9] Integrated Water Resources Management (IWRM) in Madagascar, Rakotondrainibe Herivelo-December 2013

[10] http://www.fao.org/nr/water/aquastat/countries_regions/mdg/indexfra.stm

[11] http://www.pseau.org/outils/ouvrages/cite_ps_eau_gire_madagascar_2014.pdf

Use of surface water for agriculture

However, some regions, including Atsimo Andrefana, are also each year victims of floods caused by winds and intense rains associated with cyclones or heavy rainfall. In rural areas, these floods are caused by natural vulnerability, poor watershed management and poor planning of land use. In urban areas, poor management of drainage systems mostly explains the flooding, particularly around informal occupancies and vulnerable population[12].

According to studies by the weather service, the average temperature in Madagascar could increase by 2°C and rainfall decrease by 5% by the end of this century with regional variability[13].

[12] http://siteresources.worldbank.org/INTMADAGASCARINFRENCH/Resources/GRC.pdf

[13] http://www.pseau.org/outils/ouvrages/cite_ps_eau_gire_madagascar_2014.pdf

5.5. Potential Use

Like everywhere in the world, the agriculture sector remains the largest water consuming sector in Madagascar. In 2000, renewable water was estimated at 14,970 km^3, of which 14,313 km^3 for agriculture (95.6 percent), 0.423 km^3 for domestic consumption (2.8 percent) and 0.234 km^3 for industries (1.6 percent) (See Table 2 and Figure 1). Irrigation uses surface water, given the high cost of groundwater exploitation. Wells and boreholes are mostly used as drinking water supply[14]. There are 2,568 wells and 3,900 boreholes throughout the country. They are serving 1.617 million rural residents.[15].

[14] http://www.pseau.org/outils/ouvrages/cite_ps_eau_gire_madagascar_2014.pdf

[15] http://www.fao.org/nr/water/aquastat/countries_regions/mdg/indexfra.stm

5.5.1. Agriculture

Arable lands range between 5 and 8.8 million hectares in Madagascar, of which 30% are exploited. Madagascar has an irrigation potential of about 1,516,900 hectares: 786,291 hectares of formally equipped areas, 187,000 ha of extensions of these areas which are not yet equipped but are considered irrigable, 300,000 ha of family croplands and more than 243,600 ha based on the inventory conducted by SOGREAH in 1969. These are irrigable plains through gravity-fed retention or diversion dams where direct water intake is limited to over 1,000 ha by one landowner.

With a total area of 1,086,291 ha, fully/partially controlled irrigation is essentially gravity-fed and using surface water. The most common supply structures are river water intake and diversion dams. Only 3,500 ha in the plain of Lower Betsiboka (Marovoay) are irrigated by 13 pumping stations, and 2,400 ha of sugarcane via sprinklers in the Morondava Dabara plain (Figure 2)[16].

[16] http://www.fao.org/nr/water/aquastat/countries_regions/mdg/indexfra.stm

Use of surface water for agriculture

5.5.2. Fisheries

It is estimated that Madagascar approximately has 4,500 km of coastline with 177,000 km² continental shelf and exclusive economic areas of 1,000,000 km². Given this geographical situation of Madagascar, it is clear that fishing is an important income source for some coastal municipalities. 13% of municipalities are on coastal areas, 40% have access to a lake and 87% to a river. The Province of Antananarivo is the only province of Madagascar surrounded by land, without access to the sea.

Fishery products are an important source of foreign exchange earnings for the country. In terms of poverty reduction, traditional fisheries are one of the solutions because the number of traditional fishermen in coastal regions is estimated at 40,000. They use a total of about 20,000 canoes (World Bank, 2003). Fishing is also significant in regions where there are inland lakes such as the Alaotra and Itasy Lakes, as well as the lakes around Mahajanga. However, the traditional fishing sector seems stagnant or even in decline based on the number of fishing boats and trends in the production and marketing of key products (World Bank, 2003)[17].

Fishing, one of the promising sector in Madagascar

5.5.3. Navigable Waterways

Navigable waterways in Madagascar totaled 600 km in 2011[18]. Among the modes of transport, river transport is the least known. Streams, rivers or navigable canals make up for the lack and high cost of communications in the country. It is mainly used for transporting goods, but there are some passenger transportation services, as well as recreational boating and river tourism...

This type of transport has its particular advantages, such as contribution to the opening up of remote villages, which means it allows access in areas where there are no roads or railways. The population along navigable rivers benefit from this easy and low cost transport. Agricultural products, general merchandise and much-needed commodities can be transported from one place to another. River transport also contributes to the promotion of new tourism sites because there are areas whose discovery is only possible through this type of transport. In terms of safety, inland waterway transport is safer due to the lower strength of the currents and the types of boats (wooden canoe, Zahatra...). There are currently thirteen (13) navigable rivers in Madagascar. But the mostly used rivers are the Pangalane Canal (Toamasina Vatomandry, Mahanoro to Mananjary), as well as the Tsiribihana, Sofia and Betsiboka Rivers[19].

5.5.4. Water, Energy and Industry

The water needs of the industrial sector amount to 20% of all water uses in Madagascar[20]. For now, water and electricity remain the obstacles to the development of the sector. There are currently no serviced industrial zones (with water, electricity, telecommunications, access roads). As a solution, zero technical failures and rationalisation of electricity and water tariffs should improve the competitiveness of the industry. The use of renewable energy, including hydropower, is recommended[21].

Hydropower significantly exists in Madagascar, yet the electricity access rate of the population is low at only 19% in 2009 (WorldDataBank, 2011)[22]. The hydro potential in Madagascar is estimated at 7,800 MW, but only a small fraction 2.5% of this resource is currently being exploited[23]. However, hydropower production is extremely effective and inexpensive in a country with a

[17] http://www.ilo.cornell.edu/images/th3.5.pdf
[18] http://www.indexmundi.com/fr/madagascar/voies_navigables.html
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Water fall in Ste Marie Island

mountainous terrain as Madagascar. Power production can be done by capturing water through a pipe and injecting it into a turbine coupled with a power generator.

According to the production mode, there are three types of hydropower plants:

- Gravity-fed power plants, whose water supply is ensured through simple gravity;
- Energy transfer stations through pumping, where water is pumped electrically;
- Tidal power plants, which use tidal currents[24].

[24] Energies durables pour tous, les ménages, les collectivités, et les entreprises, Tiana Amédée Randrianarisoa – Friedrich Ebert Stiftung, Octobre 2013.

Multiple use of water resources in Menabe region

6. Discussion and Conclusion


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6.1. Actions to be taken

Given its vitality and vulnerability, Madagascar must establish and implement a sustainable and integrated water resources management policy aiming for environmental conservation, watershed and catchment areas protection and the sound management of all water uses essential to life and development. Four priority actions are identified for the implementation of this policy: appropriate legal framework, holistic water management, optimal use of water resources, innovative approaches and Equity in the distribution of water resources.

6.1.1. Development of a more appropriate legal framework and policy

As part of the update and development of the Water, Sanitation and Hygiene Code, the current laws and regulations must be in accordance with the IWRM guidelines and principles as defined internationally. These should be completed: (i) The boundaries of watershed agencies and committees should be redefined per watershed but not per province and region, (ii) The powers of the National Water and Sanitation Agency (ANDEA) should be redefined to enable it to fulfill its cross-cutting mission on IWRM and (iii) The operating method of the National Water Resources Fund (FNRE) should be revised. Integrating irrigation water, industrial water, hydropower water to ensure a holistic management of water resources in the new Code is also essential. Similarly, cooperation should be established between all relevant ministries for centralisation of data on water resources and needs, as well as sanitation and environmental protection infrastructure it is necessary to. The country must have a clear policy on water shortage management, aquatic ecosystems protection and risks of flooding in the form of a master plan for the development and integrated management strategy of water resources (SDAGIRE). It is worth highlighting that any recommended changes for all existing water and sanitation laws and regulation must be in line with the IWRM principles.

6.1.2. Development and Operationalisation of a holistic water management

For a holistic management that takes into account all of the sometimes conflicting water resources needs and their optimal use, the implementation of SDAGIRE is essential for Madagascar. The development of this master plan requires the involvement and ownership of all stakeholders involved in water resources to ensure that it becomes a reference document for all interventions in this area. All forms of water use (agriculture, livestock, electricity, industry, drinking water, sanitation, river transport ...) must be included in this master plan while taking into account the economic and social dimensions of water and the sustainability of the ecosystems. Human, fauna and flora needs, economic development, environmental preservation are considered in this master plan. Indeed, it will be based on a multisectoral approach. SDAGIRE must also ensure the equitable distribution of water resources for the 22 regions of Madagascar. As an illustration, the Mandrare water transfer project in

the Anosy region to the Androy region will be part of this process. Upstream, the Anosy region, humid with forests and permanent streams but with little arable land due to relief, is occupied by the Antanosy who are mainly farmers; whereas downstream, the Androy region, arid and suffering from inadequate surface waters despite the vast surfaces of cropland is occupied by the Antandroy who are generally engaged in extensive and nomadic cattle herding[25]. Generally, an IWRM approach should be based on:

- A good knowledge of the water resources (inventory, monitoring...)
- The distribution and planning of resources use in a collaborative process taking into account all users (domestic, industrial, agricultural...)
- The implementation of resources protection measures[26].

Promoting environmental conservation, the purpose of the SDAGIRE is to ensure that water resources will be used for the country's sustainable development.

6.1.3. Developing Innovative Approaches

For the optimal use of water resources, an example of innovative techniques and approaches specific to Madagascar is proposed in this abstract.

[25] http://www.pseau.org/outils/ouvrages/cite_ps_eau_gire_madagascar_2014.pdf

[26] La Gestion intégrée des ressources en eaux (GIRE) à Madagascar Rakotondrainibe Herivelo-Décembre 2013

Groundwater Recharge

EIn theory, groundwater is naturally recharged by rain and rivers. However, in the arid regions of Madagascar, groundwater withdrawal rate is often much higher than their natural recharge. Recharging methods help keep groundwater at a level where it can be sustainably usable even with intensive use. The principle is relatively simple: creating re-infiltration watersheds and trenches on a sufficiently permeable soil.

This method can be done from a lake created with a dam or by pumping from a stream and transfer to re-infiltration watersheds. This process is also used to purify water naturally, thereby enabling its use as drinking water supply. Groundwater recharge is adapted to:

— Cities where the groundwater usage rate is greater than capacity and whose primary water resource is a river highly polluted organically: In this case, water pumping and re-injection into the groundwater allows recharge and produces good quality water suitable for drinking through natural treatment.

— Arid regions with seasonal rainfall with the construction of a dam that will recharge groundwater supply.

6.1.4. Implementing Resources Preservation Measures

Water cycle balance and stability guarantee the sustainability of surface water and groundwater. This balance and stability is highly dependent on environmental characteristics in general, particularly watersheds. Given that water resources are multipurpose, their concerted and coordinated local management by various stakeholders from various sectors (agriculture, livestock, fisheries, drinking water, electricity, sanitation, water transport...) is essential. Several steps can be taken to preserve local water resources. WaterAid Madagascar and its local partners developed an approach called Protection of Catchment Structure Areas (PPOC). This approach focuses on water resource preservation through strong involvement of the beneficiary communities of a water supply system. The approach is based on:

— Ensuring infrastructure management by the municipality by building the capacity of local authorities and developing the delegated management of the drinking water service to a private operator or community structure.

— Promoting civic education on water resources preservation.

— Meeting of flow and quality standards by drinking water supply services, structures and networks,

— Protection of watersheds through integrated multisector approach.

In practice, it consists of preserving the vegetation covers by strengthening the reforestation policy of the source areas.

The water resources in the service of tourism in Menabe

6.2. Conclusion

In conclusion, water resources are vital and highly sensitive. The potential and distribution of water resources vary throughout Madagascar. Some regions seem to not sufficiently exploit their available water resources, while others do not have enough. This is due to strong differences in rainfall between regions and some areas of the island suffering from water shortages. The country is facing many challenges in terms of water resources management in addition to the fact that freshwater resources are unevenly distributed. It is often difficult to reconcile the various and sometimes conflicting water uses. Water scarcity and difficult access to drinking water alone constitute a highly political and very strategic issue for the country. Signs of water resources deterioration are visible through the drying and pollution of water resources. Floods and droughts are already chronic phenomena in some regions of Madagascar and climate change also affects the country.

However, the figures speak for themselves about the potential use of water resources in Madagascar:

— Agriculture still has a margin of 70% in terms of current use of arable land and only half of irrigable potentials are currently formally irrigated.

— Fishery is a promising sector given that 87% of municipalities have access to a river, 40% to a lake and 13% are on coastal areas.

— Navigable waterways in Madagascar totalled 600 km in 2011.

— The hydropower potential in Madagascar is estimated at 7,800 MW, or only 2.5% of these resources are currently being used.

To ensure environmental conservation, watersheds and catchment areas protection as well as the rational management of all water uses necessary to life and to development, stakeholders at different levels must undertake the following priority actions under the leadership of the Government:

- Establish a legal framework and a more suitable policy
- Establish and implement holistic water management
- Develop innovative approaches
- Implement resources conservation measures.

By implementing sound water resources management, Madagascar will be able to meet human as well as fauna and flora needs, the development of its economy and the improved living conditions of its population (agriculture, fishing, livestock farming, tourism, energy, drinking water, sanitation…)

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8. Acknowledgement

I would like to express my sincere thanks to President of the Akademia Malagasy Mr ANDRIAMANANJARA Rajaona, Mrs Juliette RATSIMANDRAVA and their entire team for giving me the opportunity to participate in the Month of the Malagasy Language in June 2015 and for their hospitality.

Lovy Rasolofomanana

WaterAid

Près IIY 53 Bis Avaratra Antanimora – BP 6082 – Antananarivo 101 – Tél .: + 261 (0) 20 22 627 72 / 22 303 74
www.wateraid.org