DIO SERA

Climate change vulnerability assessment

Report

Edited by: Practica

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Submitted by: International Development Enterprise (iDE)
Point of Contact: Eric RAKOTO-ANDRIANTSILAVO
Telephone: +261 34 02 202 06
Email: erakoto@ideglobal.org

TABLE OF CONTENTS

TABLES

ACRONYMS AND ABBREVIATIONS

BNGRC	:	Bureau National de Gestion des Risques et Catastrophes
FSM	:	Fecal Sludge Management
FSTP	:	Fecal Sludge Treatment Plant
GIS	:	Geographic Information System
HH	:	Household
INSTAT	:	Institut National de la Statistique
JMP	:	Joint Monitoring Program
MHM	:	Menstrual hygiene materials
NSS	:	Non sewered sanitation
OD	:	Open Defecation
OSM	:	Open Street Map
OSS	:	On-Site-Sanitation
PUDI	:	Plan d'Urbanisme Directeur
PRM	:	Person with Reduced Mobility
RGPH	:	Recensement Général de la Population et de l'Habitation
SSOI	:	Service Sécurité Océan Indien
USAID	:	U.S. Agency for International Development
WASH	:	Water Sanitation Hygiene
WHO	:	World Health Organization

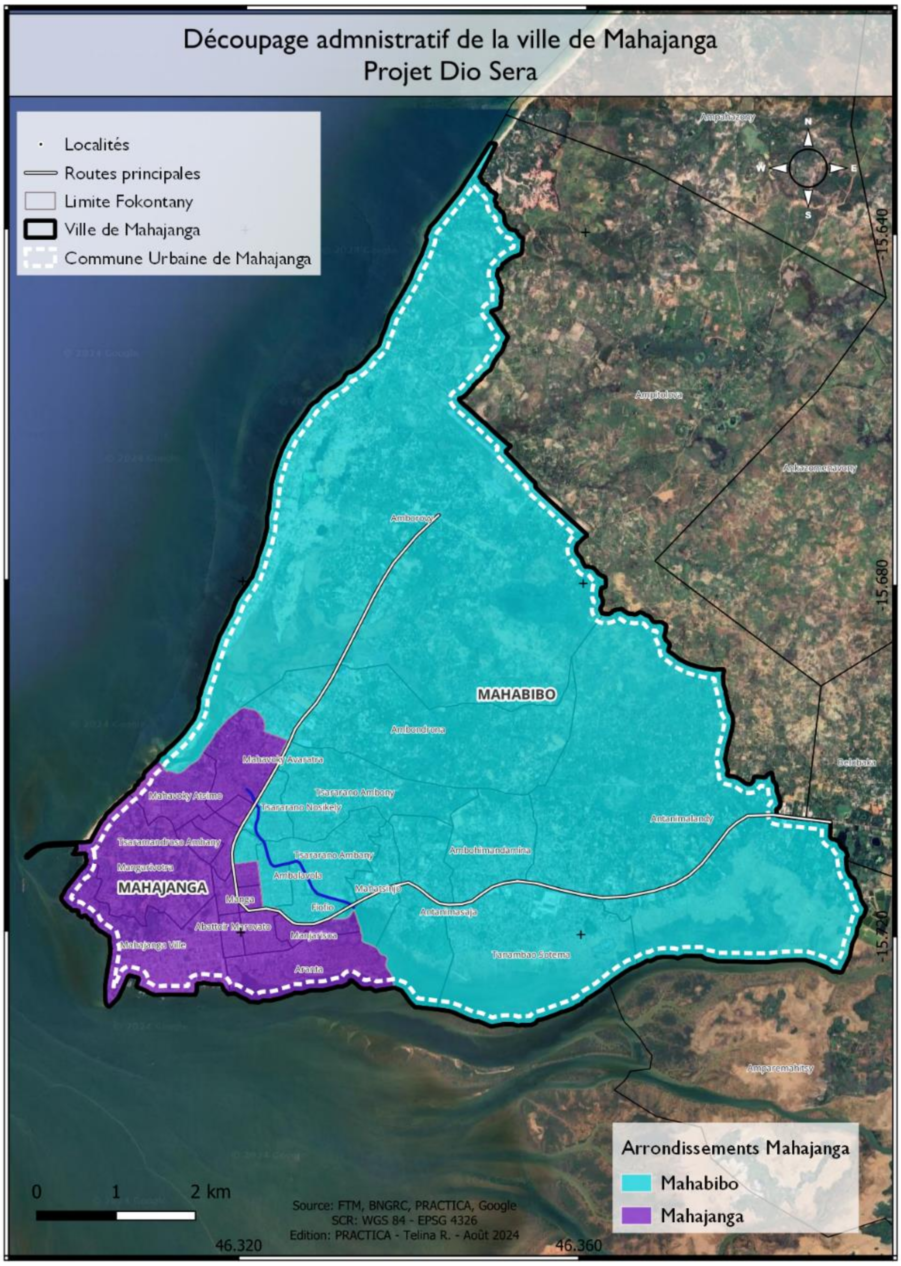
1 INTRODUCTION

The USAID Dio Sera project aims to address critical challenges in Madagascar's urban sanitation sector by unlocking financing, strengthening government policy and planning, fostering sustained changes in user behaviors, and building the capacity of local enterprises to deliver high-quality sanitation solutions. The project targets the cities of Mahajanga, Fianarantsoa and Toamasina. Implemented by iDE and consortium members WaterAid, Practica, GRET, Runway Consulting and Sango, Dio Sera adopts a unified, locally-led approach from access to toilets to fecal sludge management.

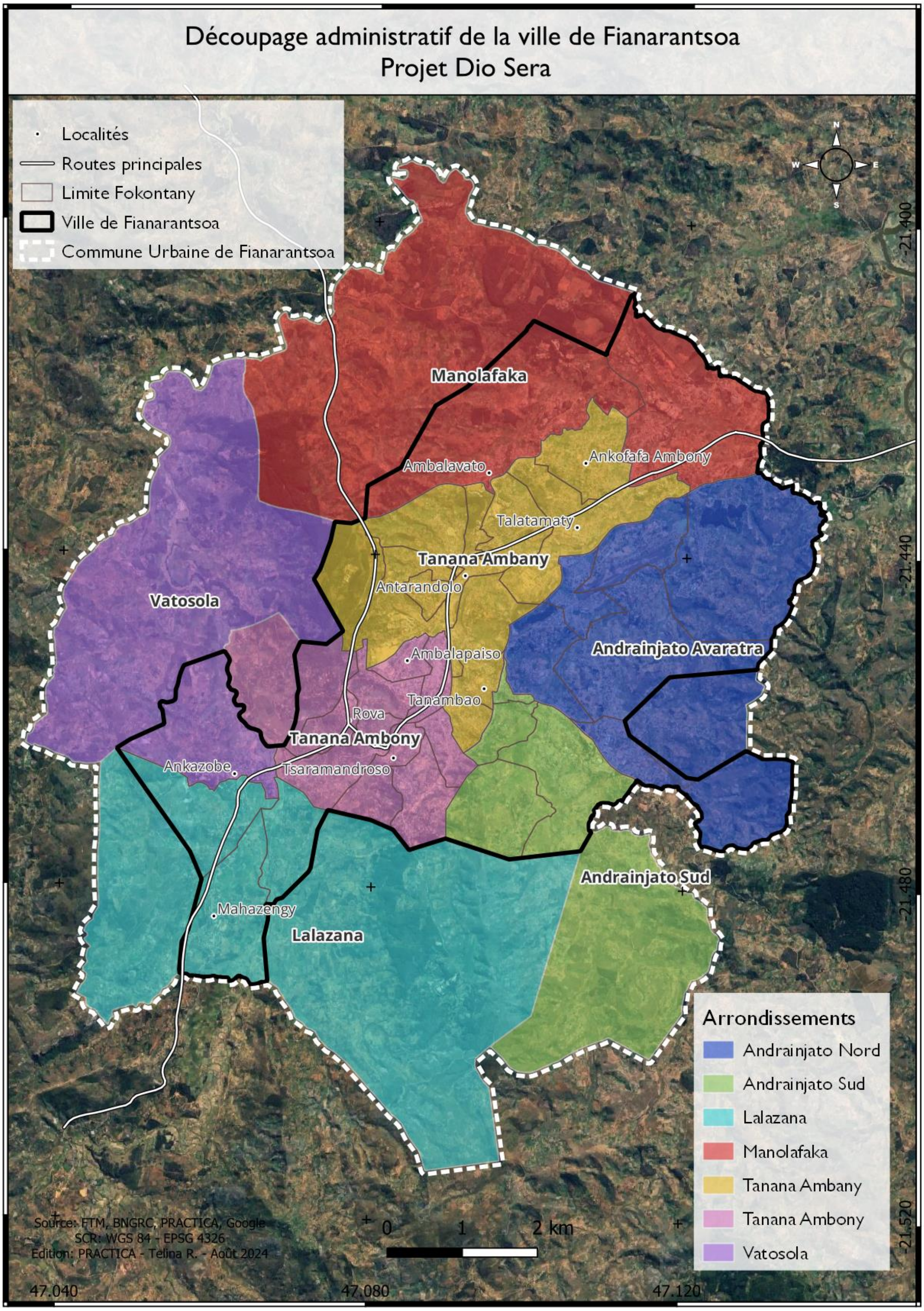
2 OBJECTIVES

The main objective of this report is to assess the vulnerability of sanitation systems to risks induced by climate change in the three intervention cities of the project. The following maps specify the geographical perimeters of each of the 3 target cities. An online version is available for consultation at this link.

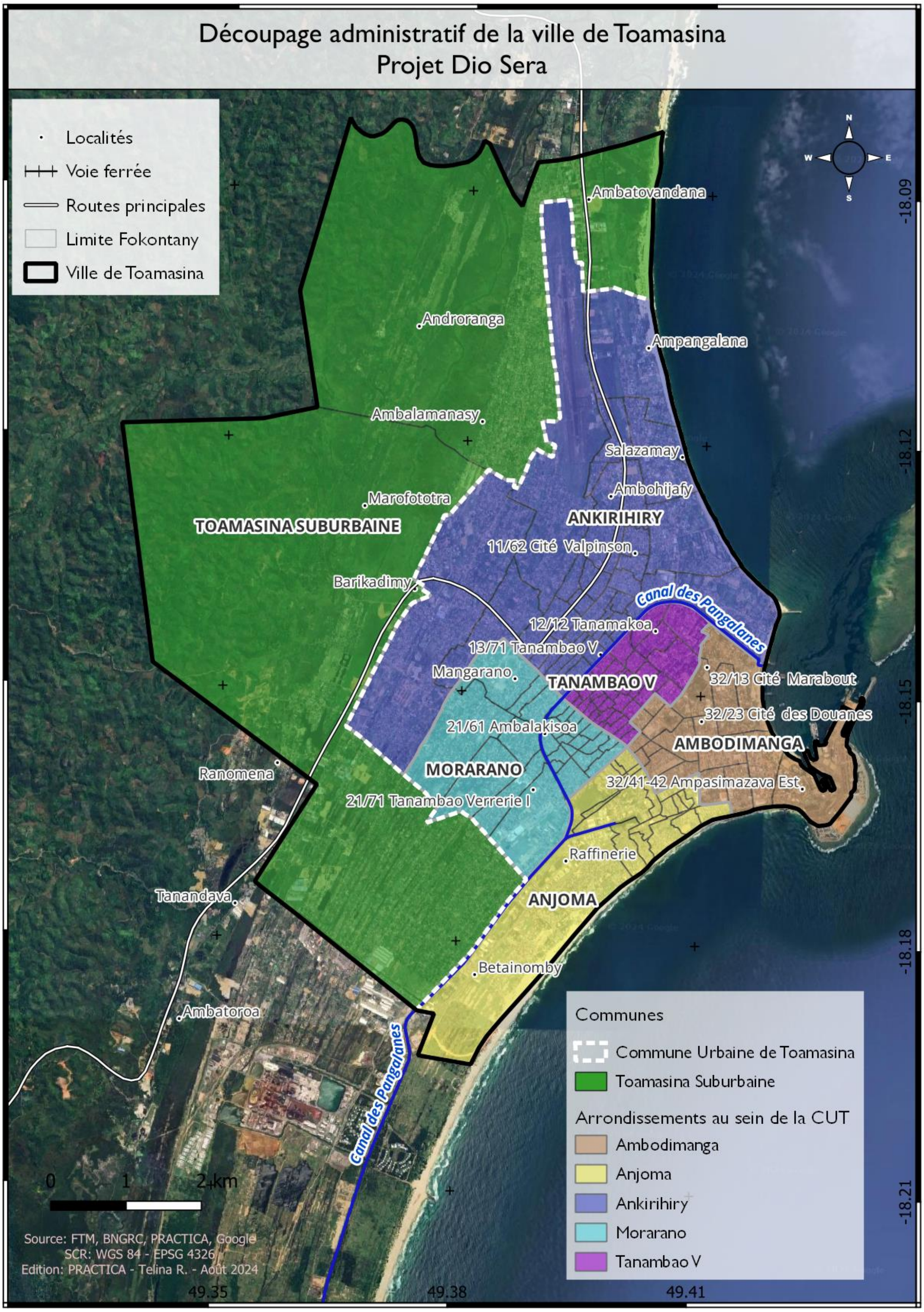
Map 1. Administrative boundaries of the city of Mahajanga



Map 2. Administrative boundaries of the city of Fianarantsoa



Map 3. Administrative boundaries of the city of Toamasina



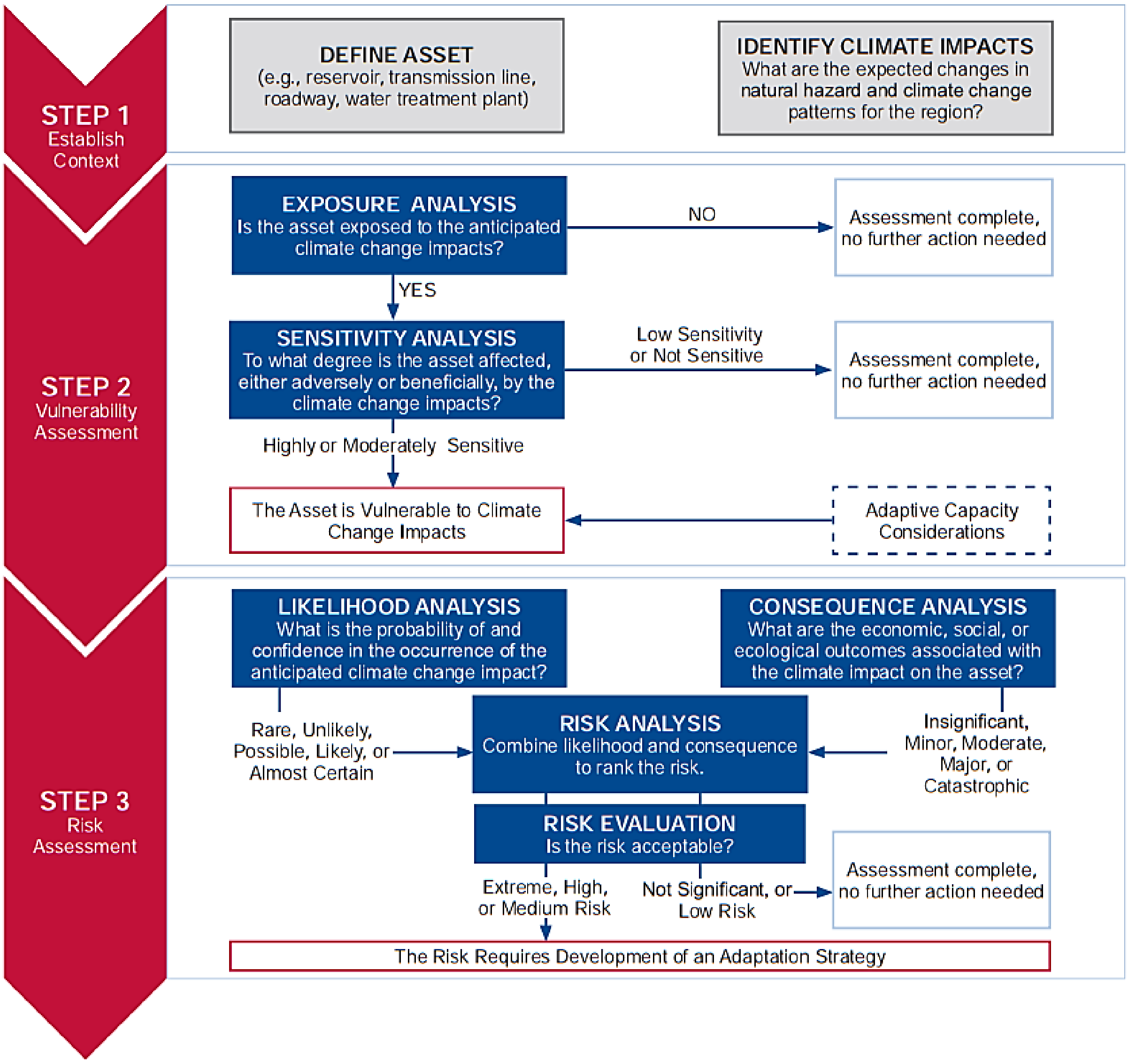
3 STUDY METHODOLOGY

3.1 FRAMEWORK

The methodology of the study is based on the Guide on Integrating Climate Change Adaptation into the Design and Planning of Sanitation Infrastructure, developed by USAID [1]. It is structured in three steps:

- **Step 1:** Presentation of the local context, sanitation systems, and various concepts considered for the study (climatic hazards, climatic impacts, induced risks, etc.);
- **Step 2:** The vulnerability of each system is assessed for the main induced risks, based on levels of exposure, sensitivity, and adaptation capacities;
- **Step 3:** The induced risks are evaluated based on their probability and severity (or potential impact). The highest risks will be addressed with adaptation measures in the next deliverable.

Figure 1. Study methodology (Source: [1])



3.2 KEY ACTIVITIES

3.2.1 Task 1: Literature review

This task involved gathering and analyzing existing scientific documents, including publications from the General Directorate of Meteorology of Madagascar, such as the Climatological Atlas of Madagascar (DGM, 2014) and the report titled Observed Climate Trends and Future Climate Changes in Madagascar (DGM, 2023). It also included technical studies and relevant documents on the three respective cities, such as the SDAUM, PUDi, Municipal Hygiene Code, and baseline surveys for Dio Sera, among others.

3.2.2 Task 2: Field visits and consultation

In each town, Practica held meetings with the heads of various municipal technical services involved in sanitation. These meetings allowed for the compilation of data on existing sanitation systems and the identification of areas vulnerable to climate hazards.

Additionally, field visits were conducted in collaboration with the Communes to directly observe domestic and collective sanitation systems, as well as existing FSM services. In this context, focus group discussions were organized with the heads of the Fokontany and residents of areas vulnerable to climate hazards. The goal was to identify the impacts of these hazards on their sanitation infrastructure and daily livelihoods.

Other regional departments from technical ministries were also consulted to collect supplementary data, including the regional meteorological service, the Regional Directorate of WASH, the Regional Directorate of Agriculture and Livestock, and the Regional Directorate of Fisheries and the Blue Economy.

Figure 2. Overview of meetings and field visits with local stakeholders in the 3 cities

4 CONTEXTS ANALYSIS

4.1 BACKGROUND

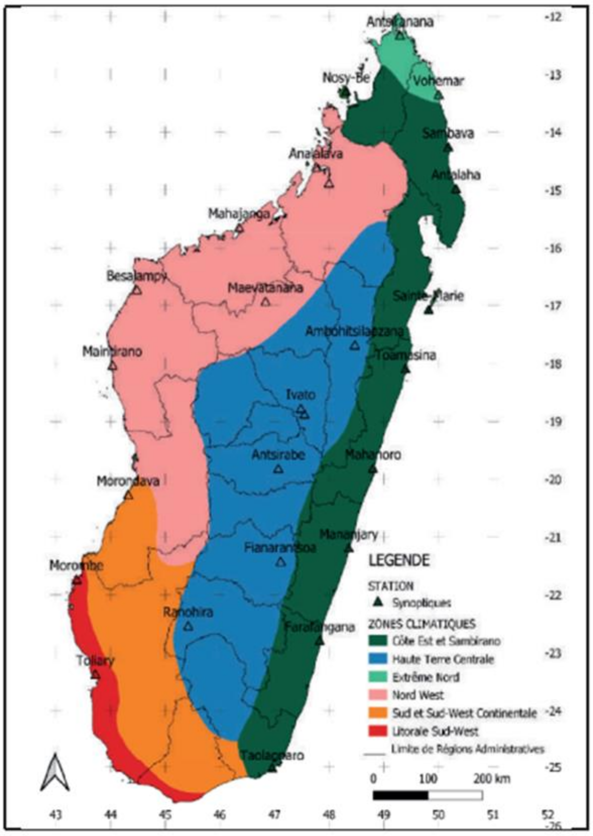
4.1.1 Climate zones of Madagascar

According to [2], Madagascar is divided into six main climatic zones as shown in Figure 3 :

- The East Coast (hot and humid tropical climate)
- The Central Highlands (tropical highland climate)
- The North-Western Region (temperate tropical climate)
- The Far North Region (transitional tropical climate between humid and highland)
- The Southern and South-Western Continental Regions (semi-arid tropical climate)
- The South-Western Coastline (arid tropical climate)

The three cities studied, namely Toamasina, Fianarantsoa, and Mahajanga, are respectively located in the climate zone of the East Coast, that of the Central Highlands, and that of the North-West.

Figure 3. Climate map of Madagascar (Source: [2])



4.1.2 Key concepts

The study aims to assess the vulnerability of sanitation systems to climatic hazards:

- **A sanitation system** consists of a series of technologies and services, specific to the context, enabling the management of excreta/wastewater and sludge, including their collection, containment, transportation, treatment, reuse, or final disposal;
- **The vulnerability of sanitation systems to climatic hazards** refers to the extent to which these systems are likely to be negatively affected by extreme weather conditions and climate change. ;
- **The consequence risks to sanitation systems** are incidents that may occur due to climatic hazards, resulting in consequences for the availability/safety of sanitation infrastructure and services. In practice, vulnerability is assessed for 'safe' sanitation systems under normal conditions, meaning those recognized as capable of providing a safely managed sanitation service according to JMP standards.

The primary climate hazards analyzed in this study align with those identified in [1] and are detailed below.

Figure 4. Climate hazards (Source: [1])

				
DRYING TREND/ DROUGHT	**EXTREME PRECIPITATION/ FLOODING**	**STORM SURGE**	**SEA LEVEL RISE**	**CYCLONES**
A prolonged dry period in a natural climate cycle which results in a shortage of water. Likely increase in drought conditions in some areas through a warming of air temperature and decrease in precipitation	Extreme precipitation events are location specific and can cause flooding when downpours exceed the capacity of river or urban drainage systems. Uncertain climate projections, expected to intensify in some areas.	The difference between the actual water level under the influence of a meteorological disturbance (storm tide) and the level which would have been attained in the absence of the meteorological disturbance (i.e. astronomical tide). Sea level rise exacerbate storm surge height.	Anticipated sea level changes due to the greenhouse effect and associated global warming. Leads to changes in erosion and accretion, long term inundation, exacerbate storm surge and tsunami height.	Severe weather systems involving damaging winds and heavy rainfall downpour, including tornados, hailstorms, tropical cyclones and hurricanes. Uncertain climate projections

4.2 CONTEXT OF MAHAJANGA

4.2.1 Climate hazards

Majunga has a warm tropical climate characterized by the following:

- High temperatures throughout the year, with monthly averages ranging between 25°C and 30°C. The hottest period is from November to April, with temperatures reaching up to 35°C. According to [4], projections indicate a temperature increase by 2070, ranging from +1.5°C to +3°C above the norm.
- Significant annual rainfall, ranging from 1,000 to 1,500 mm per year. The rainy season extends from November to April, with abundant precipitation, often exceeding 300 mm per month in January and February. During the dry season, from May to October, rainfall is very low, often below 50 mm per month or even non-existent. According to [4], an intensification of very heavy rain events and a reduction in annual rainfall by 10% to 20% by 2070 are expected in Northwestern Madagascar.
- Intense cyclones. From November to February, Mahajanga is exposed to tropical cyclones that can bring heavy rainfall and extreme weather conditions. In 2023, several neighborhoods suffered significant material damage and were left without water and electricity for several days following the passage of Cyclone Cheneso. According to the literature, there is a slight trend toward an increase in the number of systems making landfall as intense tropical cyclones in Madagascar.

Additionally, the low-lying coastal areas of the city are threatened by rising sea levels, which lead to coastal erosion and increase the risk of storm surges. Over the past 25 years, the SOOI basin has experienced a significant rise in sea levels of approximately +12 cm, or +5 mm per year on average, which is higher than the global average. Regularly, the tide floods the latrines in low-lying neighborhoods along the Betsiboka River, such as Aranta, a fishing neighborhood with fragile mangrove landfills reinforced with sandbags. Residents install latrines there, whose pits flood and overflow during high tides.

In light of the above, it is clear that the climate hazards and changes impacting sanitation systems in Mahajanga are as follows:

- Drought;
- Extreme rainfall and flooding;
- Intense tropical cyclones;
- Sea level rise.

Figure 5. Overview of Flooding in Mahajanga Following Cyclone Cheneso (Source: BNGRC)

4.2.2 Sanitation systems

The following table lists the different sanitation systems existing in Mahajanga and the respective proportions of households using them in 2024.

Table 1. Sanitation systems in Mahajanga (Source: [12])

System	% HHs	Description
Non-sewered sanitation		
Household toilets		
Flush toilet to septic tank	43%	Squat or western style toilets that evacuate waste to a pit, most often connected to a soakaway pit.
Flush toilet to pit	4%	Squat or western style toilets connected to a masonry pit, where liquids infiltrate and sludge accumulates.
Dry toilet with lined pit	11%	Dry latrines consisting of a pit, covered by a slab or a perforated platform through which the waste is dropped.
Dry toilet with unlined pit	26%	Dry latrines with a pit constructed without any masonry reinforcement structure
Public toilets		
Flush toilet to septic tank	8%	Public infrastructure with paid access, managed by the CUM. The cabins generally feature a mechanical flushing system, connected to a septic tank and a soakaway pit.
Open defecation		
Open defecation	8%	Practice of defecation in bushes or fields, ditches, or in surface water (drainage channels, beaches, or rivers).
Fecal Sludge Management		
Municipal FSM service	8%	Service provided by a vacuum truck or a tractor equipped with a slurry tank, allowing for the pumping and transportation of sludge.
Manual emptiers	14%	Informal operators performing "in-situ" desludging, either by creating an opening in the pit or extracting sludge using a bucket from the surface.
Marohogo FSTP	8%	FSTP infrastructure using covered unplanted drying beds, and facultative ponds followed by infiltration beds. The plant is located 20 km from the city center, along the RN4, heading towards Ambatoboeny.
Sewered sanitation		
Combined sewer system	1%	An open drainage network, with a main collector 3 km long, which discharges wastewater into the Betsiboka estuary. The main collector is completely covered by water hyacinths and no longer provides adequate drainage. In certain neighborhoods, this canal has become a dumping ground. All tertiary and secondary canals are also blocked by sediments and waste

From a qualitative perspective, it is noted that:

- Only 14% of households have toilets inside their residential buildings.
- 20% of households use domestic toilets with cabins built from "light" materials: wood, sheet metal, or salvaged materials.
- Open defecation, manual desludging, and wastewater discharge into the combined sewer system do not constitute improved sanitation systems and pose constant health risks regardless of weather conditions.

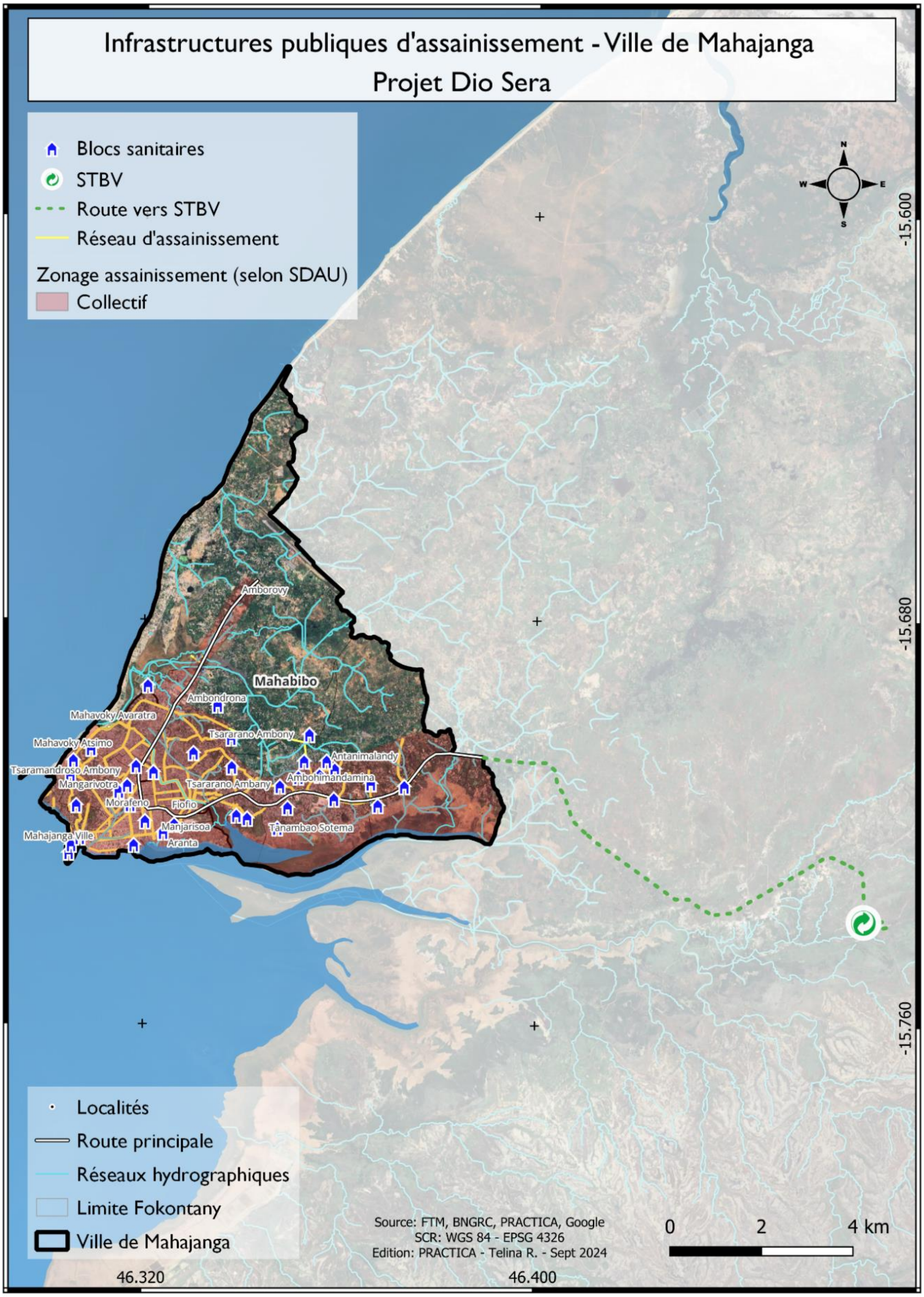
Figure 6. Overview of Sanitation Systems in Mahajanga

Cabins, dry toilet, flush toilet and septic tank

Municipal emptying service

FSTP of Mahajanga (Marohogo)

Map 4. Public sanitation infrastructure of Mahajanga (Source: Présente étude)



4.3 CONTEXT OF FIANARANTSOA

4.3.1 Climate hazards

Fianarantsoa has a tropical highland climate that is relatively mild due to its altitude:

- **Average temperatures range between 18°C and 20°C.** The warmest months are generally from November to February, while the coolest months, especially June and July, can see lows near 10°C. According to [4], projections indicate a temperature increase of +0.3°C per decade for this climate zone;
- **Annual rainfall is around 1,500 mm.** About 90 to 95% of the yearly precipitation falls from November to April, while the remaining months can be very dry, causing water supply shortages, particularly in higher-altitude neighborhoods. Rainfall is often intense, especially in January and February, encouraging dense vegetation but also marked soil erosion due to the steep terrain. According to [4], an increase in extreme rainfall events and a decrease in annual precipitation by approximately -0.77% per decade are expected;
- **Cyclones.** Although inland, Fianarantsoa can be indirectly affected by cyclones hitting Madagascar's eastern coast. These cyclones, typically occurring between January and March, can bring heavy rains, flooding, landslides, and strong winds when they move inland.

In conclusion, the climate risks and changes that could impact sanitation systems in Fianarantsoa include:

- Drought;
- Extreme rainfall and flooding;
- Cyclones.

Figure 7. Overview of Flooding in Fianarantsoa Following Cyclone Batsirai in 2022 (Source: BNGRC)

4.3.2 Sanitation systems

The following table lists the different sanitation systems existing in Fianarantsoa and the respective proportions of households using them in 2024.

Table 2. Sanitation systems in Fianarantsoa (Source: [12])

System	% HHs	Description
Non-sewered sanitation		
Household toilets		
Flush toilet to septic tank	17%	Squat or western style toilets that evacuate waste to a pit, most often connected to a soakaway pit.
Flush toilet to pit	4%	Squat or western style toilets connected to a masonry pit, where liquids infiltrate and sludge accumulates.
Dry toilet with lined pit	3%	Dry latrines consisting of a pit, covered by a slab or a perforated platform through which the waste is dropped.
Dry toilet with unlined pit	74%	Dry latrines with a pit constructed without masonry reinforcement, a design widely used in Fianarantsoa due to the natural stability of the soil.
Public toilets		
Flush toilet to septic tank	8%	Public infrastructure with paid access, managed by the CUF. The cabins are equipped with flush toilets connected to a septic tank and a soakaway pit. They are used occasionally during the day, mainly by merchants.
Open defecation		
Open defecation	8%	Practice of defecation in bushes or fields.
Fecal Sludge Management		
Municipal desludging service	7%	Service provided by a tractor equipped with a slurry tank for pumping and transporting sludge, or by manual desludging equipment loaded onto a flatbed trailer.
Manual emptiers	4%	Informal operators performing "in-situ" desludging by opening the pit or extracting sludge with a bucket from the surface.
FSTP of Ambalataratasy	7%	FSTP with covered unplanted drying beds and facultative ponds followed with infiltration trenches. The FSTP is located atop a hill overlooking the city, 4 km from the center.
Sewered sanitation		
Combined sewer system	1%	Fianarantsoa has several kilometers of underground and open drainage networks (earthen or masonry channels). Some households directly discharge their wastewater into these systems

From a qualitative perspective, it is noted that:

- Only 8% of households have toilets inside their residential buildings.
- 24% of households use domestic toilets with cabins built from rammed earth.
- Open defecation, manual emptying, and the discharge of wastewater into the drainage network do not constitute improved sanitation systems and pose constant health risks, regardless of weather conditions

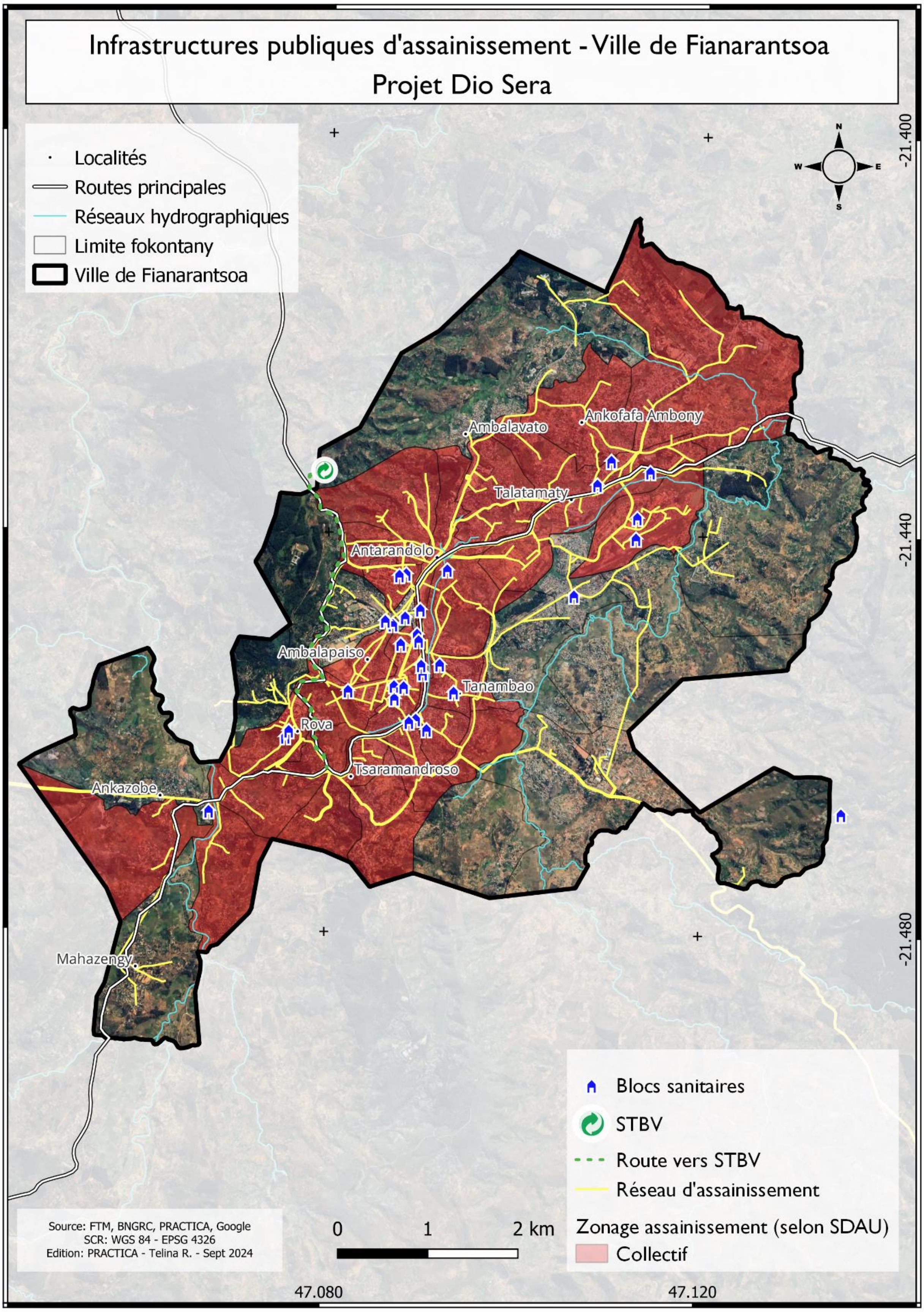
Figure 8. Overview of Sanitation Systems in Fianarantsoa

Cabin, dry toilet and flush toilet

Municipal emptying service

FSTP of Fianarantsoa

Map 5. Public sanitation infrastructure of Fianarantsoa (Source: Present study)



4.4 CONTEXT OF TOAMASINA

4.4.1 Climate hazards

Toamasina has a monsoon tropical climate, characterized by high temperatures and high humidity throughout the year:

- **High temperatures:** Temperatures are relatively stable year-round, with monthly averages ranging between 21°C and 27°C. According to [4], projections suggest an increase in temperatures of +0.21°C per decade.
- **Very abundant rainfall:** The annual average precipitation is very high (often exceeding 3,000 mm), making Toamasina one of the rainiest areas in Madagascar. The wettest months are between December and April, with peaks of up to 500 mm per month in January and February. Rainfall is frequent and intense during the rainy season, leading to numerous floods, which typically last more than a month. According to [4], an intensification of extreme rainfall events and a decrease of about -2% in the annual precipitation total per decade is expected.
- **Cyclones:** Toamasina is one of the cities in Madagascar most affected by tropical cyclones. From 1982 to 2022, 82 systems made landfall in Madagascar, averaging 2 systems per season during the cyclone season (November to April). These extreme weather events are accompanied by strong winds (gusts up to 190 km/h), heavy rainfall, and an increased risk of flooding and material damage.
- Additionally, the low-lying coastal areas of the city are threatened by **rising sea levels,** which lead to coastal erosion and increase the risk of storm surges. Over the past 25 years, the SOOI basin has experienced a significant rise in sea levels of approximately +12 cm, or +5 mm per year on average, which is higher than the global average. High tides regularly flood and/or wash away the pits of toilets built in the Dépôt Analakininina neighborhoods.

Given the above, the climate risks and changes that could impact sanitation systems in Toamasina include:

- Extreme rainfall and flooding;
- Intense tropical cyclones;
- Rising sea level.

Figure 9. Flooding in Toamasina Following the Passage of Cyclone Dumazile in 2018 (Source: Cyclone OI)

4.4.2 Sanitation systems

The following table lists the different sanitation systems existing in Toamasina and the respective proportions of households using them in 2024

Table 3. Sanitation systems in Toamasina (Source: [12])

System	% HHs	Description
Non-sewered sanitation		
Household toilets		
Flush toilet to septic tank	43%	Squat or western style toilets that evacuate waste to a pit, most often connected to a soakaway pit.
Flush toilet to pit	33%	Squat or western style toilets connected to a masonry pit, where liquids infiltrate and sludge accumulates.
Dry toilet with lined pit	27%	Dry latrines consisting of a pit, covered by a slab or a perforated platform through which the waste is dropped.
Dry toilet with unlined pit	6%	Dry latrines with a pit constructed without any masonry reinforcement structure
Public toilets		
Flush toilet to septic tank	1%	Public infrastructure with paid access. The cabins are equipped with flush toilets connected to a septic tank and a soakaway pit. They are rarely used on a daily basis by households.
Open defecation		
Open defecation	5%	Practice of defecation, primarily on the beach.
Fecal Sludge Management		
Municipal desludging service	4%	Service provided by a tractor equipped with a slurry tank for pumping and transporting sludge.
Manual emptiers	40%	Informal operators performing "in-situ" desludging by creating an opening in the pit or extracting sludge with a bucket from the surface.
FSTP of Fanandrana	4%	Sludge treatment infrastructure using planted drying beds, facultative ponds and infiltration of percolate. The BV treatment plant is located 10 km from the city, along the RN2, heading towards Brickaville.
Sewered sanitation		
Combined sewer system	1%	The stormwater network is used by some households to discharge their wastewater. This network is structured around a section of the Pangalanes canal (8.5 km) and 7 primary canals. These include trapezoidal earthen ditches, masonry rectangular canals, and concrete rectangular canals. The total length is approximately 15 km

From a qualitative perspective, it is noted that:

- Only 10% of households have toilets inside their residential buildings.
- 55% of households use domestic toilets with cabins constructed from light materials (sheet metal, bamboo), which are vulnerable to wind gusts.
- Open defecation, manual emptying, and the discharge of wastewater into the drainage network do not constitute improved sanitation systems and pose constant health risks, regardless of weather conditions.

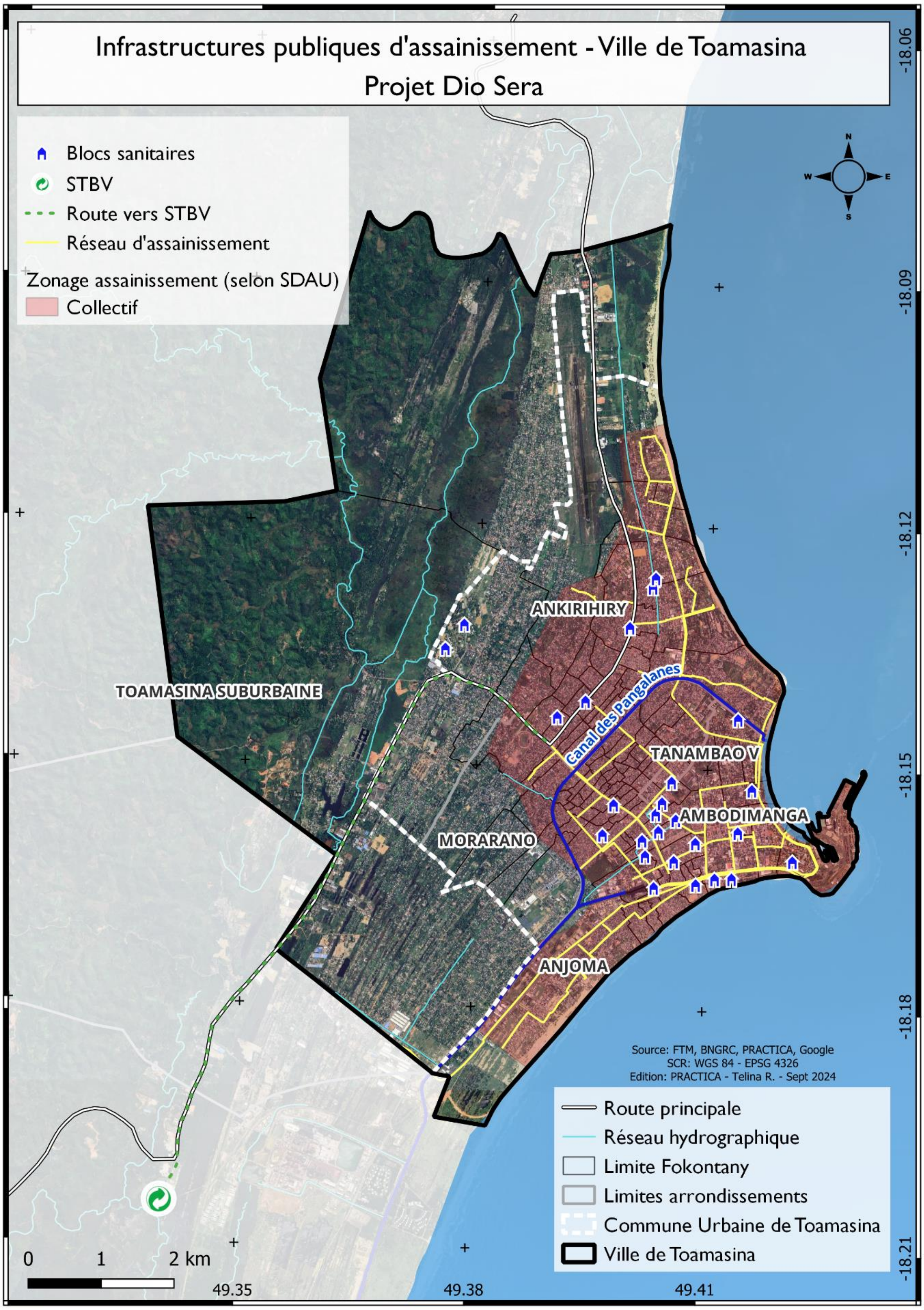
Figure 10. Overview of Sanitation Systems in Toamasina

Domestic toilets with cabins made of light, durable materials, a simple detached pit, and a septic tank (Source: Practica)

Municipal emptying service (Source: Practica)

FSTP of Toamasina (Source: Google Earth)

Map 6. Public sanitation infrastructures of Toamasina (Source : Present study)

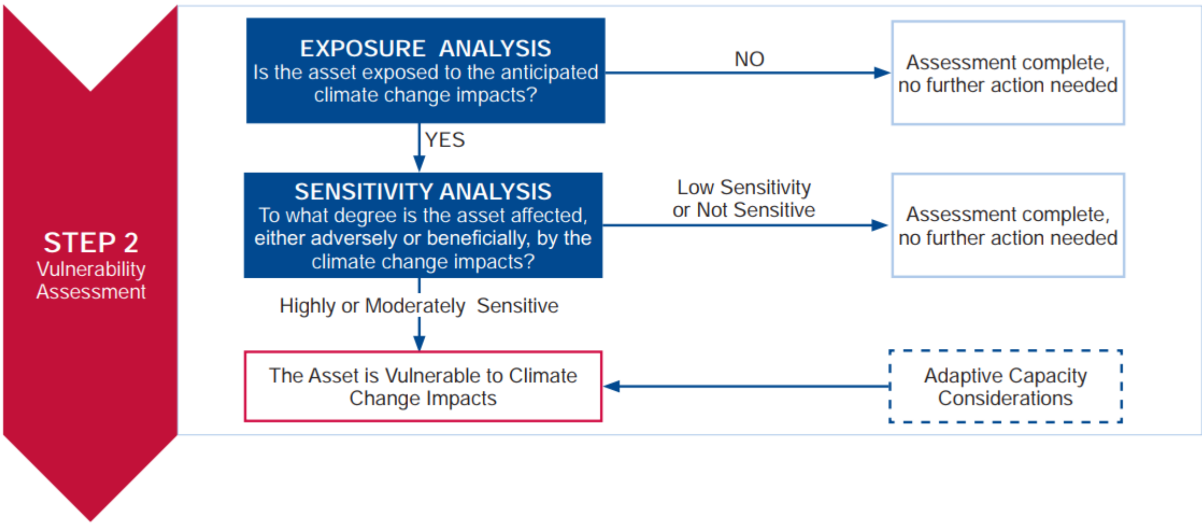


5 VULNERABILITY ASSESSMENT

5.1 METHODOLOGY

This step considers the degree to which improved sanitation systems are susceptible when exposed to hazards identifying those that warrant more detailed investigation. The vulnerability screening involves understanding an asset's vulnerability to specific climate change impacts over time.

Figure 11. Vulnerability assessment framework (Source: [1])



Exposure is the nature and degree to which a system is subject to a climate impact. For example, a FSTP likely to be impacted by annual flooding would be exposed to this climate impact, whereas a plant that is not likely to be impacted by flooding would be considered not exposed. Spatial information related to hazards will assist this process;

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate stressors. For example, latrines with a solid superstructure are less vulnerable to strong winds than those with a superstructure made of recovered materials. Table 4 outlines the levels of sensitivity ranging from Not Sensitive to High Sensitivity. Using this scale, improved sanitation systems that are rated as having a Moderate or High Sensitivity would be deemed vulnerable to the climate impacts associated with the relevant climate hazard and be the focus of the risk assessment.

Table 4. Levels of sensitivity to climate change impacts

Level of sensitivity	Definition
Not sensitive	• No infrastructure service disruption or damage
Low sensitivity	• Localized infrastructure service disruption; no permanent • Some minor restoration work required
Moderate sensitivity	• Widespread infrastructure damage and service disruption requiring moderate repairs • Partial damage to local infrastructure
High sensitivity	• Permanent or extensive damage requiring extensive repair

5.2 MAHAJANGA

5.2.1 Exposure analysis

5.2.1.1 Drought

The rise in temperatures and the decrease in rainfall are causing episodes of drought and water scarcity that impact the entire city. Already, 25% of households report that they do not have enough water for their daily needs (cf. [12]).

As a result, all domestic and public flush toilets in the city are at risk of non-functioning in the event of water scarcity due to drought, leading to a lack of hygiene and potentially a return to unsanitary sanitation practices (open defecation, flying toilets, etc.).

The municipal FSM service is not exposed. The design of the FSTP (planted drying beds and aerated ponds followed by infiltration) tends to be optimal when the weather is dry and temperatures are high.

5.2.1.2 Flooding

In Mahajanga, flood-prone built-up areas represent approximately 14% of the built-up area, with more than 40,000 inhabitants (see Map 7). The majority of these areas are located in the Vallon Metzinger, covering 10 fokontany. Although unsuitable for habitation due to high flood risks related to its topography, this area is rapidly populated due to a lack of regulation.

Thus, all domestic and public toilets located in flood-prone areas are at risk of clogging and the release of excreta and fecal sludge during floods, leading to the risk of fecal contamination.

The coverage of the municipal emptying service is limited during heavy rains and floods due to the poor condition of roads and tracks in flood-prone neighborhoods. It should be noted, however, that the FSTP has the advantage of being accessible and functional year-round.

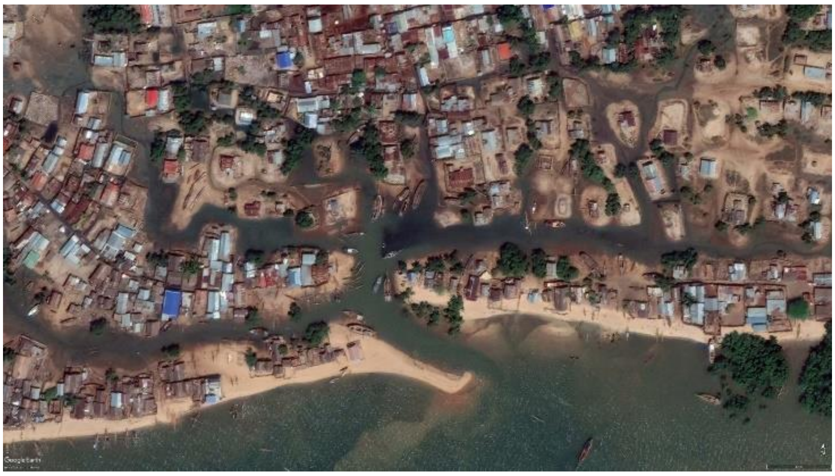
5.2.1.3 Cyclones

In addition to the heavy rainfall, cyclones bring destructive wind gusts that threaten the entire city. In practice, it is primarily the outdoor toilet cabins and the roofs of the drying beds at the FSTP that are exposed to the potential impacts of these winds (risk of tearing off or even destruction).

5.2.1.4 Sea level rise

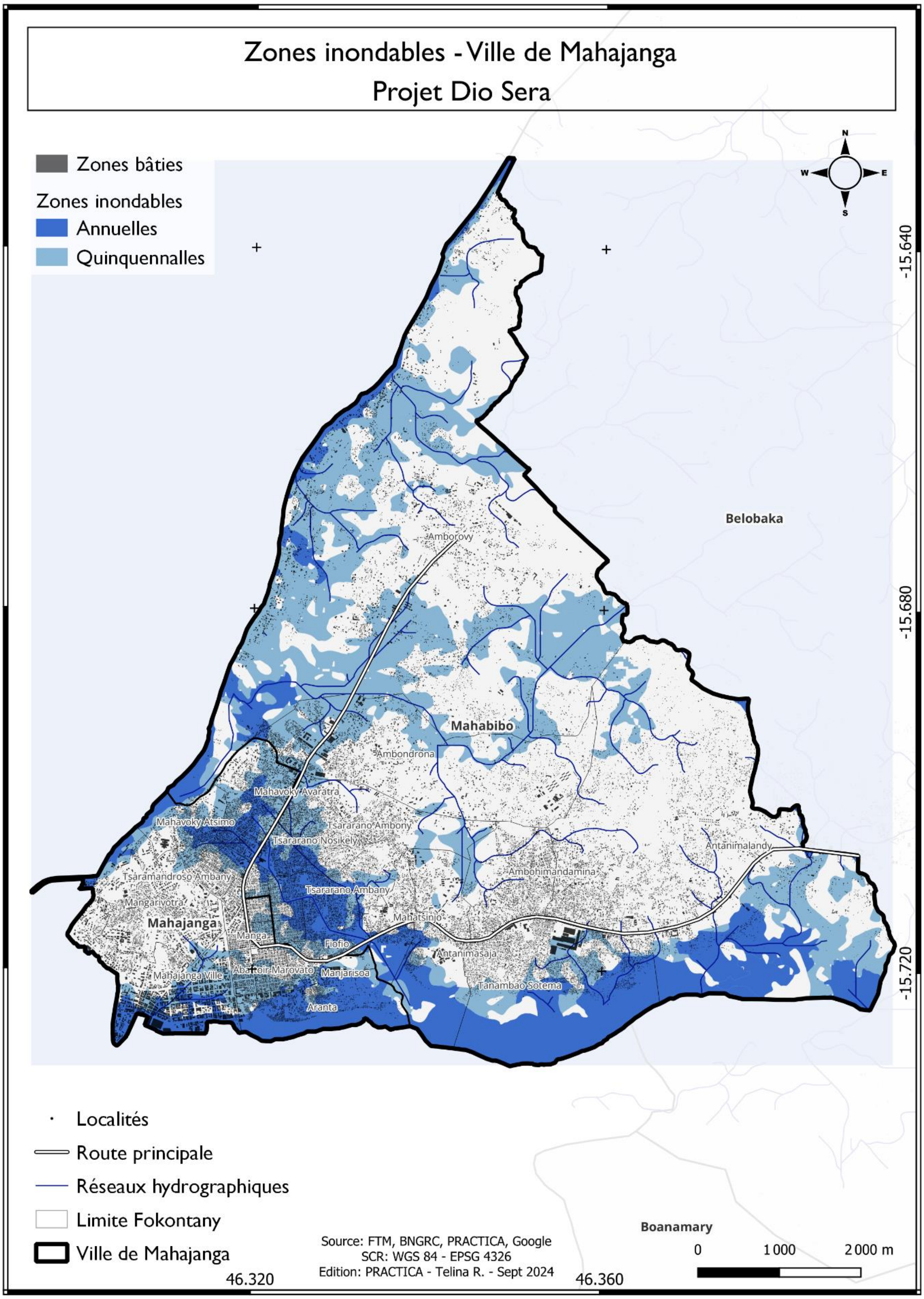
This phenomenon threatens domestic and public toilets in low-lying coastal areas. In practice, it leads to a risk of degradation, clogging, and overflow of toilets.

Figure 12. Satellite view of a fishing village in Aranta located in a low coastal area (Source: Google Earth)



The affected areas cover a built-up area of approximately 26 ha across the city, representing nearly 8,000 people. Main fokontany at risk include Mahajanga City, Aranta, Tanambao Sotema, and Antanimalandy.

Map 7. Flood prone areas in the city of Mahajanga



5.2.2 Sensitivity analysis

The following matrix presents the assessment of the vulnerability of the improved sanitation systems in Mahajanga exposed to the climatic hazards identified in section 4.2.1

Table 5. Vulnerability Assessment Matrix of Sanitation Systems in Mahajanga

Climate hazards	Sanitation system	Consequent risks	Level of sensitivity
Drought	Domestic and public flush toilets	Water restrictions resulting in non-functioning of toilets and unsafe sanitation practices	Low
Extreme precipitation / Flooding	Domestic toilets with a simple pit in flood-prone areas	Pits overflow / collapse leading to practices such as OD / flying toilets and fecal contamination	High sensitivity
	Domestic and public toilets with septic tanks in flood-prone areas	Overflow of sewage from septic tanks leading to fecal contamination	Moderate
	Municipal FSM service	Inaccessibility of unpaved alleys to FSM service leading to pits / septic tanks overflow and fecal contamination	Low
Cyclones	Domestic toilets located in the yard	Damage to superstructures making latrine unusable	Moderate
	FSTP	Damage of roofs covering drying beds	Moderate
Sea level rise	Domestic and public toilets located in low coastal areas	Damage to pits / septic tanks and overflow leading to fecal contamination	High sensitivity

5.3 FIANARANTSOA

5.3.1 Exposure analysis

5.3.1.1 Drought

The progressive decline in rainfall during the dry season leads to drought episodes and water scarcity affecting the entire city. According to [12], 25% of households report insufficient water to meet their daily needs. In 2020, most public sanitary blocks struggled to function due to water cuts lasting several consecutive days.

All domestic and public flush toilets in the city are at risk of non-functioning due to water scarcity caused by drought, leading to hygiene issues and even a return to unsanitary sanitation practices (open defecation, flying toilets, etc.).

However, the municipal sludge removal service is not exposed to this risk. Indeed, the principle of the FSTP (planted drying beds and aerated ponds followed by infiltration) is actually optimized when the weather is dry and temperatures are high.

5.3.1.2 Flooding

In Fianarantsoa, flood-prone areas represent about 6% of the total built-up area, affecting more than 13,000 inhabitants. Most of these areas are in fokontany with buildings located in low-lying areas, such as Idanda, Beravina, Talatamaty, and Antarandolo, among others. In practice, the city's morphology leads to population growth in flood-prone zones, as buildable plots at higher altitudes become scarcer.

Thus, all domestic and public toilets located in flood-prone areas are exposed to risks of destruction and blockage/release of fecal sludge during floods, leading to significant fecal contamination risks.

The coverage of the municipal sludge removal service is limited during heavy rains/floods due to the state of the roads in low-lying neighborhoods. Furthermore, the two access routes to the FSTP are highly exposed to runoff during rains due to their steep slopes. On several occasions, the Ambalataratasy track had to be rehabilitated due to erosion and/or landslides.

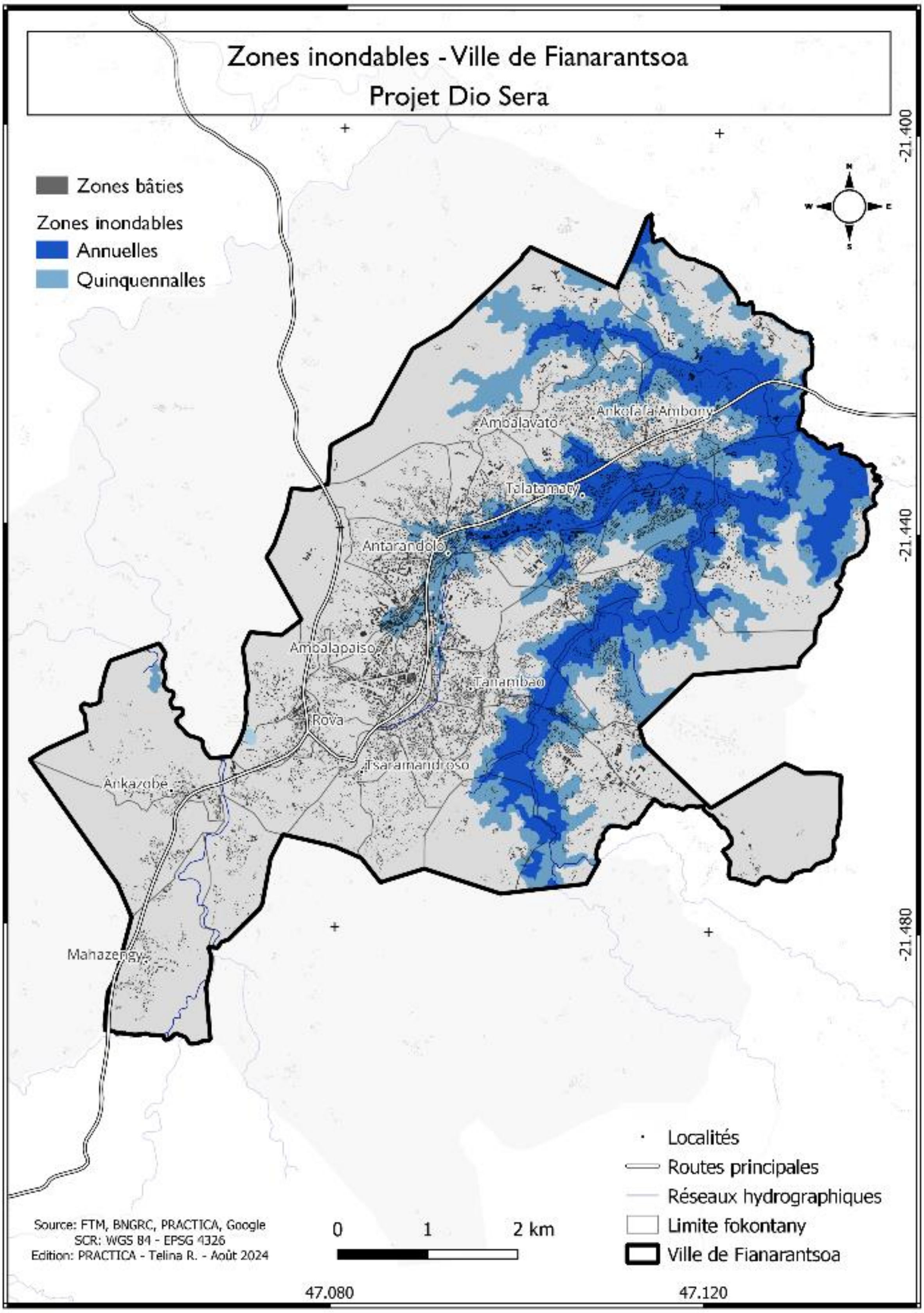
Figure 13. Landslide cutting access to the STBV after heavy rainfall in 2021 (Source: Practica)

5.3.1.3 Cyclones

Beyond heavy rainfall, cyclones bring destructive gusts of wind that can threaten the entire city.

In practice, it is primarily the outdoor toilet stalls and the roofs over the drying beds of the FSTP that are exposed to potential impacts from these winds, with risks of tearing off or even destruction.

Map 8. Flood prone areas in the city of Fianarantsoa



5.3.2 Sensitivity analysis

The following matrix presents the assessment of the vulnerability of the improved sanitation systems in Fianarantsoa exposed to the climatic hazards identified in section 4.3.1

Table 6. Vulnerability Assessment Matrix of Sanitation Systems in Fianarantsoa

Climate hazards	Sanitation system	Consequent risks	Level of sensitivity
 Drought	Domestic and public flush toilets	Water restrictions resulting in non-functioning of toilets and unsafe sanitation practices	Moderate
 Extreme precipitation / Flooding	Domestic toilets with a simple pit in flood-prone areas	Pits overflow / collapse leading to practices such as OD / flying toilets and fecal contamination	High sensitivity
	Domestic and public toilets with septic tanks in flood-prone areas	Overflow of sewage from septic tanks leading to fecal contamination	Moderate
	Domestic toilets with a simple pit in highland/sloped neighborhoods	People « drain » toilets during flood event	High sensitivity
	Municipal FSM service	Inaccessibility of flood-prone areas and FSTP leading to FSM service interruption	Moderate
 Cyclones	Domestic toilets located in the yard	Damage to superstructures making latrine unusable	Low
	FSTP	Damage of roofs covering drying beds	Moderate

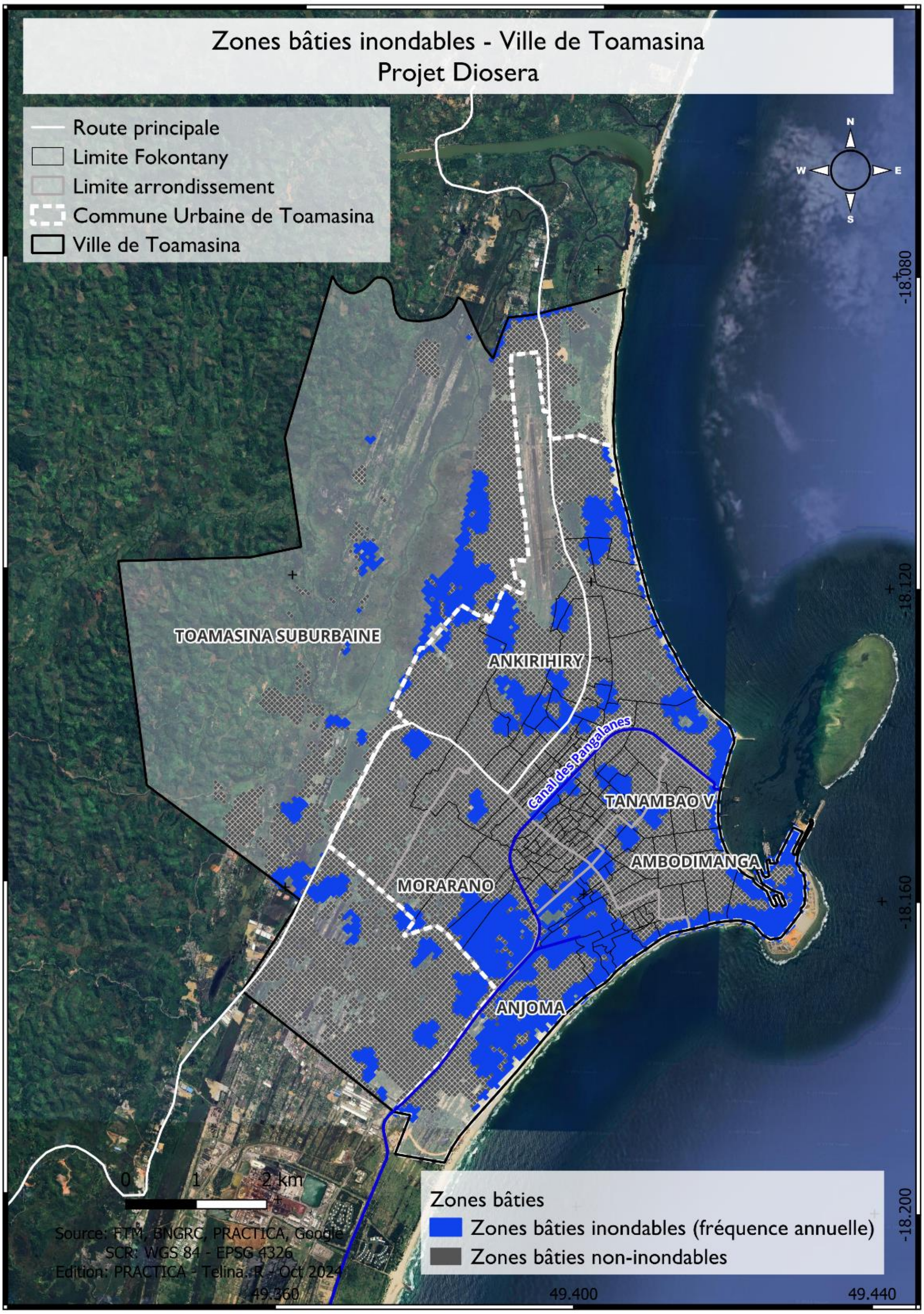
5.4 TOAMASINA

5.4.1 Exposure analysis

5.4.1.1 Inondations

In Toamasina, flood-prone built-up areas represent about 25% of the total built area and are home to over 100,000 residents. Many fokontany are flood-prone, located across the districts of Anjoma (Dépôt Analakininina...), Morarano (Tanambao verrerie...), Ankirihiry, and Ambodimanga.

Map 9. Flood prone areas in the city of Toamasina



All domestic and public toilets located in flood-prone areas are at risk of overflow and discharge of excreta and fecal sludge during floods, leading to significant risks of fecal contamination.

Moreover, the coverage of the municipal sludge removal service is limited during heavy rains or floods due to the condition of roads in flood-prone neighborhoods. The FSTP, however, remains accessible and operational throughout the year, as it is built on an embankment above the highest water levels of the nearby Vorikiny River.

5.4.1.2 Cyclones

Beyond heavy rainfall, cyclones bring destructive gusts of wind that threaten the entire city. In practice, it is primarily the outdoor toilet stalls that are exposed to potential impacts from these winds, with risks of tearing off or even destruction. The risk of material damage is particularly high since most households use stalls made of lightweight materials.

Figure 14. Overview of improved toilet stalls made of light materials (Source: Practica)

5.4.1.3 Sea level rise

This phenomenon threatens the domestic and public toilets along the southeastern coastal frontage of Toamasina, with acute risks of degradation and/or clogging and overflow. The affected areas cover a built-up area of approximately 56 hectares, with nearly 7,000 residents, primarily in the fokontany of Dépôt Analakininina.

Figure 15. Satellite view of the Dépôt Analakininina neighborhood exposed to storm surges (Source: Google Earth)

5.4.2 Sensitivity analysis

The following matrix presents the assessment of the vulnerability of the improved sanitation systems in Toamasina exposed to the climatic hazards identified in section 4.4.1.

Table 7. Vulnerability Assessment Matrix of Sanitation Systems in Toamasina

Climate hazards	Sanitation system	Consequent risks	Level of sensitivity
Extreme precipitation / Flooding	Domestic toilets with a simple pit in flood-prone areas	Pits overflow / collapse leading to practices such as OD / flying toilets and fecal contamination	High sensitivity
	Domestic and public toilets with septic tanks in flood-prone areas	Overflow of sewage from septic tanks leading to fecal contamination	Moderate
	Municipal FSM service	Inaccessibility of unpaved alleys to FSM service leading to pits / septic tanks overflow and fecal contamination	Low
Cyclones	Domestic toilets located in the yard	Damage to superstructures making latrine unusable	High sensitivity
	FSTP	Damage to infrastructure	Low
Sea level rise	Domestic and public toilets located in low coastal areas	Damage to pits / septic tanks and overflow leading to fecal contamination	High sensitivity

6 RISK ASSESSMENT

6.1 METHODOLOGY

The risk assessment focused on the sanitation systems identified as critically vulnerable in the previous step. Risks are often expressed as the combination of the consequences of an event and the associated likelihood of it occurring: RISK = LIKELIHOOD x CONSEQUENCES

Following table provides examples of qualitative definitions that have been used to characterize the likelihood of a risk occurring. The probability of a risk occurring is often described in qualitative terms. Only when there is sufficient data and capability can a quantitative description of likelihood be made, where the time horizon is the life of the asset.

Table 8. Qualitative definitions of likelihood

Level of Likelihood		Definition
5	**Almost certain**	More likely than not, probability greater than 50%
4	**Likely**	As likely as not, 50 / 50 chance
3	**Possible**	Less likely than not but still appreciable, probability less than 50% but still quite high
2	**Unlikely**	Unlikely but not negligible, probability low but noticeably greater than zero
1	**Rare**	Negligible, probability very low, close to zero

The definition of consequences was developed in collaboration with key stakeholders to identify important criteria. The selected criteria remained pragmatic, as follows:

- **Asset Damage:** Damage requiring minor restoration or repair is considered minor, while permanent damage or total loss of an asset is considered a significantly higher consequence;
- **Health and Safety:** A system whose malfunction or degradation affects a large population (for example, by contaminating a drinking water supply or agricultural fields) has higher consequences than one impacting a small population;

Table 9. Descriptor for consequences

Level of consequence		Definition
5	**Catastrophic**	Permanent damage and / or loss of infrastructure Substantial changes to the health and safety profile; risk of multiple fatalities as a result of extreme events.
4	**Major**	Extensive infrastructure damage requiring extensive repair Marked changes in the health and safety profile
3	**Moderate**	Damage recoverable by maintenance and minor repair Noticeable changes to health and safety profile
2	**Minor**	No permanent damage / Minor restoration work required Slight changes to health and safety profile
1	**Insignificant**	No damage Negligible or no changes to health and safety profile

Once the likelihood and consequence have been defined, the risk level was determined by multiplying the likelihood value by the consequences value to result in a score from 1 (Low) to 25 (Extreme). A resulting score was assigned one of five levels of risk: Not Significant (1), Low (2 to 4), Medium (5 to 10), High (12 to 16), or Extreme (20 to 25).

6.2 MAHAJANGA

The following table summarizes the results of the risk assessment of climate-induced hazards and climate change impacts on Mahajanga's sanitation systems. Key findings include:

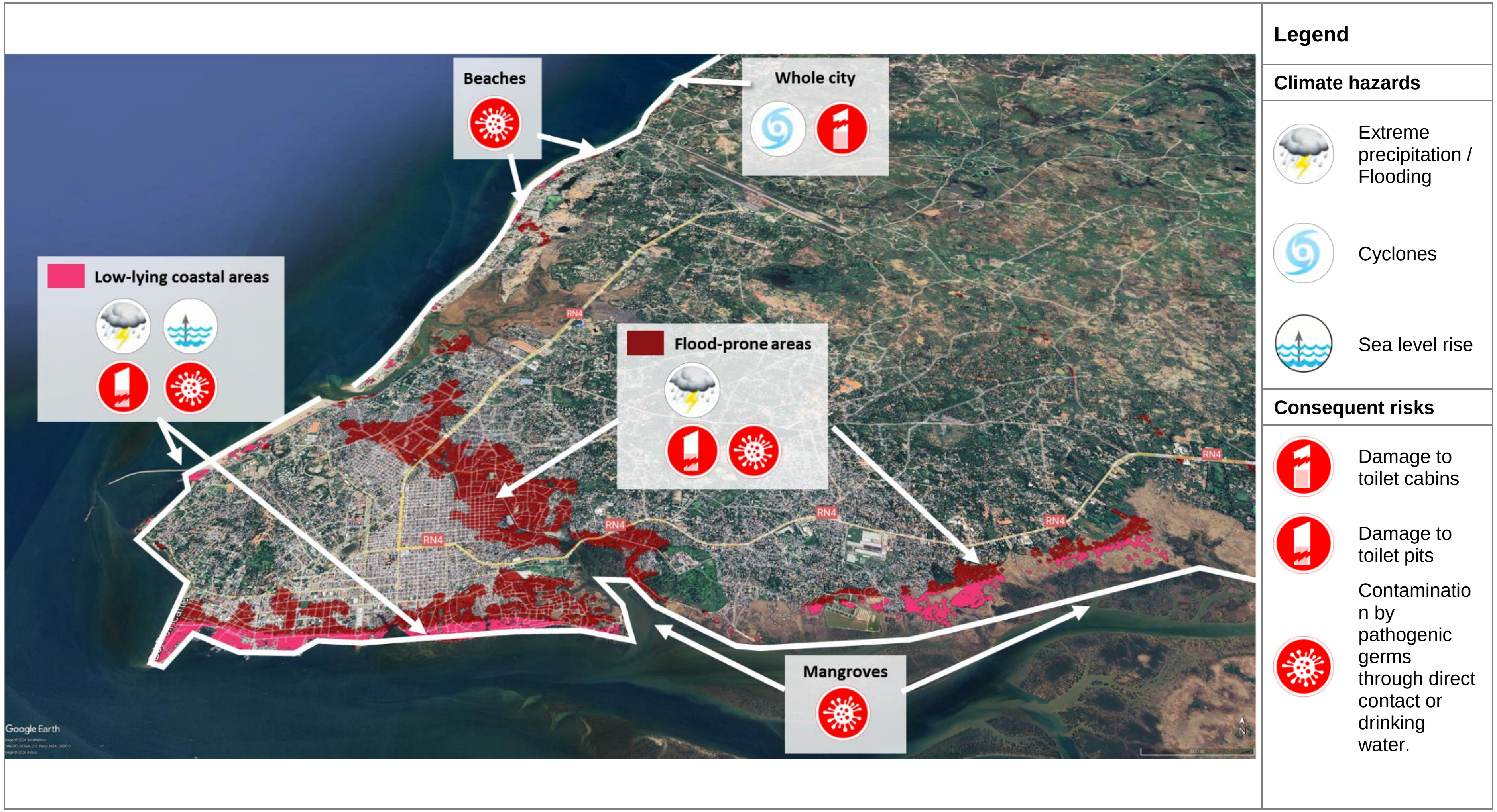
- **Flood risks for domestic toilets with simple pits are at an "extreme" level.** This is due to the high frequency of annual floods and the severe consequences they bring, with damage directly threatening more than 4,000 households, the release of excreta and fecal sludge in densely populated areas, and associated economic and environmental impacts (reconstruction costs and coastal degradation);
- **Overflow risks for septic tank toilets in flood-prone areas are "high."** More than 4,500 households in flood-prone neighborhoods use these installations, which risk releasing their contents and germs during heavy rains;
- Also classified as "high" risks are **(i) cyclone-induced degradation of the superstructures of outdoor domestic toilets**, particularly because 20% of the city's households (over 15,000 households) use toilets with stalls made from light materials, and **(ii) sea level rise damaging toilets in low coastal areas.** More than 2,000 households are directly affected, as well as public toilets. Additionally, the surrounding environment (beaches, fishing areas, mangroves) is especially vulnerable.
- **Cyclone damage risks to the FSTP roofs are classified as "moderate."** The FSTP location, over 10 km from the coast, lowers the likelihood of severe impact, and the FSTP can still function without a roof (added in 2021 to optimize the treatment capacity of the facility).

Table 10. Risk Assessment Matrix of Induced Risks in Mahajanga

Climate hazards	Sanitation system	Climate impacts and consequent risks	Likelihood	Consequences	Level of risk
 Extreme precipitation / Flooding	Domestic toilets with a simple pit in flood-prone areas	Pits overflow / collapse leading to practices such as OD / flying toilets and fecal contamination	4	5	Extreme (20)
	Domestic and public toilets with septic tanks in flood-prone areas	Overflow of sewage from septic tanks leading to fecal contamination	3	4	High (12)
 Cyclones	Domestic toilets located in the yard	Damage to superstructures making latrine unusable	3	4	High (12)
	FSTP of Marohogo	Damage of roofs covering drying beds	2	4	Medium (8)
 Sea level rise	Domestic and public toilets located in low coastal areas	Damage to pits / septic tanks and overflow leading to fecal contamination	4	4	High (16)

It should be noted that the "extreme" and "high" risks mentioned above are already impacting the sanitation systems in Mahajanga. What the climate projections in Chapter 4.2.1 clarify is the potential for the extension and intensification of these risks in the future. Therefore, these risks will require adaptation measures, which will be defined in a collaborative manner with stakeholders.

Figure 16. Visualization of the risks induced by climate hazards on sanitation systems in Mahajanga



6.3 FIANARANTSOA

The following table summarizes the results of the risk assessment of climate-induced hazards and climate change impacts on the sanitation systems in Fianarantsoa. Key findings include:

- **The risks associated with flooding of domestic toilets with simple pits are the highest, at an "extreme" level.** This is due to the high frequency of floods (annual) and the magnitude of their consequences, with damage directly threatening more than 4,500 households, and the release of fecal matter in a context where more than half of the population relies on vulnerable well water and large areas of lowlands are cultivated;
- **The risk of interruption of the municipal sludge removal service due to access route blockages from heavy rains is classified as "high."** Massive road damage can occur, leading to prolonged service interruptions and significant rehabilitation costs. Additionally, there are risks of accidents during transport operations;
- **The risk of "draining" the simple pit toilets during heavy rains, in the neighborhoods located at higher altitudes, is also "high."** Technically, more than 35,000 HHs could resort to this practice, which is difficult to control and leads to massive pollution in neighborhoods and large agricultural areas in lowlands.

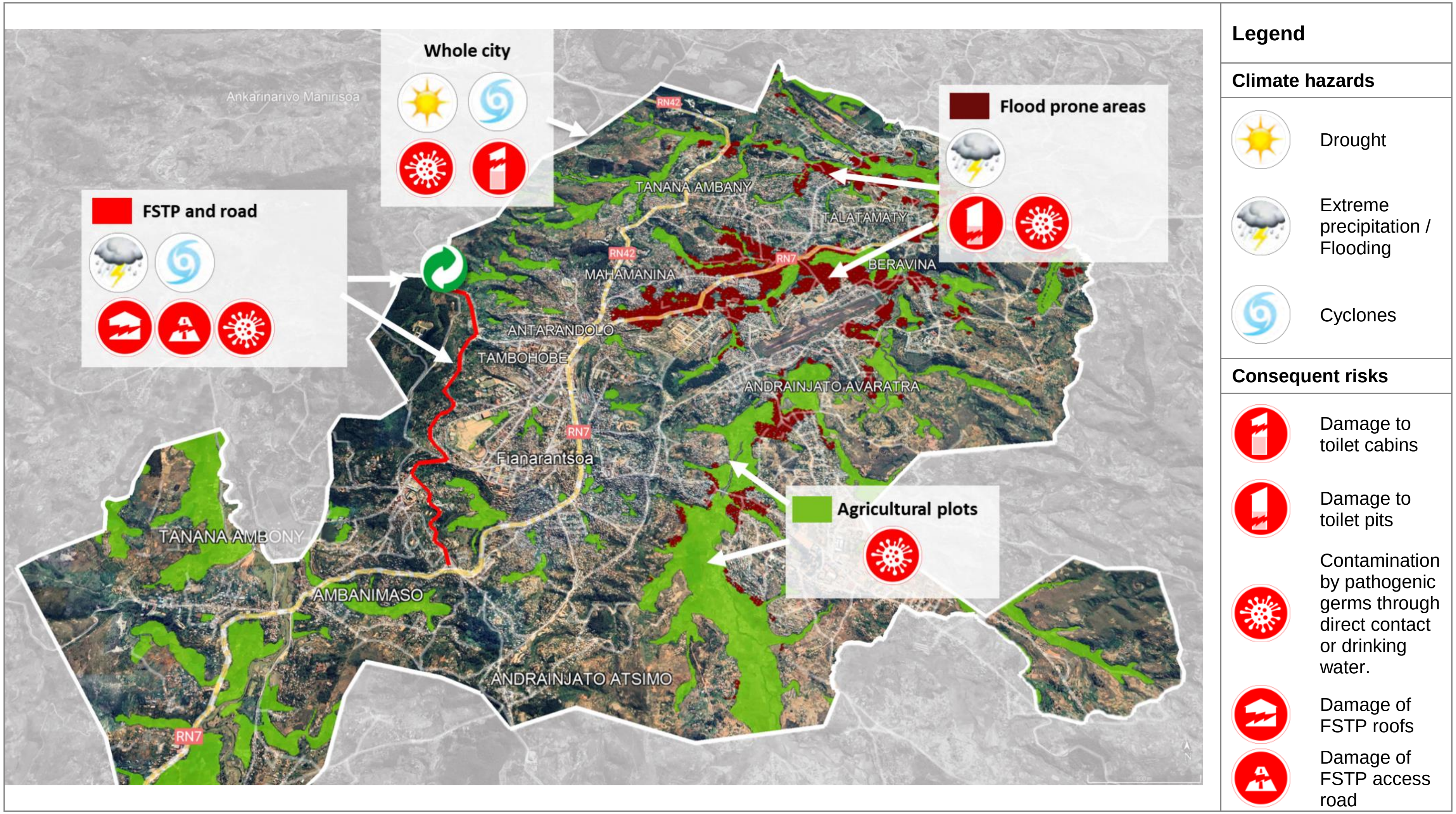
Table 11. Risk Assessment Matrix of Induced Risks in Fianarantsoa

Climate hazards	Sanitation system	Climate impacts and consequent risks	Likelihood	Consequences	Level of risk
 Drought	Domestic and public flush toilets	Water restrictions resulting in non-functioning of toilets and unsafe sanitation practices	2	3	Medium (6)
 Extreme precipitation / Flooding	Domestic toilets with a simple pit in flood-prone areas	Pits overflow / collapse leading to practices such as OD / flying toilets and fecal contamination	4	5	Extreme (20)
	Domestic and public toilets with septic tanks in flood-prone areas	Overflow of sewage from septic tanks leading to fecal contamination	2	4	Medium (8)
	Domestic toilets with a simple pit in highland/sloped neighborhoods	People « drain » toilets during flood event	3	5	High (15)
	Municipal FSM service	Inaccessibility to FSTP leading to FSM service interruption	4	4	High (16)
 Cyclones	FSTP	Damage of roofs covering drying beds	2	4	Medium (8)

The risks of overflow from septic tank toilets in flood-prone areas are classified as "moderate" as only around 1,000 households in flood-prone neighborhoods use this type of installation, which risks releasing their contents and the germs they contain during heavy rains. Also categorized as "moderate" risks are (i) the malfunction of flush toilets, primarily because only 20% of the population uses this type of facility, and (ii) the risk of roof degradation for the FSTP, mainly because Fianarantsoa is not regularly exposed to cyclone gusts and the FSTP can operate without a roof.

It should be noted that the "extreme" and "high" risks mentioned above are already impacting the sanitation systems in Fianarantsoa. What the climate projections in Chapter 4.4.1 highlight is the potential for the extension and intensification of these risks in the future. Therefore, these risks will require adaptation measures, which will be defined collaboratively with stakeholders.

Figure 17. Visualization of the risks induced by climate hazards on sanitation systems in Fianarantsoa



6.4 TOAMASINA

The following table summarizes the results of the risk assessment of climate-induced hazards and climate change impacts on the sanitation systems in Toamasina. Key findings include:

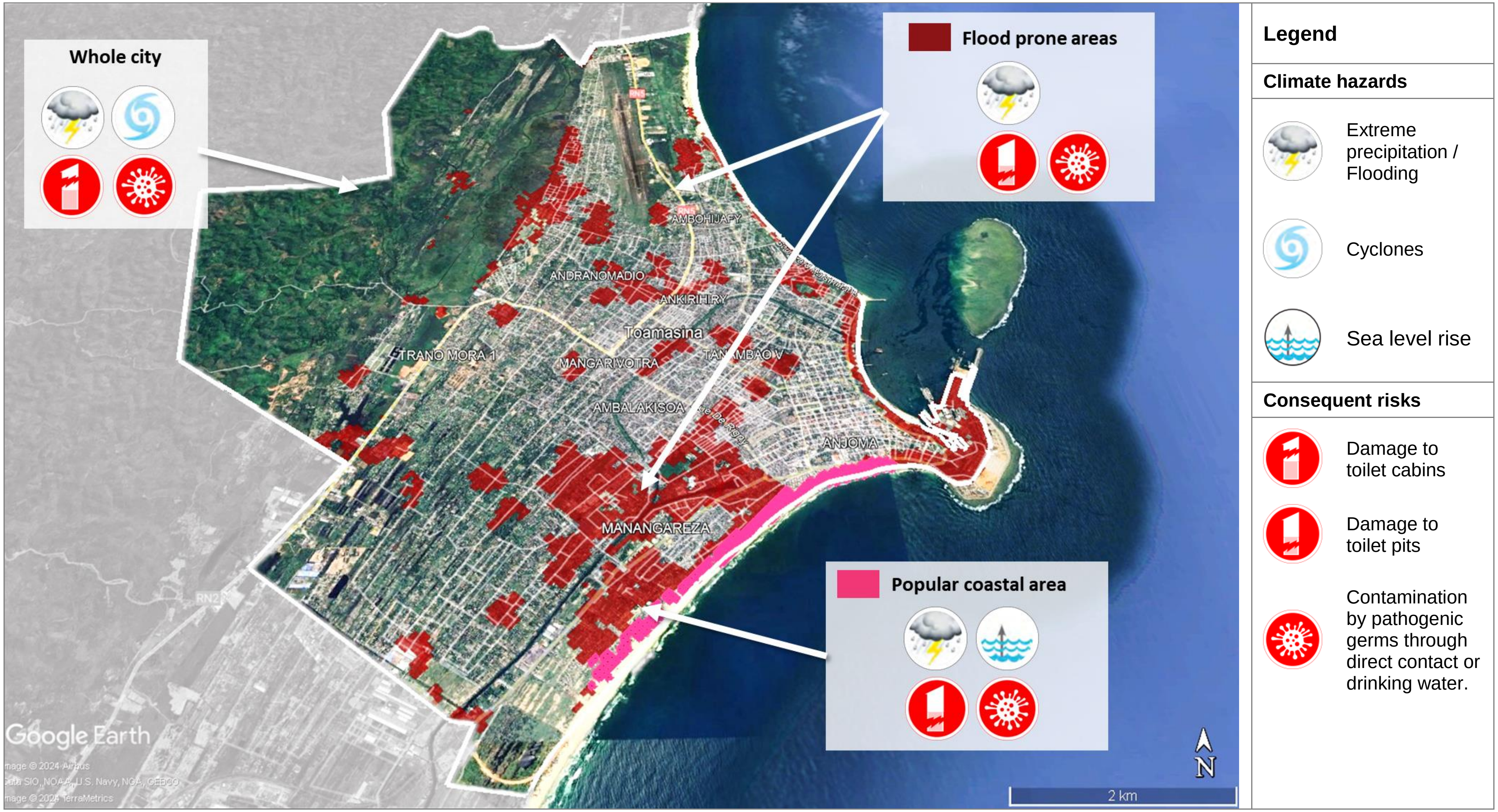
- **Flood risks for domestic toilets with simple pits are the highest, classified as "extreme".** This is due to the high frequency of floods (annual) and their severe consequences, with damage directly threatening over 16,000 households, the release of excreta and fecal sludge in densely populated areas, and associated economic and health impacts, particularly since 55% of households rely on tany pumps for water, which are vulnerable to surface contamination;
- **Overflow risks for septic tank toilets in flood-prone areas are also classified as "extreme".** Nearly 10,000 households in flood-prone neighborhoods use this type of installation, which risks releasing their contents and pathogenic germs onto the surface during heavy rains, contaminating water from pitch pumps;
- **The risk of cyclone-induced degradation of the superstructures of outdoor domestic toilets is "high"**, particularly as 55% of the population (over 65,000 households) uses toilets with stalls made from lightweight materials. While this practice is part of a resilience strategy, it compromises user privacy and safety in daily use and impacts post-cyclone access to toilets;
- **Risk related to sea level rise and domestic and public toilets in Dépôt Analakininina are also "high".** Nearly 2,000 households are directly affected, as well as public toilets. Additionally, the surrounding environment (dense neighborhoods, fishing areas) is especially sensitive.

Table 12. Risk Assessment Matrix of Induced Risks in Toamasina

Climate hazards	Sanitation system	Climate impacts and consequent risks	Likelihood	Consequences	Level of risk
Extreme precipitation / Flooding	Domestic toilets with a simple pit in flood-prone areas	Pits overflow / collapse leading to practices such as OD / flying toilets and fecal contamination	5	5	Extreme (25)
	Domestic and public toilets with septic tanks in flood-prone areas	Overflow of sewage from septic tanks leading to fecal contamination	5	4	Extreme (20)
Cyclones	Domestic toilets located in the yard	Damage to superstructures making latrine unusable	4	3	High (12)
Sea level rise	Domestic and public toilets located in low coastal areas	Damage to pits / septic tanks and overflow leading to fecal contamination	4	4	High (16)

It should be noted that the "extreme" and "high" risks mentioned above are already impacting the sanitation systems in Toamasina. Climate projections in Chapter 5.4.1 indicate the likelihood of these risks extending and intensifying in the future. Therefore, these risks will require adaptation measures, which will be collaboratively defined with stakeholders.

Figure 18. Visualization of the risks induced by climate hazards on sanitation systems in Toamasina



7 CONCLUSION

The three intervention cities of Dio Sera have tropical climates, imposing significant constraints on sanitation infrastructure, especially due to heavy rainfall, flooding, and cyclones. Expert forecasts indicate that these extreme events are expected to persist or even intensify.

In Mahajanga, the primary climatic hazards affecting sanitation systems are extreme rainfall, floods, intense cyclones, and sea level rise.

The main resulting risks are:

1. Degradation and overflow of simple pit toilets and septic pit toilets in flood-prone areas during heavy rains, a particularly severe risk as 15% of the population (around 12,000 households) live in such areas;
2. Damage to outdoor toilet cabins from cyclone winds, which endangers 20% of the population (around 15,000 households) who use structures made of lightweight materials;
3. Deterioration of coastal toilets due to tidal surges, affecting 3% of the population (around 2,000 households) and several public toilets;

In addition to localized health and economic impacts, there are risks of contaminating swimming areas (used by over 100,000 people annually), fishing areas, and mangroves, which are essential resources for the city and its inhabitants.

In Fianarantsoa, the most threatening climatic hazards for sanitation systems are drought, extreme rains, and flooding.

The main resulting risks are:

1. Degradation and overflow of simple pit toilets in flood-prone areas during heavy rains, directly impacting 6% of the population (around 3,000 households).
2. Degradation and potential blockage of the access route to the FSTP, a particularly vulnerable route due to the condition of the paths and the steep slopes leading to the site. Several erosion and landslide events have occurred in the last five years.
3. “Drainage” of simple pit toilets by households in highland areas, a difficult-to-control practice that poses contamination risks to lower-lying neighborhoods and agricultural lowlands.

Additional "medium" risks include (i) septic pit toilet overflow in flood-prone areas, (ii) malfunctioning of flush toilets due to drought, and (iii) damage to FSTP roofs from intense cyclones.

Overall, the breakdown and degradation of sanitation systems indirectly threaten wells (used by over half the population) and the vast lowland agricultural areas (over 600 hectares) integral to the daily life, economy, and cultural identity of Fianarantsoa.

In Toamasina, the climatic threats to sanitation systems are extreme, with average rainfall of about 3,000 mm/year and nearly annual cyclones. Heavy rains, floods, cyclones, and sea level rise are major risks to the economic capital of the country.

The main risks to sanitation systems include:

1. Degradation and overflow of simple and septic pit toilets in flood-prone areas during heavy rains, affecting 25% of the population (about 30,000 households).
2. Damage to outdoor toilet cabins from tropical cyclone winds, threatening 55% of households (around 65,000 households) using structures made of lightweight materials. While this practice reflects a resilience strategy, it affects user privacy, safety, and access to toilets post-cyclone.

3. High risk of degradation of domestic and public toilets due to sea level rise in Dépôt Analakininina. Nearly 2,000 households and public toilets are directly affected, with significant sensitivity in surrounding areas (densely populated neighborhoods, fishing zones).

In addition to local health and economic impacts, there are risks of contaminating groundwater, used by half the population, as well as fishing areas, which are key socio-economic resources for the city.

Already, above mentioned risks heavily impact the three cities, with high occurrence rates and substantial health, economic, and environmental consequences.

Climate hazards are already occurring. Several public toilets are affected by these climate hazards, such as those in Mahajanga and Toamasina, where latrine pits deteriorate due to tidal influences, and those in Fianarantsoa, where water supply must be brought by cart during the dry season.

Regarding FSM, the study indicates that the design of existing systems has considered current and future climate risks, selecting resilient transport and treatment solutions (for drought, heavy rains, and cyclones). However, the degradation or blockage of the access road to the FSTP remains a critical issue likely to worsen in the short term.

Next steps. Based on the previous analyses, the study will continue with the identification of adaptation measures, in collaboration with partner stakeholders in each of the three cities.

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8 REFERENCES

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9 APPENDICES

ANNEXE 1: ATTENDANCE SHEETS

(link)

ANNEXE 2: CLIMATE ANALYSIS / MAHAJANGA

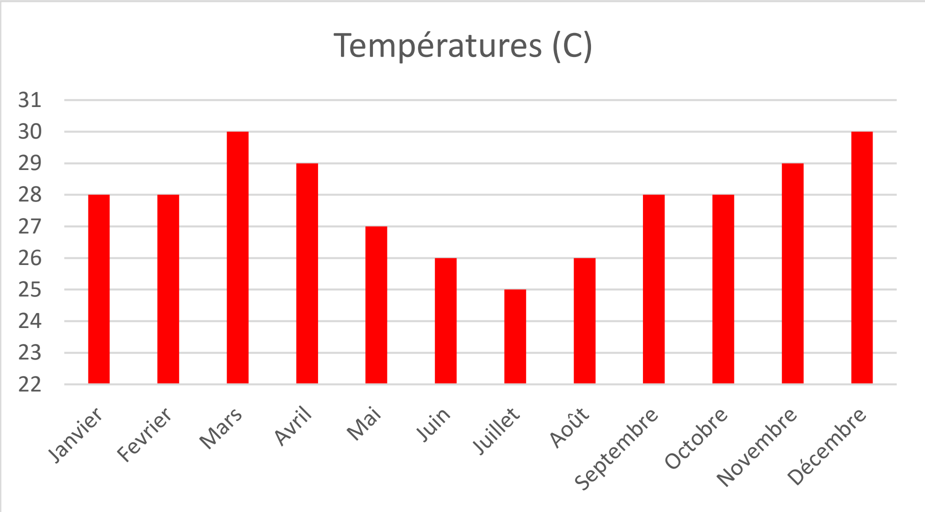
9.1.1 Revue des paramètres

Mahajanga est située dans la zone climatique Nord-Ouest selon la classification de la Direction Générale de la Météorologie. Il est caractérisé par un climat relativement plus chaud et plutôt sec.

Température

La température moyenne annuelle de Mahajanga se situe généralement autour de 25°C à 30°C, la température maximale peut atteindre 34°C. La figure ci-après illustre la variabilité de la température au cours d'une année.

Figure 19 : Température moyenne annuelle de la ville de Mahajanga

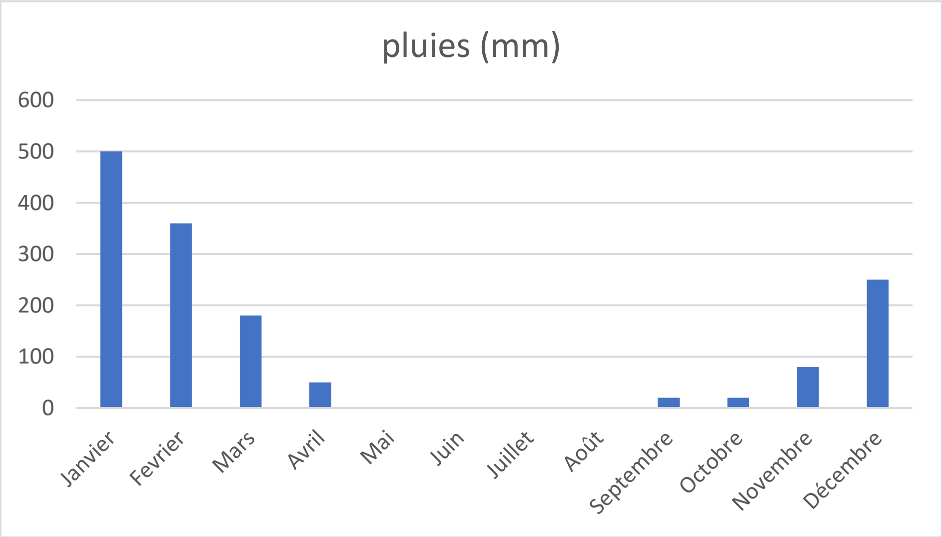


Source : Atlas Climatologique de Madagascar, Direction Générale de la Météorologie, 2014

Pluviométrie

Mahajanga reçoit annuellement 1 000 à 1 500 mm de précipitations avec une saison pluvieuse, oppressant et couvert en mois de Novembre à Avril ; et une saison sèche lourd, venteux et dégagé dans l'ensemble en mois de mai à octobre.

Figure 20 : Pluviométrie moyenne annuelle à Mahajanga



Source : Atlas Climatologique de Madagascar, Direction Générale de la Météorologie, 2014

Cyclones tropicaux

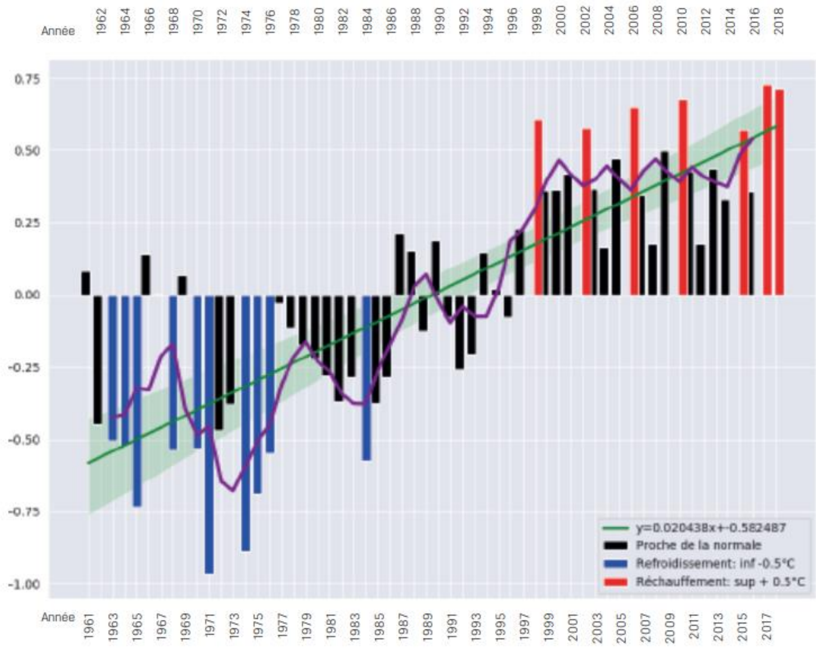
Mahajanga, sur la côte nord-ouest de Madagascar, est une région vulnérable aux cyclones tropicaux, bien que la fréquence et l'intensité des cyclones qui l'atteignent soient généralement moindres que sur la côte-est de l'île. Néanmoins, Mahajanga n'est pas à l'abri des impacts directs et indirects des cyclones, laissant des dégâts catastrophiques considérables.

9.1.2 Tendances

Tendance de la Température

La figure suivante indique l'évolution temporelle de température moyenne annuelle (en °C), observées sur la côte Nord-Ouest de Madagascar entre 1961 et 2018.

Figure 21 : Evolution temporelle de température moyenne annuelle à Mahajanga entre 1961 et 2018



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar – 2023

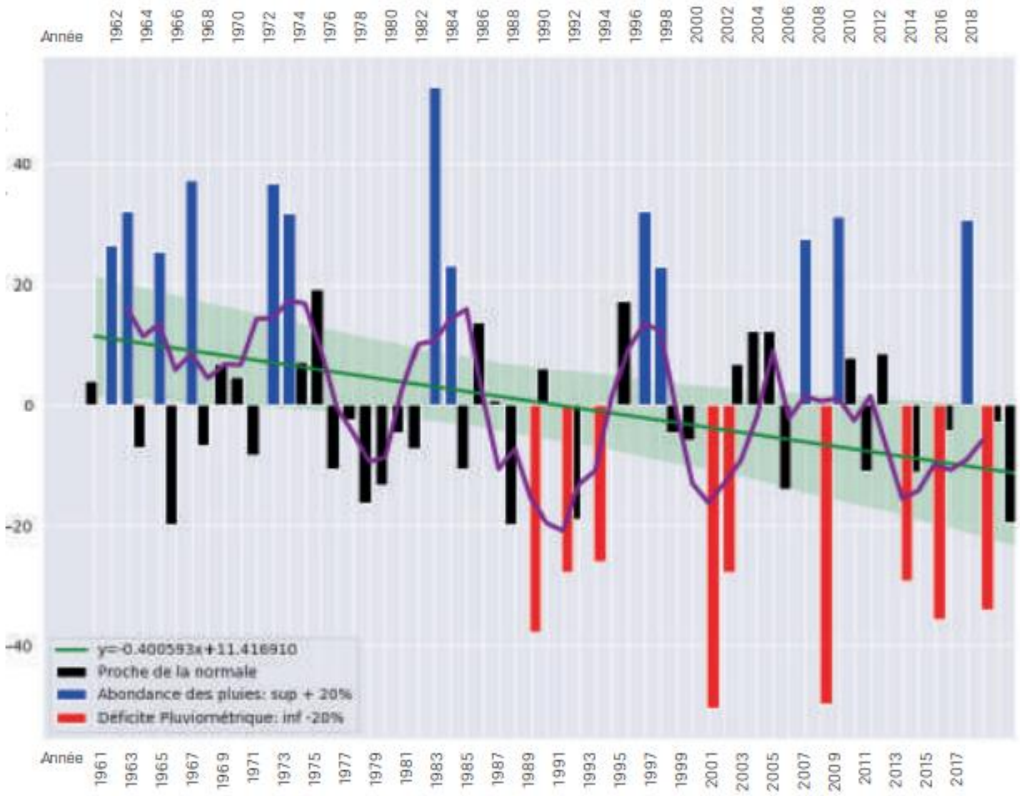
<u>Observations de la DGM :</u>

La ligne verte représente la tendance la température moyenne annuelle pendant la période d'observation. Une augmentation de la témpérature de +0,23°C par décennie sur la côte Nord-Ouest est observé.

<u>Tendance de la Pluviométrie annuelle</u>

La figure suivante indique l'évolution temporelle du cumul annuel de précipitations observées sur la zone climatique de la Côte Nord-Ouest entre 1961 et 2018.

Figure 22 : Evolution temporelle du cumul annuel de précipitations à Mahajanga entre 1961 et 2018



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar – 2023

Observations de la DGM :

La ligne verte dans la figure représente la tendance de la pluviométrie annuelle pendant la période d'observation. Une baisse de -4,5% du cumul annuel de précipitations sur la côte Nord-Ouest est observée en 58 ans.

Tendance de Cyclones tropicaux

Même situation que dans l'ensemble de l'île, soit une légère tendance à la hausse pour le nombre de système ayant atterri au stade de cyclone tropical intense.

Tendance d'augmentation du niveau de la mer

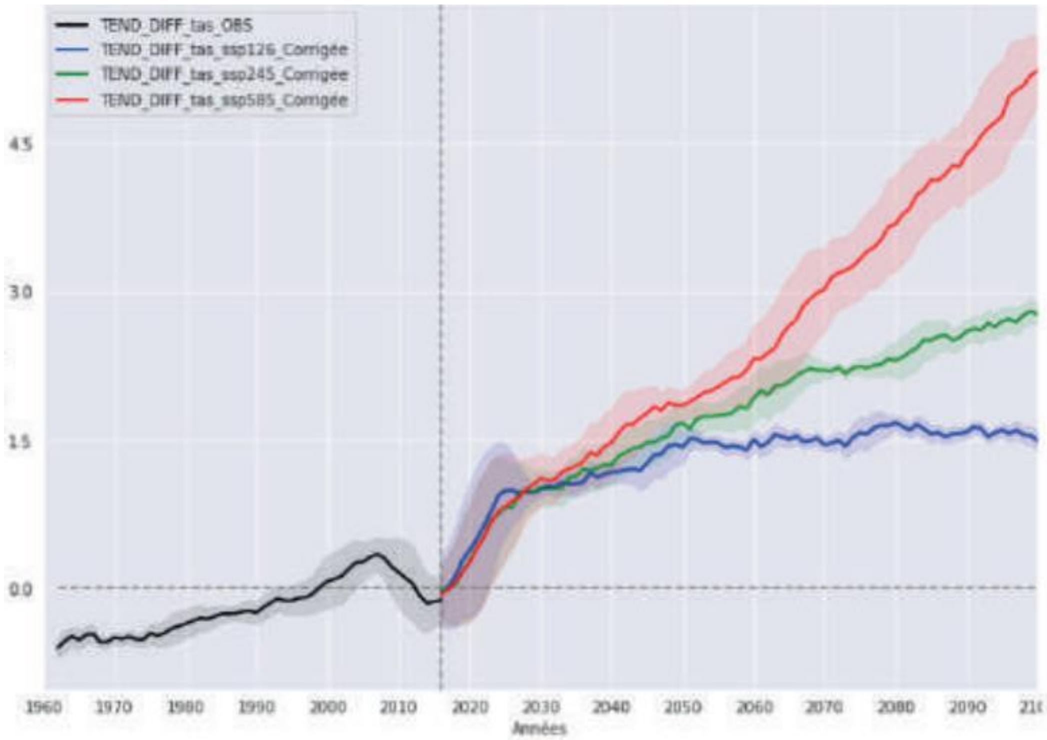
Même situation qu'à Toamasina, sur les 25 dernières années, on relève pour le bassin SOOI une élévation relativement importante du niveau de la mer de +12 cm, soit +5 mm/an en moyenne, supérieure à la valeur moyenne relevée sur le globe.

9.1.3 Projections

Projection de la Température

Selon la même étude de la direction générale de la météorologie de Madagascar sur les tendances climatiques et les futurs changements climatiques à Madagascar, on peut voir l'évolution temporelle de températures moyennes annuelles de la zone Nord-Ouest jusqu'à l'an 2100 suivant les 3 scénarios SSP sur la figure ci-après

Figure 23 : Evolution temporelle de la température sur la période 1961-2100 selon les trois scénarios à Mahajanga



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar – 2023

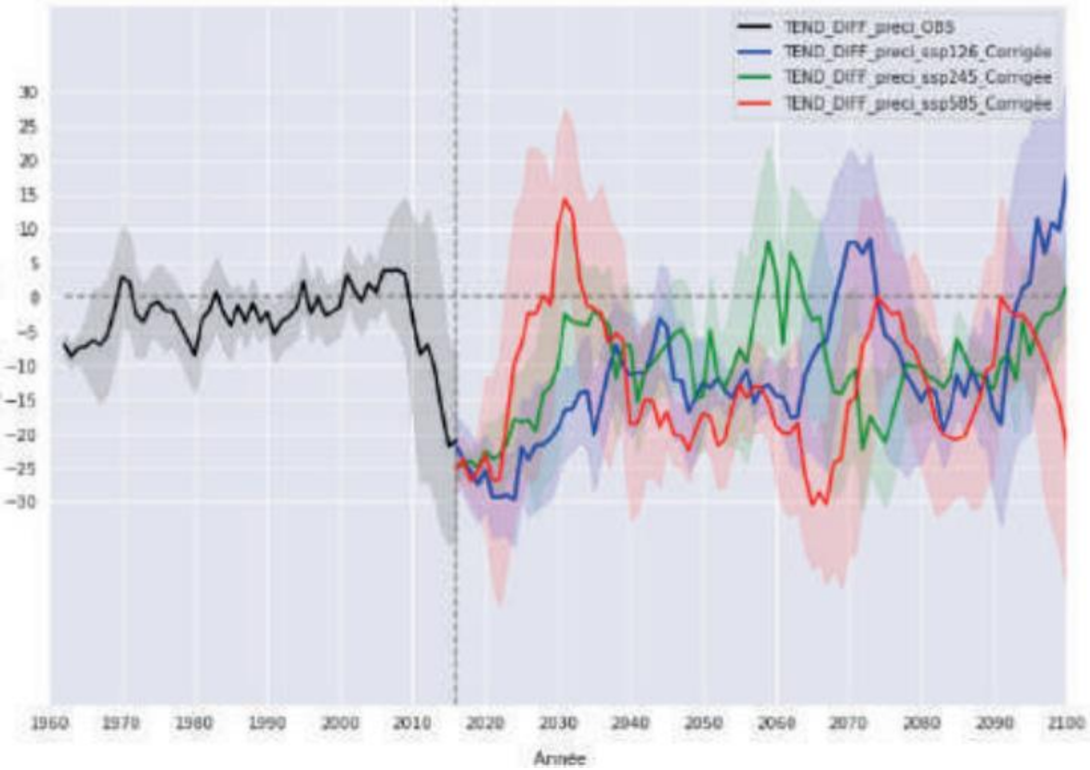
Observations de la DGM :

Dans les 3 scénarios, comme dans le cas général de toute l'île on peut observer une montée significative de la température, de l'ordre de +1,5°C pour le scénario le plus optimiste et de +3°C à +5°C par rapport à la normale pour le scénario le plus pessimiste attendu entre 2071 à 2100 pour la zone climatique de la côte Nord-Ouest.

Projection de la Pluviométrie

La projection de l'évolution temporelle sur la période 1961-2100 des précipitations annuelles pour la zone climatique du Nord-Ouest et selon les trois scénarios climatiques se présente sur la figure ci-après :

Figure 24 : Evolution temporelle de la pluviométrie sur la période 1961-2100 à Mahajanga



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar – 2023

Observations de la DGM:

On peut constater que tous les scénarios projettent une baisse des précipitations entre -10% et -20% pour la zone Nord-Ouest.

9.1.4 Synthèse du climat, de la tendance et de la projection du climat à Mahajanga

La ville de Mahajanga est caractérisée par :

- Un climat tropical chaud et plutôt sec avec (i) une température moyenne annuelle de 25°C à 30°C et une température maximale de 34°C, (ii) des précipitations annuelles variant de 1000 mm et 1500 mm dont la grande partie est enregistrée en janvier et février, où les précipitations mensuelles peuvent atteindre entre 300 mm et 500 mm, (iii) des passages de cyclone intense, (iv) des marées hautes de plus en plus fréquentes
- Une tendance à la hausse de la température +0,23°C par décennie et une baisse de -4,5% par décennie du cumul annuel de précipitations en 58 ans,
- Une projection d'augmentation de la température de l'ordre de +1.5°C jusqu'à 2100 selon le scénario le plus optimiste, une baisse des précipitations annuelles, de l'ordre de -10% à -20% au même horizon.

Les précipitations mensuelles de janvier et février, coïncidant généralement avec la période cyclonique, sont relativement abondantes, ayant comme impact l'inondation du vallon de Metzinger, et ainsi y affecte le système d'assainissement.

Les faibles précipitations observées sur la longue période de mars à novembre n'affectent pas de manière significative le bon fonctionnement des toilettes à chasse dans la ville de Mahajanga étant donné que l'approvisionnement en eau du réseau JIRAMA est assuré par des forages profonds.

Les marées hautes de plus en plus fréquentes ces dernières années ravagent les toilettes utilisées dans le village des pêcheurs situés dans la mangrove.

En résumé, les pluies intenses de janvier - février, les cyclones tropicaux et la montée du niveau de la mer sont les aléas qui pèsent directement sur le système d'assainissement dans la ville de Mahajanga

ANNEXE 3: CLIMATE ANALYSIS / FIANARANTSOA

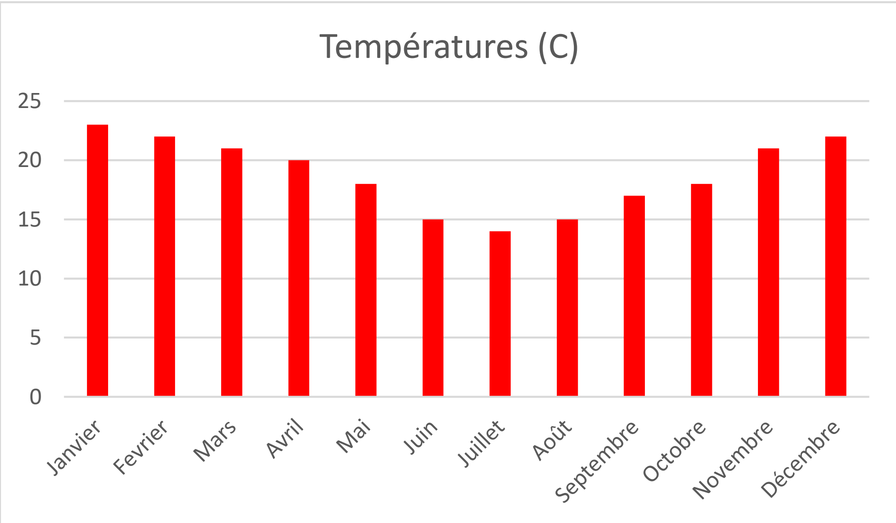
9.1.5 Revue des paramètres

Fianarantsoa est située dans la zone climatique des Hautes Terres Centrales suivant la classification de la Direction Générale de la Météorologie. Il est caractérisé par un climat tropical d'altitude, avec des précipitations plus abondantes en Novembre et avril ; puis d'un climat sec et froides de mai en octobre.

Température

La température moyenne annuelle de Fianarantsoa se situe généralement autour de 18°C à 20°C, avec une température maximale de 25°C. Les variations de température sont modérées tout au long de l'année. La figure ci-après illustre la variabilité de la température au cours d'une année.

Figure 25 : Moyennes mensuelles des températures Fianarantsoa

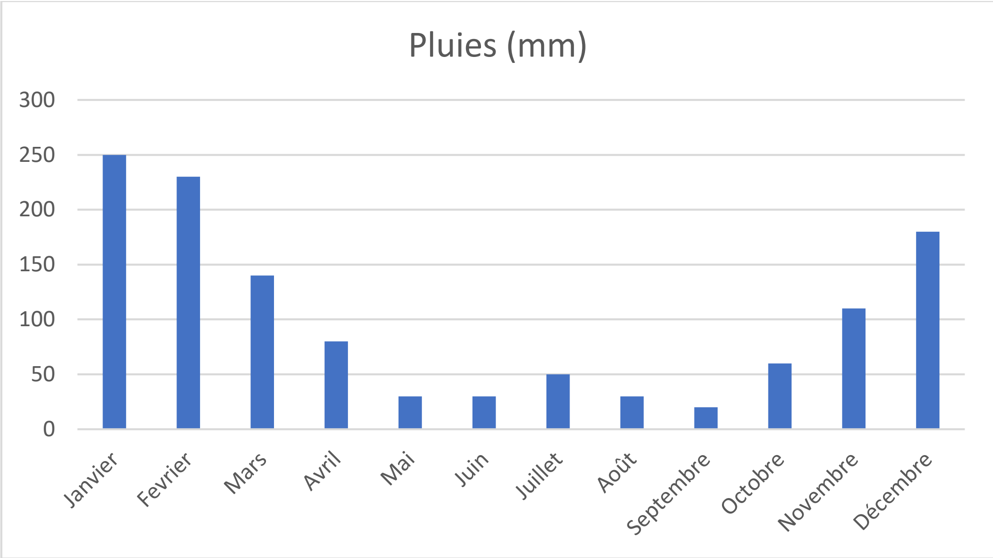


Source : Atlas Climatologique de Madagascar, Direction Générale de la Météorologie, 2014

Pluviométrie

Fianarantsoa reçoit annuellement 1 000 à 2 000 mm de précipitations ; 90 à 95 % du total annuel des précipitations tombent de novembre à avril, tandis que le mois le plus sec se situe en septembre.

Figure 26 : Moyennes Mensuelles des pluies Fianarantsoa



Source : Atlas Climatologique de Madagascar, Direction Générale de la Météorologie, 2014

Cyclones tropicaux :

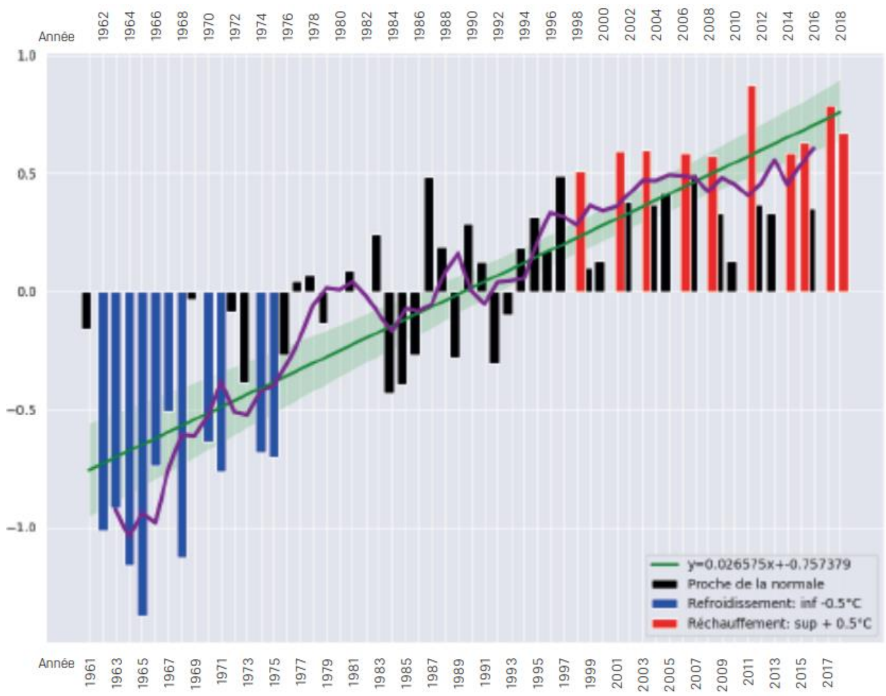
En matière de cyclones, la ville de Fianarantsoa subit des effets plus atténués que les zones côtières. Située dans les Hautes Terres Centrales, elle n'est pas directement touchée par les cyclones, mais elle subit souvent des effets secondaires sous forme de pluies torrentielles, inondations, glissements de terrain, et vents violents lorsque les cyclones se déplacent à l'intérieur des terres. ´

9.1.6 Tendances

Tendance de la température

La figure 12 indique l'évolution temporelle de la température moyenne annuelle (en °C), observée sur la zone tropicale d'altitude de Madagascar entre 1961 et 2018.

Figure 27 : Evolution temporelle de la température moyenne annuelle



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar, Direction Générale de la Météorologie Madagascar – 2023

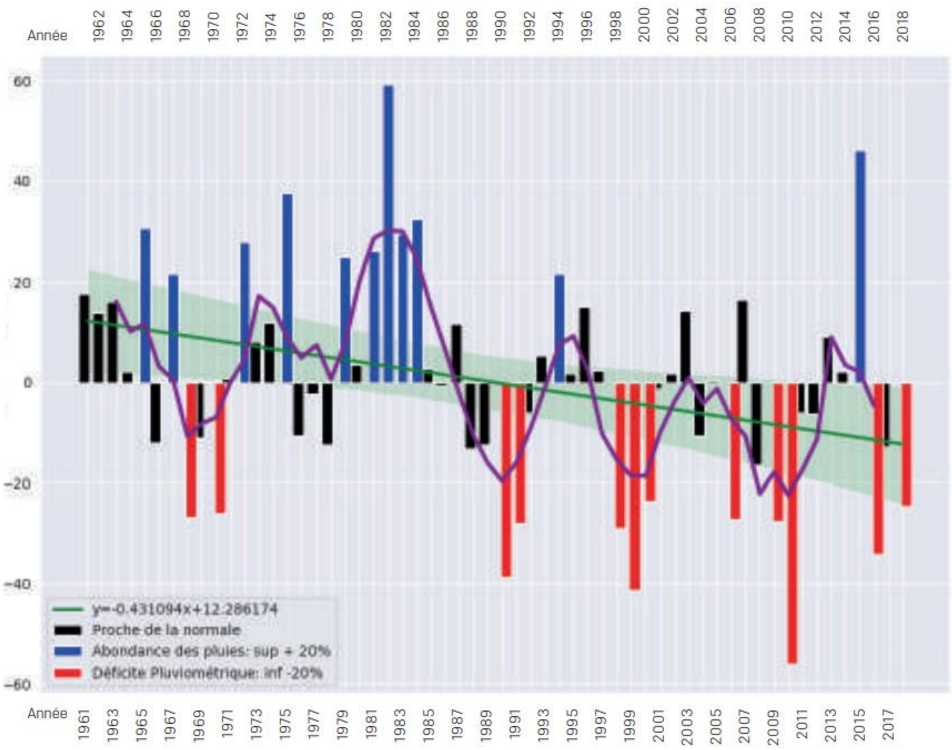
Observations de la DGM :

La ligne verte représente la tendance moyenne de la température sur la période 1961-2018. On constate une augmentation de +0,3°C par décennie sur les Hautes Terres Centrales.

Tendance de la Pluviométrie

La figure 13 indique l'évolution temporelle du cumul annuel de précipitations observées sur la zone de climat tropical d'altitude entre 1961 et 2018.

Figure 28: Evolution temporelle du cumul annuel de précipitations



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar – 2023

Observations de la DGM :

La tendance de la précipitation représentée par la ligne verte montre une baisse de -4,5% du cumul annuel de précipitations sur les hautes terres centrales en 58 ans.

Tendance des cyclones tropicaux

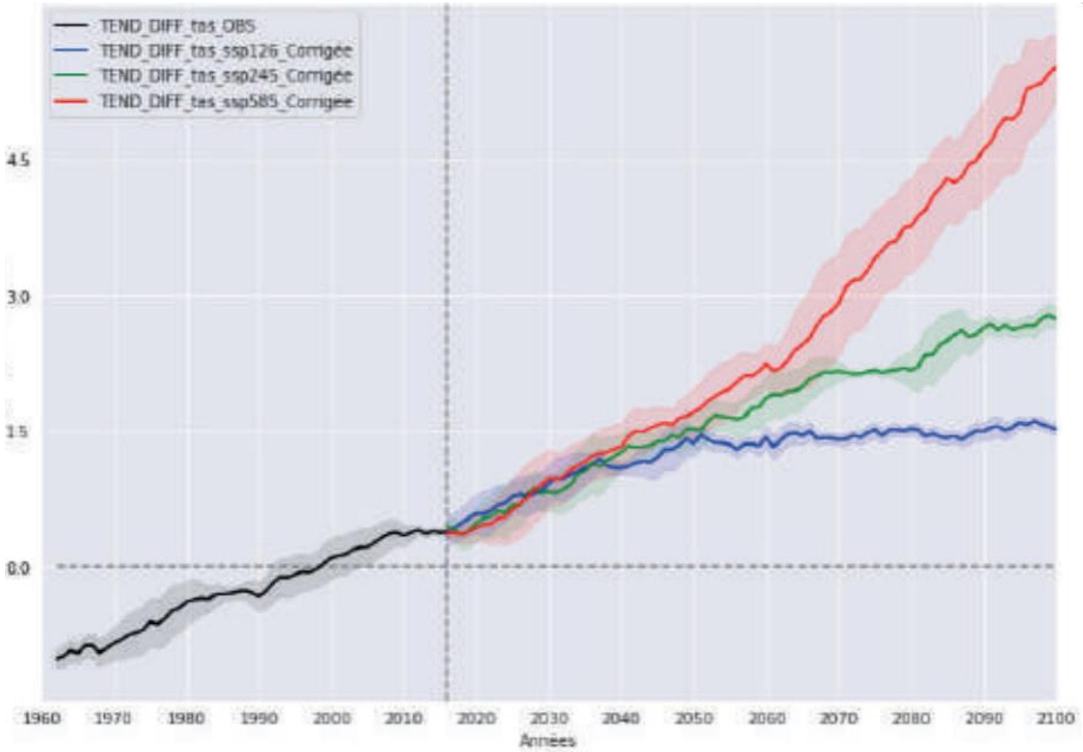
Identique à la situation de Madagascar, soit une légère tendance à la hausse pour le nombre de formation ayant aboutie au stade de cyclone tropical intense.

9.1.7 Projections

Projection de la Température

L'évolution temporelle des températures moyennes annuelles de la zone climatique en Hautes Terres centrales jusqu'à l'an 2100 est montrée par la figure ci-après :

Figure 29 : Evolution temporelle de la température moyenne annuelle sur la période 1961-2100 selon les divers scénarios



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar – 2023

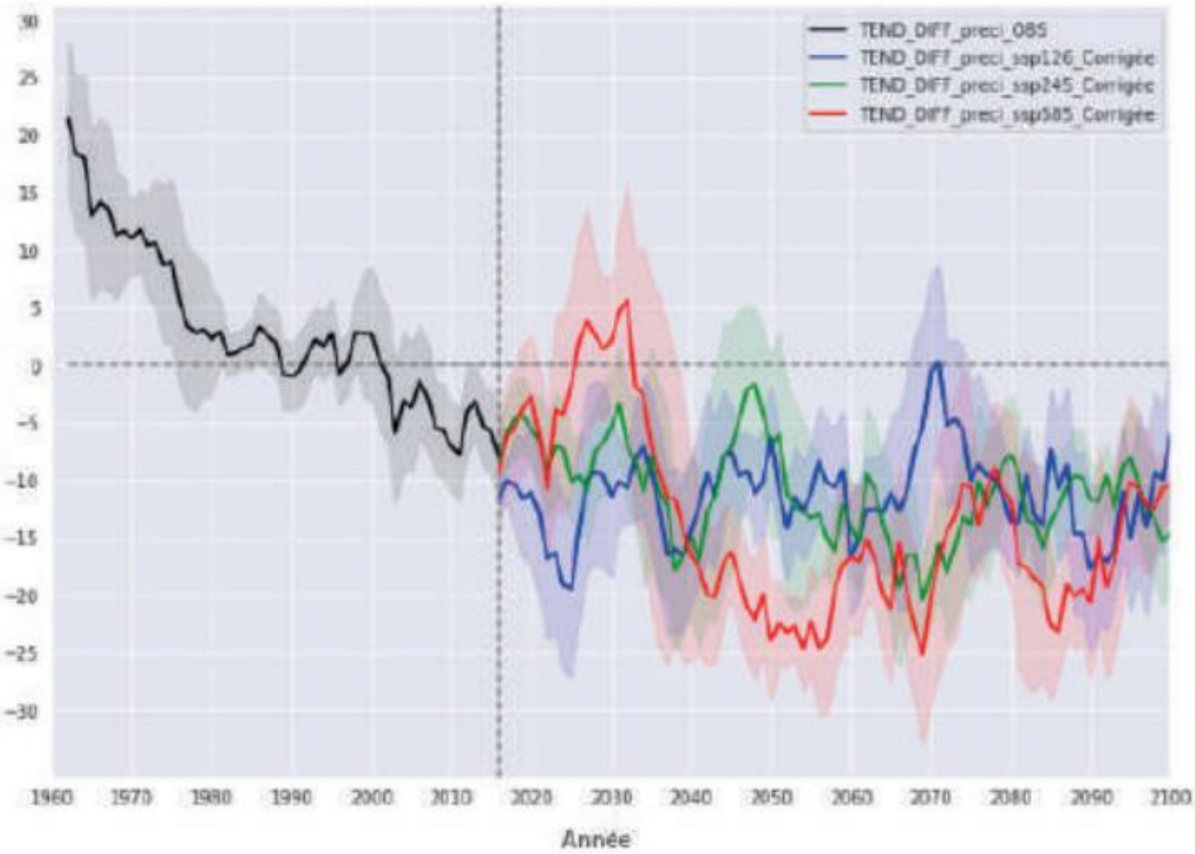
<u>Observations de la DGM :</u>

L'étude constate une augmentation de température, dans tous les cas de scénarios, qui s'élève à au moins +1,5 °C de la température normale attendue entre 2071-2100.

<u>Projection de la Pluviométrie</u>

Selon cette même analyse, la projection de l'évolution temporelle sur la période 1961-2100 de précipitations annuelles pour la zone des Hautes Terres Centrales et selon les trois scénarios climatiques se présente sur la figure ci-après :

Figure 30 : Evolution temporelle des précipitations sur la période 1961-2100



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar – 2023

Observations de la DGM :

Dans tous les scénaros, on constate une baisse des précipitations annuelles, de l'ordre de -10% et -20%. Le modèle ALADIN anticipe aussi une accentuation de l'amplitude de la variabilité interannuelle des précipitations. Les extrêmes seront plus importants, les risques de sécheresse et d'inondation seraient plus élevés que dans le passé

C'est dans le scénario pessimiste SSP5-8.5 que la baisse des précipitations annuelles moyennes sera la plus prononcée, atteignant des extrêmes à presque -30% sur les hautes terres centrales en milieu de siècle.

Projection des cyclones tropicaux

Identique à la situation de Toamasina mais à une intensité atténuée vue la situation géomorphologique de la ville de Fianarantsoa.

9.1.8 Synthèse du climat, des tendances et de la projection du climat à Fianarantsoa

La ville de Fianarantsoa est caractérisée par :

- Un climat tropical d'altitude avec une température moyenne annuelle de 20°C et une température maximale de 25°C, une pluviométrie annuelle entre 1000 à 2000 mm et une intensité modérée de cyclone.
- Une tendance à la hausse de la température +0,3°C/décennie et une baisse de -4,5% par décennie du cumul annuel de précipitations en 58 ans,
- Une projection d'augmentation de la température de l'ordre de +1.5°C jusqu'à 2100 selon le scénario du plus optimiste, une baisse des précipitations annuelles, de l'ordre de -10% à -20% au même horizon,

Vu que la ville de Fianarantsoa est bâtie sur un site de collines alternées de vallées, l'insuffisance d'eau pendant la saison sèche (mai à octobre) se fait déjà sentir dans les quartiers des villes hautes, et affecte ainsi le système d'assainissement à chasse.

Du côté des villes basses, surtout dans les vallées, l'inondation pendant la période des pluies coïncidant avec la période cyclonique est source de dommages et des perturbations sur le fonctionnement des systèmes d'assainissement

En résumé, la sècheresse, les pluies intenses et les cyclones tropicaux sont les aléas qui pèsent directement sur le système d'assainissement dans la ville de Fianarantsoa

ANNEXE 4: CLIMATE ANALYSIS / TOAMASINA

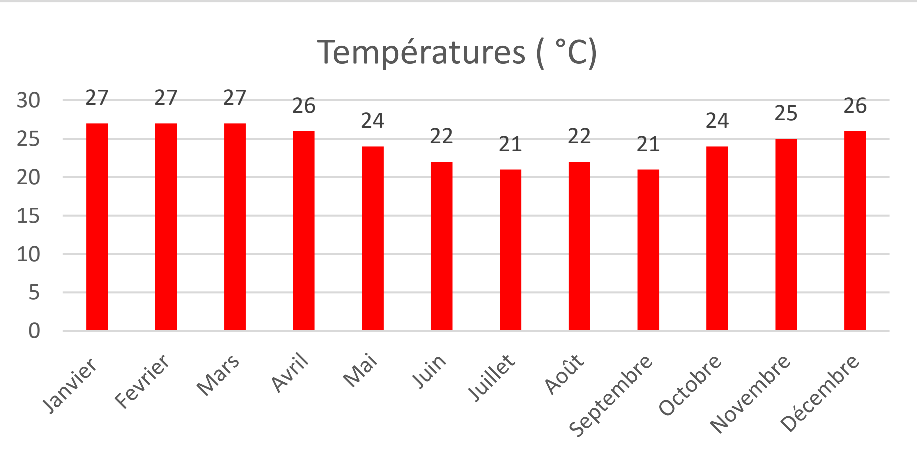
9.1.9 Revue des paramètres

Toamasina est située dans la zone climatique de la Côte Est selon la classification de la DGM. Cette zone présente un climat tropical chaud et humide avec une saison chaude et pluvieuse de novembre à avril, puis une saison plus fraîche et sèche de mai à octobre.

Température :

La température moyenne annuelle à Toamasina est de 24°C environ. Au cours de l'année, la température est comprise entre *18 °C* et *30 °C*. La figure ci-après résume la variabilité de la température au cours d'une année.

Figure 31 : Moyennes Mensuelles des températures Toamasina

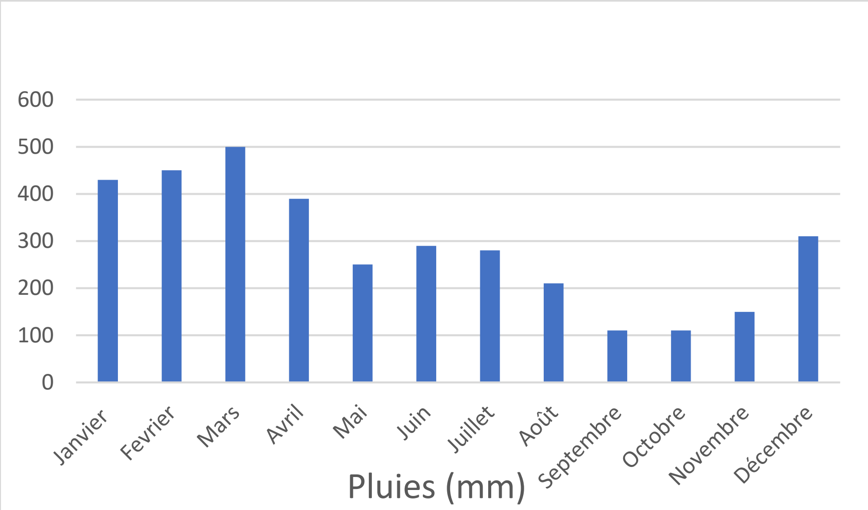


Source : Atlas climatologique de Madagascar. Direction Générale de La Météorologie, 2014

Pluviométrie :

La pluviométrie moyenne annuelle de la ville de Toamasina varie de 2500 mm à 3500 mm. Les valeurs moyennes mensuelles des précipitations sont présentées dans la figure ci-après

Figure 32 : Moyennes Mensuelles des pluies Toamasina



Source : Atlas climatologique de Madagascar. Direction Générale de La Météorologie, 2014

9.1.10 Tendances

L'analyse de l'évolution temporelle des aléas climatiques est cruciale pour comprendre l'impact du changement climatique sur la vulnérabilité des systèmes d'assainissement dans les trois villes objet de l'étude. En effet, l'augmentation de la fréquence et de l'intensité de ces phénomènes peut surcharger les infrastructures d'assainissement déjà fragiles, entraînant des inondations, la contamination des ressources en eau, et des risques sanitaires accrus pour les populations urbaines. En anticipant les tendances des aléas climatiques à travers une analyse temporelle rigoureuse, les décideurs peuvent adapter les systèmes d'assainissement pour mieux répondre aux défis futurs et renforcer leur résilience face aux impacts du changement climatique.

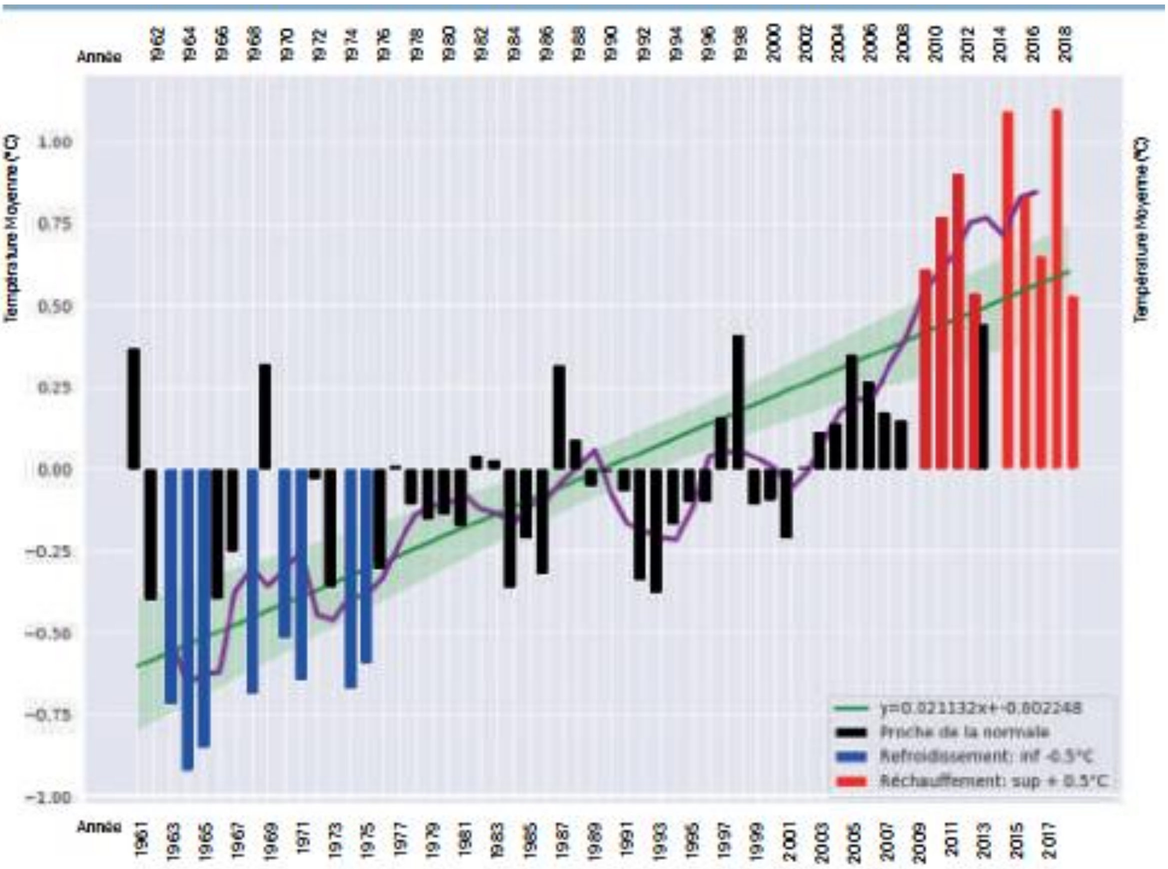
L'objectif de la connaissance des tendances climatiques est de pouvoir situer si les systèmes d'assainissement de ces villes subissent déjà les conséquences tangibles du changement climatique. La surveillance des tendances climatiques permet de mieux comprendre ces impacts actuels et de renforcer les actions nécessaires pour adapter les infrastructures aux nouvelles réalités imposées par le changement climatique, assurant ainsi la protection de la santé publique et de l'environnement

Pour atteindre cet objectif, tout d'abord, il est essentiel de recueillir et d'analyser les données climatiques disponibles, en se basant sur les publications scientifiques et les rapports émis par la Direction Générale de la Météorologie de Madagascar. Ces données fournissent un aperçu des tendances historiques des 50 dernières années et actuelles des événements climatiques extrêmes, tels que les précipitations intenses, les sécheresses et les cyclones. Ensuite, ces informations doivent être croisées avec les études de cas sur le terrain, en examinant la performance des infrastructures d'assainissement existantes dans les 3 villes. Enfin, on évalue comment ces infrastructures réagissent aux conditions climatiques changeantes, en mesurant les impacts tels que les débordements, les inondations, la détérioration des équipements et les problèmes de gestion des eaux usées.

<u>Tendances de la température</u>

La figure ci-après indique l'évolution temporelle de température moyenne annuelle (en °C), observée entre 1961 et 2018 pour la zone climatique Côte Est dans laquelle se situe la ville de Toamasina.

Figure 33 : Evolution temporelle de température moyenne annuelle Toamasina



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar, Direction Générale de la Météorologie Madagascar – 2023

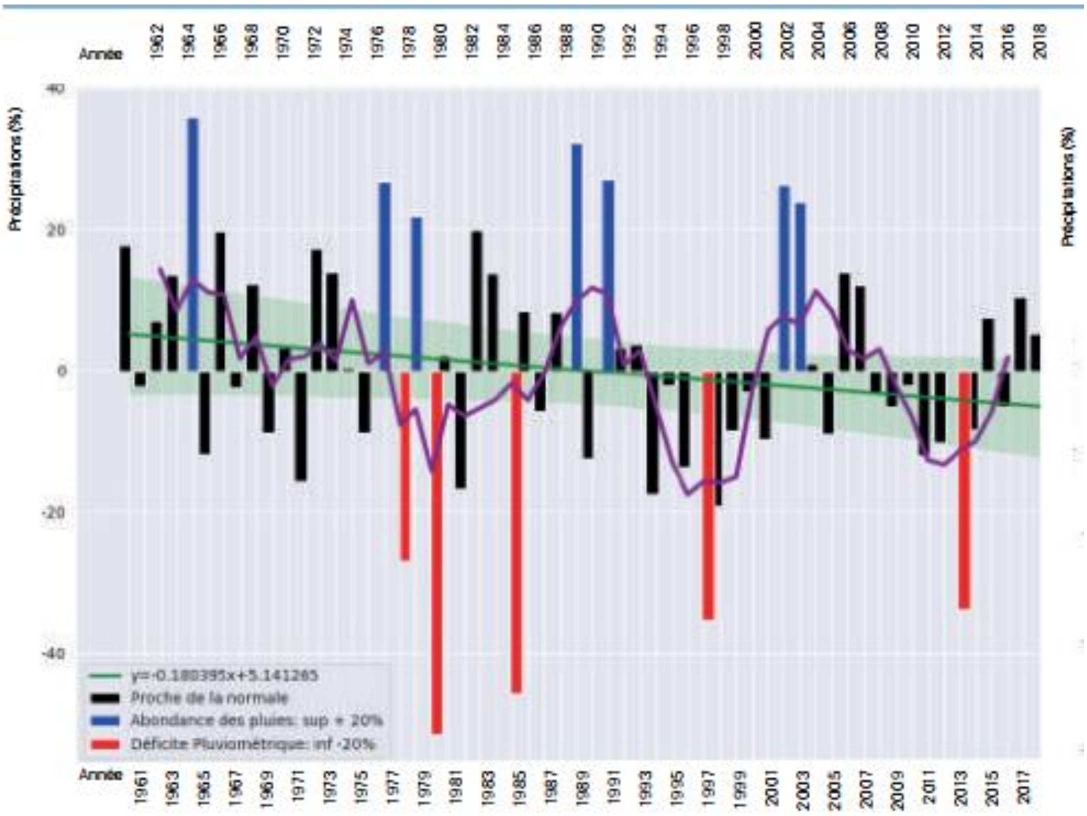
<u>Observations de la DGM</u> :

La ligne verte représente la tendance moyenne de la température pendant la période d’observation. Elle met en évidence l’augmentation de la température de +0,23°C par décennie.

<u>Tendance de la Pluviométrie</u>

La figure suivante indique l'évolution temporelle des précipitations observées sur la zone climatique de la Côte Est entre 1961 et 2018.

Figure 34 : Evolution temporelle du cumul annuel de précipitations Toamasina



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar, Direction Générale de la Météorologie Madagascar – 2023

<u>Observations de la DGM :</u>

La ligne verte représente la tendance moyenne des précipitations sur la période 1961-2018. On observe ainsi une baisse de -2% par décennie du cumul annuel de précipitations en 58 ans. D'après la même source, en termes de saison, les précipitations en été montrent un déclin par rapport aux précipitations en hiver. Le nombre de jours où il y a des pluies extrêmes en une journée diminue en général.

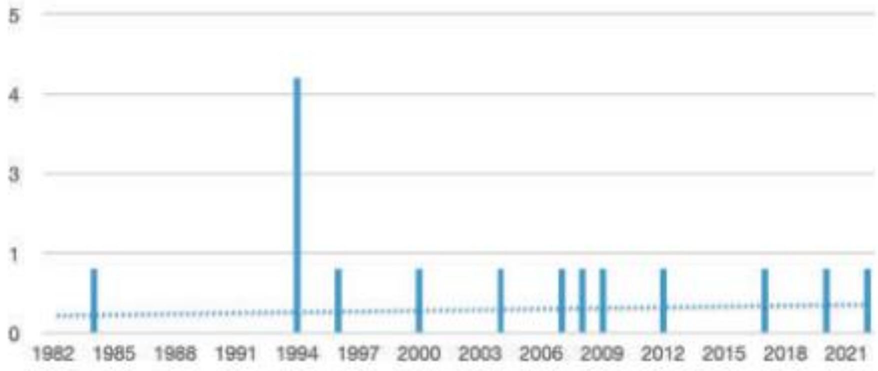
<u>Tendance des Cyclones tropicaux</u>

En moyenne et par saison cyclonique (officiellement de Novembre à Avril), dix (10) perturbations tropicales évoluent dans le bassin du Sud-Ouest de l'Océan Indien (SOOI), parmi lesquelles cinq (5) deviennent des cyclones (Leroux et al., 2018).

Depuis la saison cyclonique 1981/1982, on constate à Madagascar une forte variabilité interannuelle du nombre et de l'intensité des phénomènes cycloniques mais de tendance presque nulle.

Les cyclones qui touchent la Grande Île prennent naissance soit dans l'Océan Indien, soit dans le Canal de Mozambique. Pendant les 41 dernières années (1982 à 2022), un total de 82 systèmes a atterri à Madagascar. Ce qui fait en moyenne 2 systèmes par saison pendant la saison cyclonique (Novembre à Avril). Si on ne s'intéresse qu'aux cyclones intenses qui affectent gravement les infrastructures, la figure ci-après illustre l'évolution des nombres de ce type de cyclone pendant les 40 dernières années.

Figure 35 : Nombre de cyclone tropical intense ayant atterri à Madagascar de 1982 à 2022



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar, Direction Générale de la Météorologie Madagascar – 2023

Observations de la DGM :

On observe une légère tendance à la hausse pour le nombre de formation ayant aboutie au stade de cyclone tropical intense.

Tendance d'augmentation du niveau de la mer

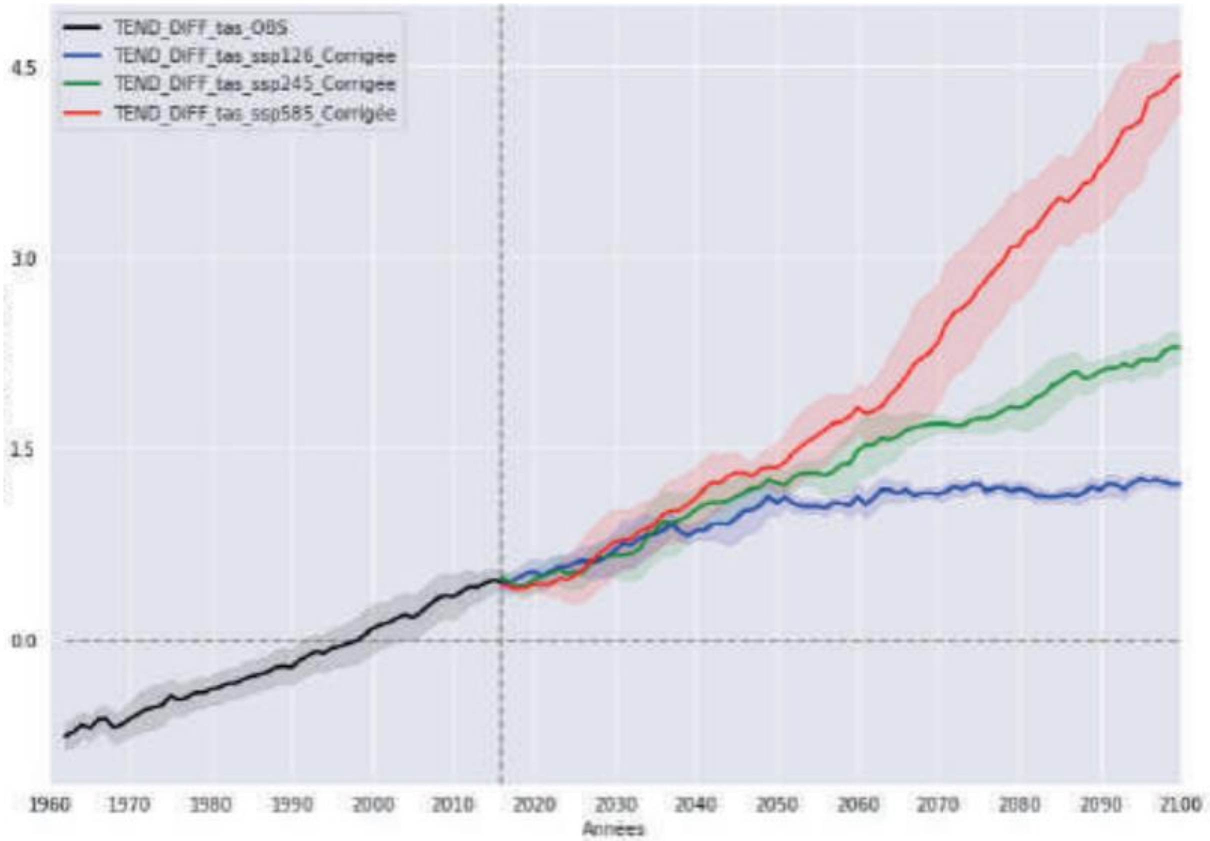
Sur les 25 dernières années, on relève pour le bassin SOOI une élévation relativement importante du niveau de la mer de +12 cm, soit +5 mm/an en moyenne, supérieure à la valeur moyenne relevée sur le globe.

9.1.11 Projections

Projection sur la Température

La même étude publiée par la Direction Générale de la météorologie de Madagascar sur les tendances climatiques et les futurs changements climatiques à Madagascar (2023) comprend la projection de la température jusqu'à l'an 2100. La figure ci-après montre cette évolution sur la période 1961-2100 pour trois scénarios SSP : SSP1-2.6 (scénario à faible hausse des émissions de GES), SSP2-4.5 (scénario de hausse intermédiaire des émissions de GES) et SSP5-8.5 (scénario de très forte hausse des émissions de GES).

Figure 36: Evolution temporelle de la température sur la période 1961-2100 dans la zone climatique de la Côte Est de Madagascar



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar, Direction Générale de la Météorologie Madagascar – 2023

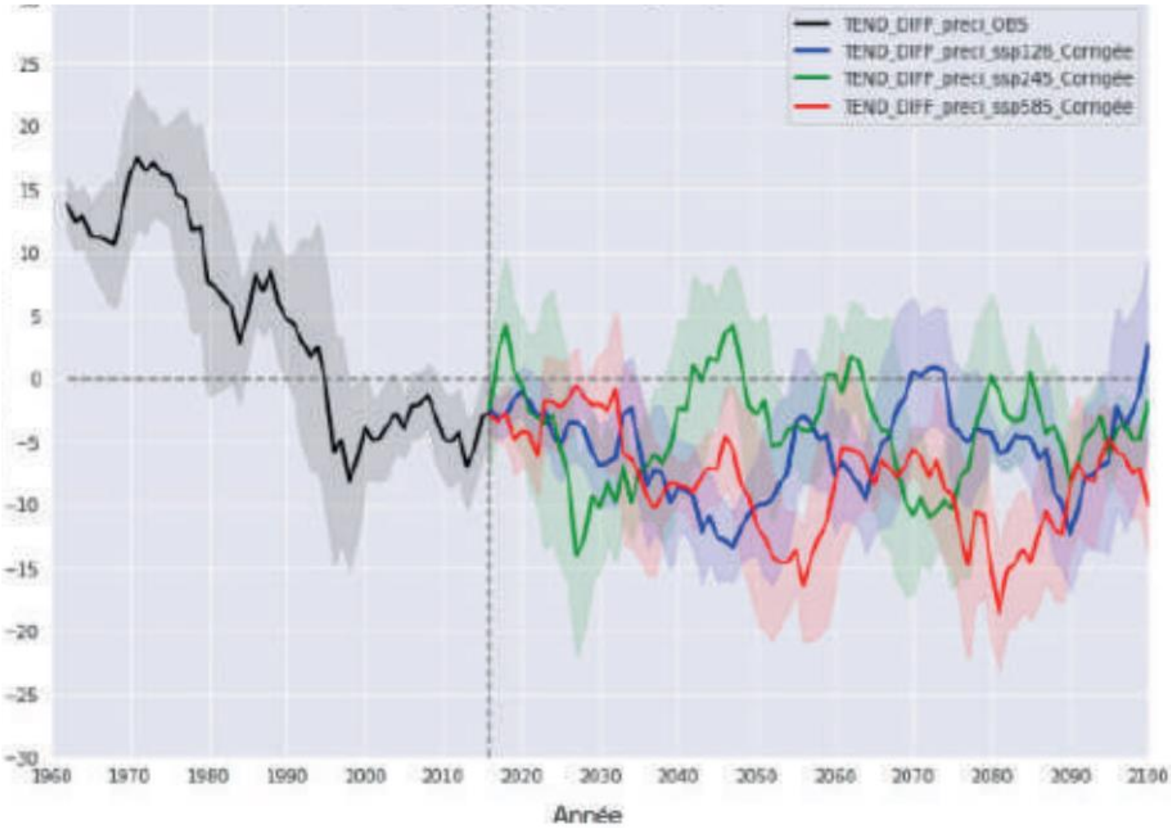
Observations de la DGM :

Ce modèle projette vers la fin du siècle (entre 2071-2100) une augmentation de l'ordre de +1.5°C pour le scénario SSP1-2.6, une augmentation de +2°C à +3°C pour le scénario SSP2-4.5, vers la fin du siècle. Selon le scénario pessimiste SSP5-8.5, une augmentation de la température de +3°C à +5°C sera attendue entre 2071 à 2100.

Projection de la Pluviométrie

La projection de l'évolution temporelle de précipitations sur la période 1961-2100 pour la zone climatique de la Côte Est suivant les trois scénarios climatiques se présente sur la figure ci-après :

Figure 37: Evolution temporelle de la pluviométrie sur la période 1961-2100 dans la zone climatique de la Côte Est de Madagascar



Source Les tendances climatiques observées et les futurs changements climatiques à Madagascar, Direction Générale de la Météorologie Madagascar – 2023

Observations de la DGM :

Quel que soit le scénario, une baisse des précipitations annuelles, de l'ordre de -5% à -10%, est attendue sur la côte Est à l'horizon 2100.

Projection des cyclones tropicaux

La projection climatique effectuée par la DGM montre une probable diminution du nombre total de systèmes dépressionnaires dans le SOOI., un nombre de systèmes intenses ou très intenses constant ou en hausse, et une probable augmentation du maximum d'intensité cyclonique. Dans le contexte du réchauffement climatique, on peut donc s'attendre à une intensification des précipitations et des vents au sein des systèmes dépressionnaires tropicaux au cours du 21ème siècle.

9.1.12 Synthèse du climat, des tendances et de la projection du climat à Toamasina

La ville de Toamasina est caractérisée par :

- Un climat chaud avec une température maximale de 30°C, une pluviométrie abondante entre le mois de décembre et avril à laquelle coïncide la période cyclonique.
- Une tendance à la hausse de la température +0,23°C par décennie et une baisse du cumul annuel de précipitations de -2% par décennie en 58 ans, puis une légère tendance à la hausse pour le nombre de système ayant atterri au stade de cyclone tropical intense, accompagné de forte précipitation et de vent fort.
- Une projection d'augmentation de la température de l'ordre de +1.5°C à +5°C jusqu'à 2100 selon le scénario du plus optimiste au plus pessimiste, une baisse des précipitations annuelles, de l'ordre de -5% à -10% au même horizon, un nombre de cyclones tropicaux

intenses ou très intenses constant ou en hausse, et une probable augmentation du maximum d'intensité cyclonique traduit par une intensification des précipitations et des vents au sein des systèmes dépressionnaires tropicaux au cours du 21ème siècle

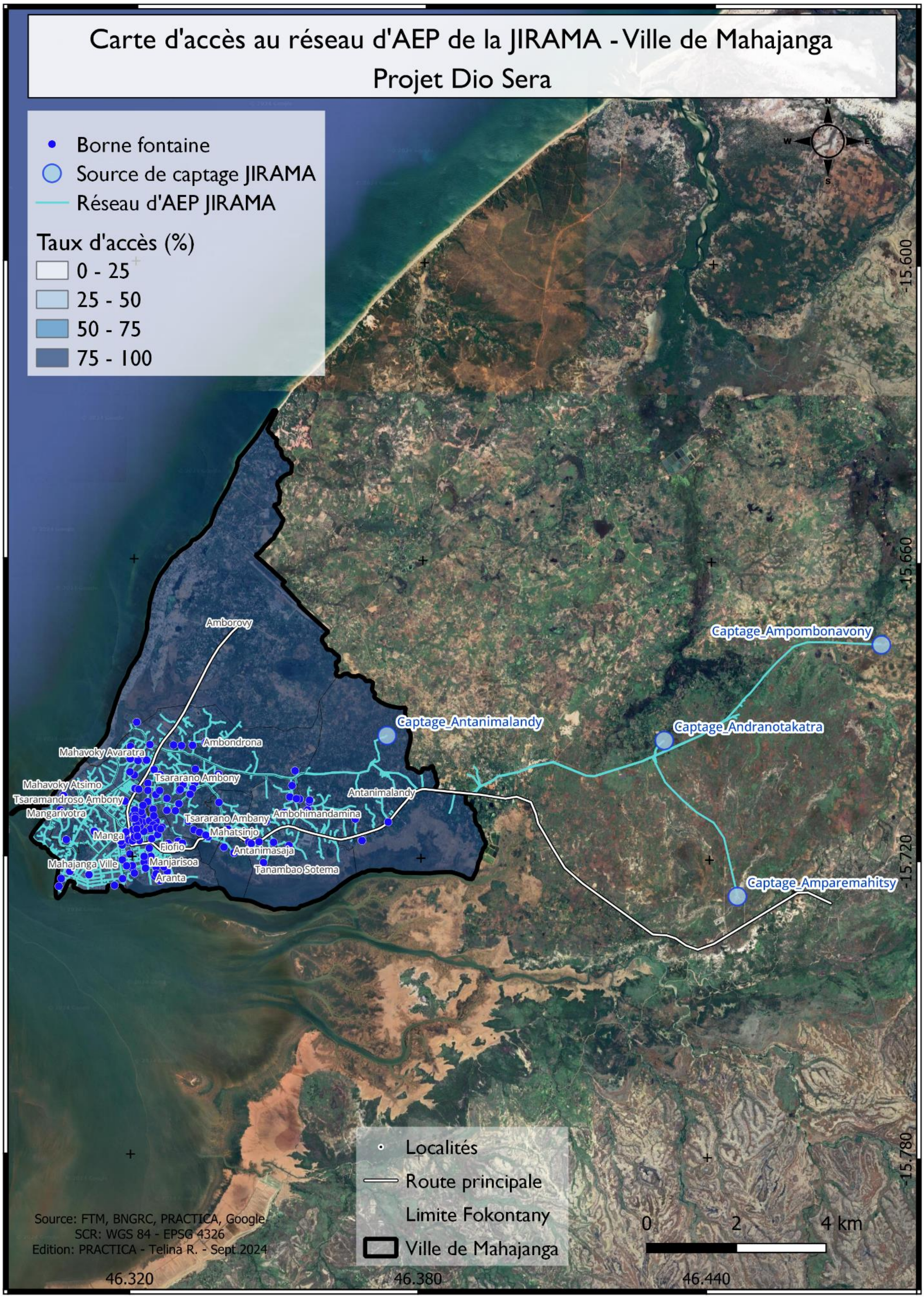
L'abondance de précipitations dans la ville de Toamasina est d'ores et déjà source d'inondation dans plusieurs quartiers, ceci est accentué par la défaillance du système de drainage de la ville. Les infrastructures d'assainissement dont les fosses sont généralement implantées sous le terrain naturel sont ainsi immergées pendant ces périodes.

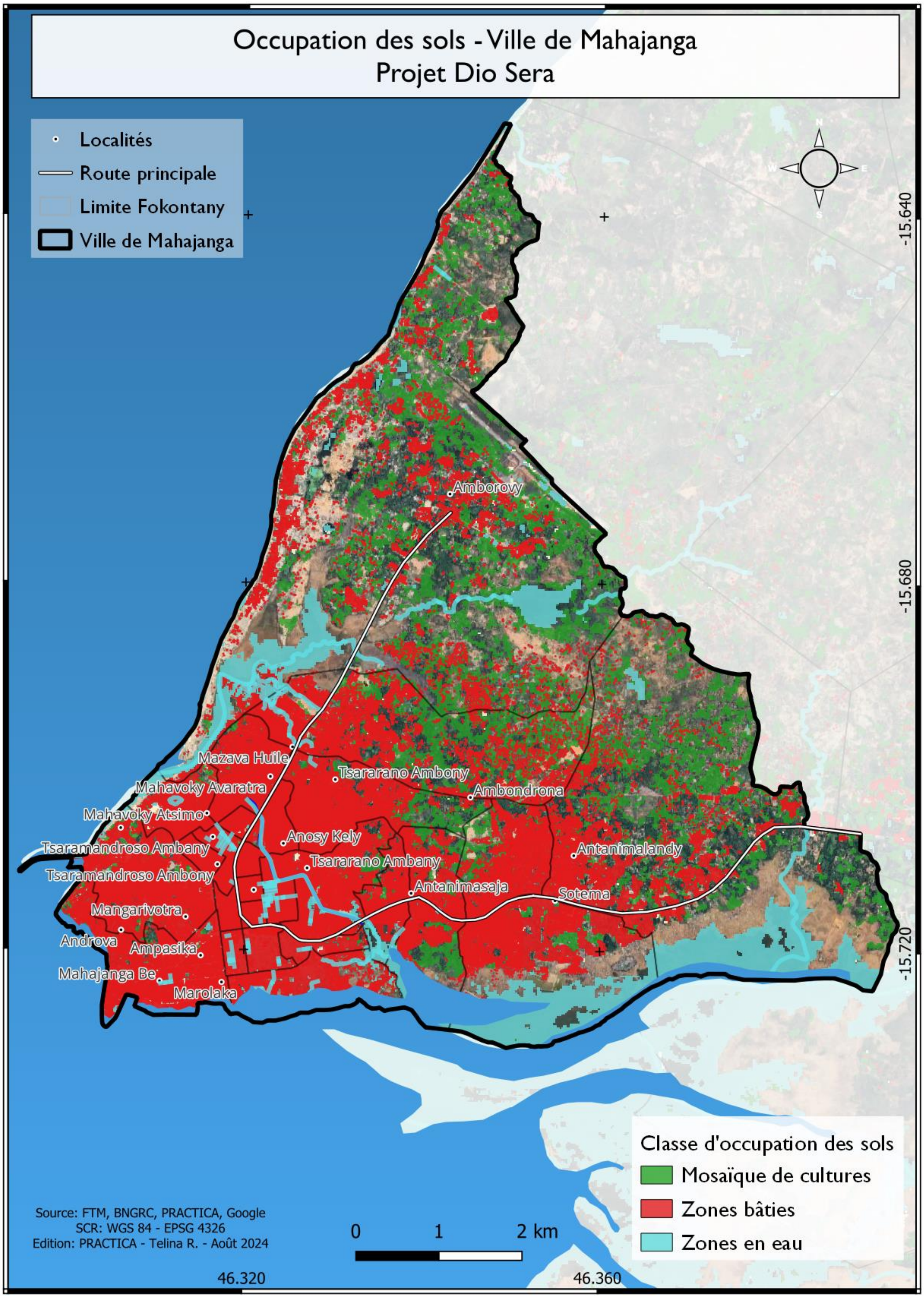
Malgré la tendance à la baisse du cumul annuel des précipitations observées depuis les 50 dernières années et la projection d'une baisse jusqu'à la fin du siècle, la quantité reste volumineuse et on s'attend toujours aux inondations répétitives pendant les périodes des pluies de novembre à Avril. En outre, l'augmentation de l'intensité des cyclones tropicaux caractérisés par des fortes précipitations et des vents forts impactent les superstructures des systèmes d'assainissement les plus exposés.

Les quartiers situés en bordure de la mer voient des marées hautes de plus en plus fréquentes arrivent à recouvrir les infrastructures d'assainissement.

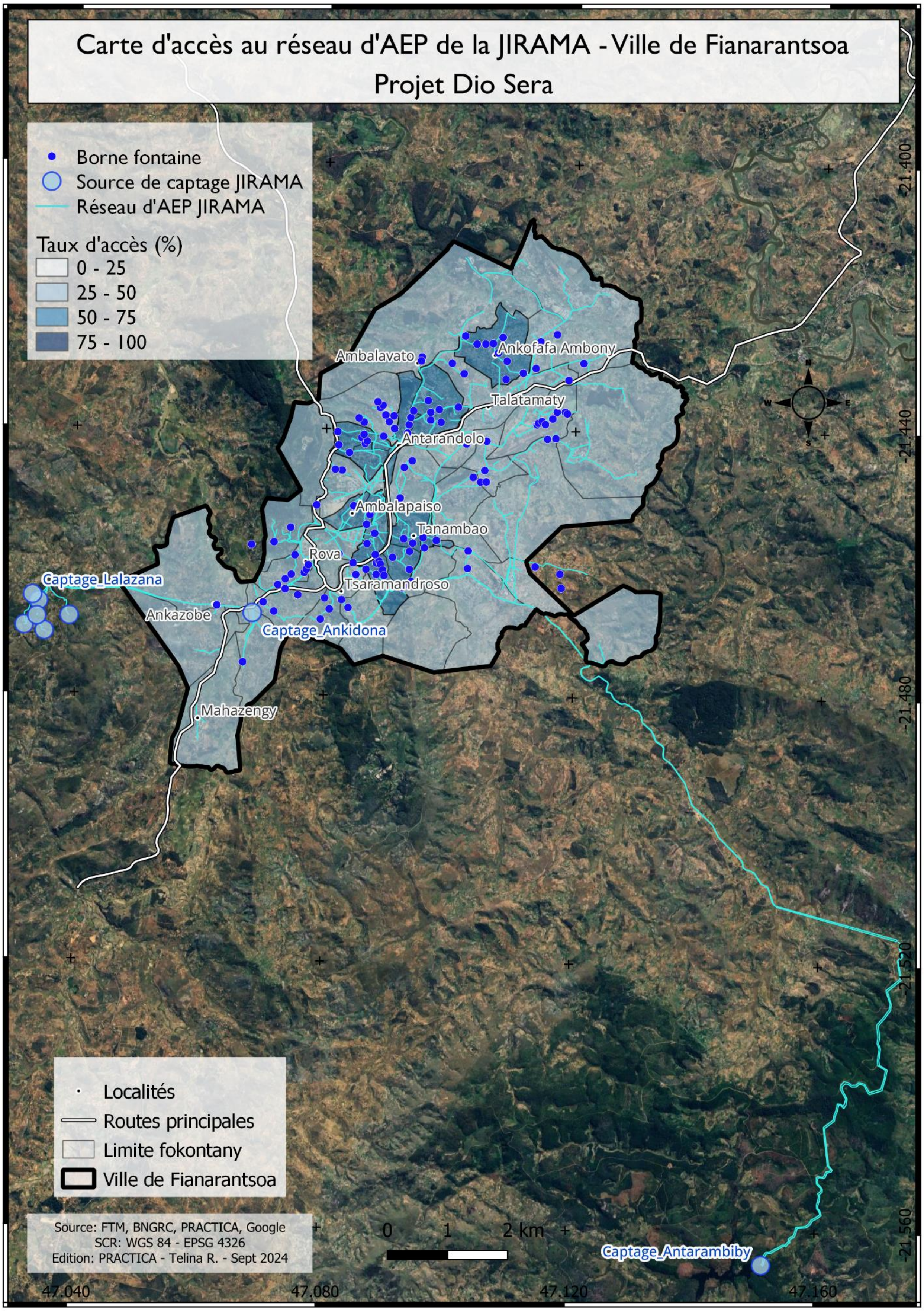
En résumé, les précipitations, les cyclones tropicaux et vents forts, l'élévation du niveau de la mer sont les aléas qui pèsent directement sur le système d'assainissement dans la ville de Toamasina

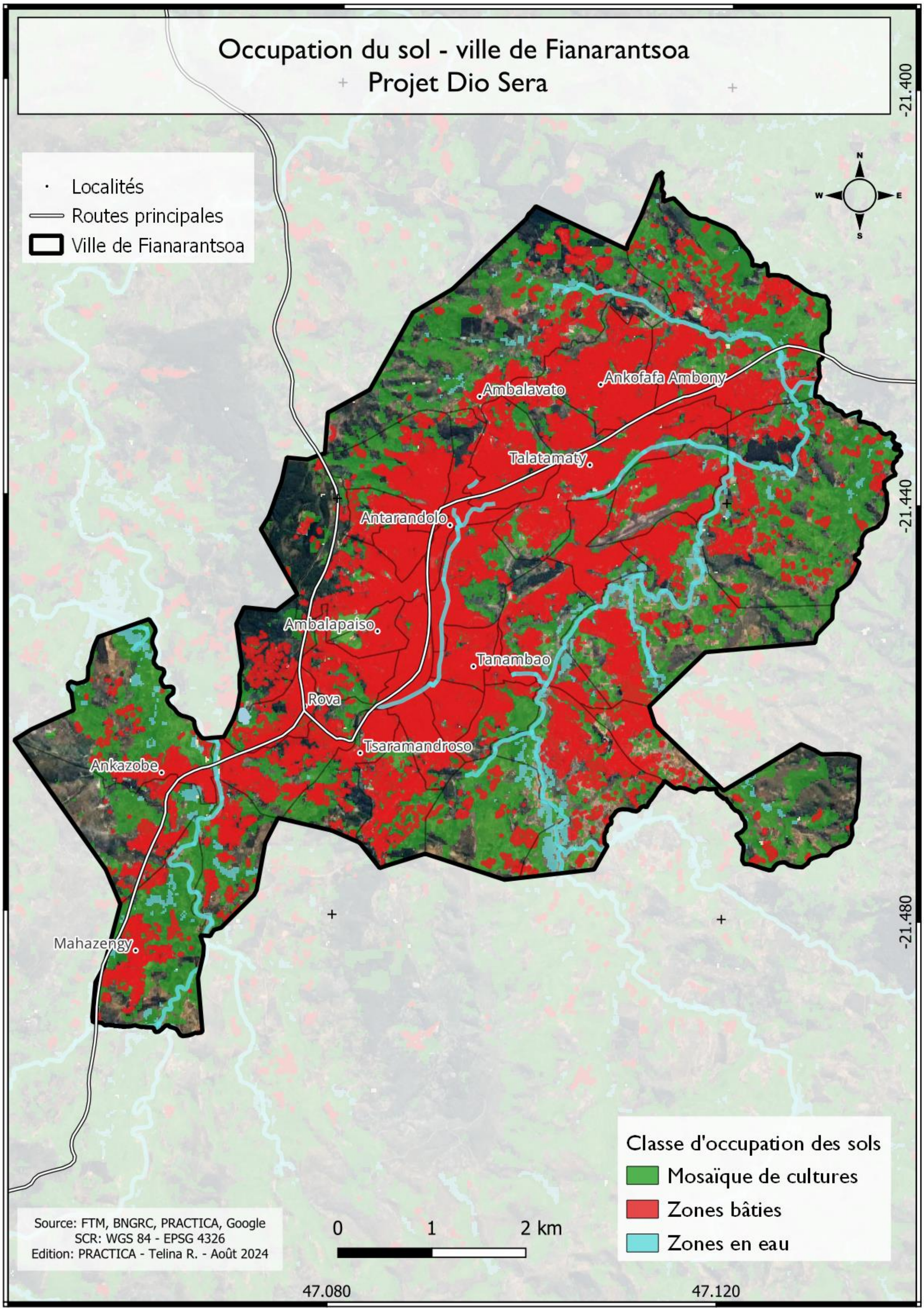
ANNEXE 5: POTABLE WATER AND AGRICULTURE / MAHAJANGA



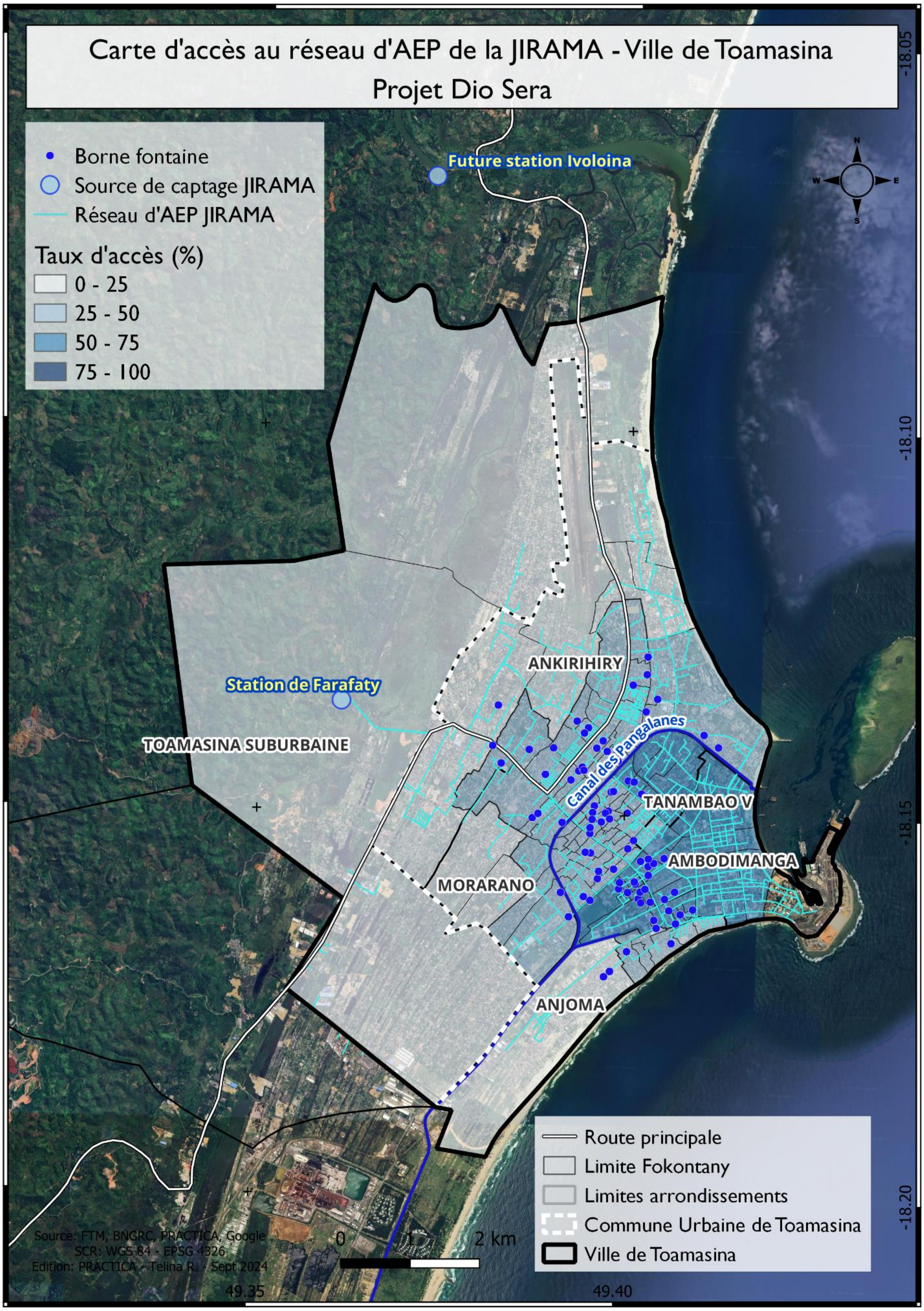

Occupation des sols - Ville de Mahajanga
Projet Dio Sera
Localités
Route principale
Limite Fokontany
Ville de Mahajanga
Amborovy
Mazava Huile
Tsararano Ambony
Mahavoky Avaratra
Ambondrona
Mahavoky Atsimo
Anosy Kely
Tsaramandroso Ambany
Tsararano Ambany
Antanimalandy
Tsaramandroso Ambony
Antanimasaja
Sotema
Mangarivotra
Androva
Ampasika
Mahajanga Be
Marolaka
-15.640
-15.680
-15.720
Classe d'occupation des sols
Mosaïque de cultures
Zones bâties
Zones en eau
Source: FTM, BNGRC, PRACTICA, Google
SCR: WGS 84 - EPSG 4326
Edition: PRACTICA - Telina R. - Août 2024
0
1
2 km
46.320
46.360

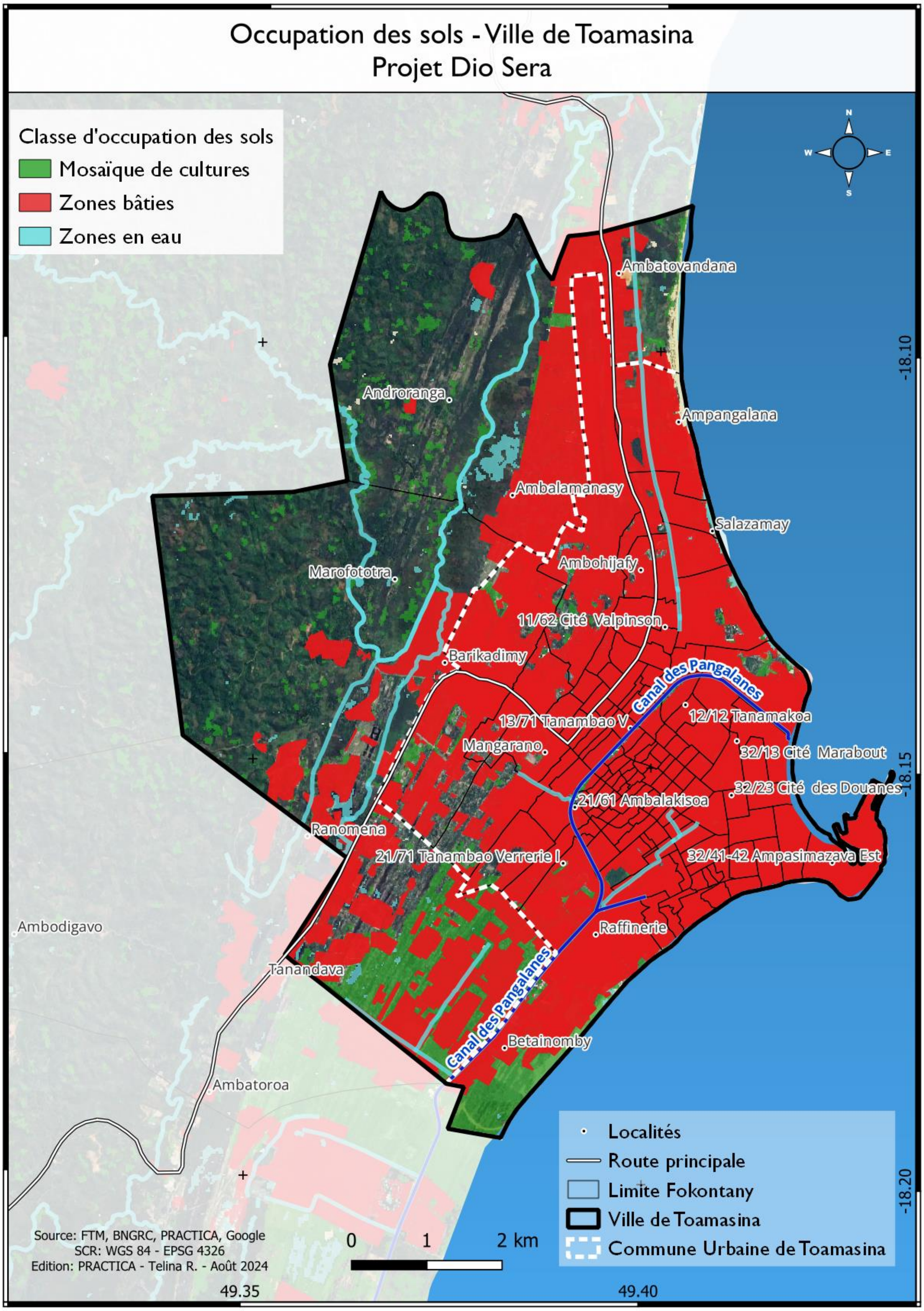
ANNEXE 6: POTABLE WATER AND AGRICULTURE / FIANARANTSOA




Occupation du sol - ville de Fianarantsoa
Projet Dio Sera
Localités
Routes principales
Ville de Fianarantsoa
Ambalavato
Ankofafa Ambony
Talatamaty
Antarandolo
Ambalapaiso
Tanambao
Rova
Tsaramandroso
Ankazobe
Mahazengy
-21.400
-21.440
-21.480
47.080
47.120
Classe d'occupation des sols
Mosaïque de cultures
Zones bâties
Zones en eau
0 1 2 km
Source: FTM, BNGRC, PRACTICA, Google
SCR: WGS 84 - EPSG 4326
Edition: PRACTICA - Telina R. - Août 2024

ANNEXE 7: POTABLE WATER AND AGRICULTURE / TOAMASINA




Occupation des sols - Ville de Toamasina
Projet Dio Sera
Classe d'occupation des sols
Mosaïque de cultures
Zones bâties
Zones en eau
Ambatovandana
Ampangalana
Androranga
Ambalamanasy
Salazamay
Ambohijafy
Marofototra
11/62 Cité Valpinson
Barikadimy
Canal des Pangalanes
12/12 Tanamakoa
13/71 Tanambao V.
Mangarano
32/13 Cité Marabout
32/23 Cité des Douanes
21/61 Ambalakisoa
Ranomena
21/71 Tanambao Verrerie I
32/41-42 Ampasimazava Est
Raffinerie
Ambodigavo
Tanandava
Betainomby
Ambatoroa
Localités
Route principale
Limite Fokontany
Ville de Toamasina
Commune Urbaine de Toamasina
Source: FTM, BNGRC, PRACTICA, Google
SCR: WGS 84 - EPSG 4326
Edition: PRACTICA - Telina R. - Août 2024
0 1 2 km
49.35
49.40
-18.10
-18.15
-18.20