Climate Risk Profile

CLIMATE RISKS IN URBAN AND URBANIZING GEOGRAPHIES

MADAGASCAR

March 2018
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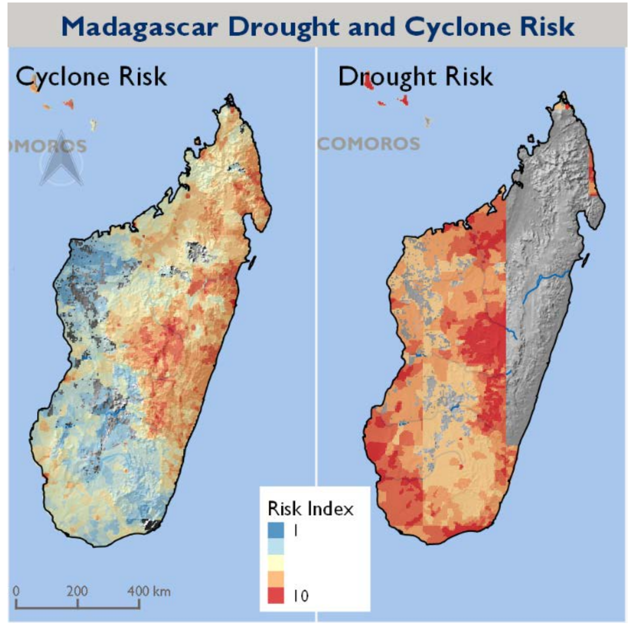
INTRODUCTION

Madagascar is ranked “highly vulnerable” to climate trends (20 of 181 countries) based on climate projections and is poorly prepared to address climate-related impacts (ND-GAIN 2015). Urbanization and climate trends in the country are increasing the risk of diminished public health and food insecurity in urban areas. This document assesses the climate risks to services, populations and infrastructure in urban centers and urbanizing rural towns, and the opportunities for adaptive responses.



Note: The risk index is presented on a scale of 1 to 10, with 10 representing highest risk. Limited data are available for drought risk in eastern Madagascar. Data source: CIESIN 2005, Dilley et al. 2005.

COUNTRY OVERVIEW

Nearly the entire country is exposed to cyclones, which strike an average of 3–4 times per year. Cyclones and heavy rain events lead to high flood risk everywhere but the southwest. The southern regions in particular, however, suffer recurring drought, including the recent four-year drought, 2013–2016, and six droughts during 1981–2010 (Masih et al. 2014). Cyclones, flooding and prolonged drought diminish human health, cause major losses in the agriculture sector, and greatly disrupt economic activities in urban areas. The country is already significantly food insecure, and an estimated 53 percent of children under five suffer from stunting (UNICEF 2015).

CLIMATE PROJECTIONS

1.2–2.1°C rise in temperatures by 2050

Likely decrease in precipitation, ranging from -8 to +1 percent by 2050

Increased cyclone intensity with +4ºC

19-47 cm rise in sea level by 2056

KEY CLIMATE IMPACTS IN URBAN AREAS

WATER, SANITATION & HYGIENE

Contaminated water supply
Increased waterborne disease
Water scarcity
Saline intrusion

STORM- & WASTEWATER MANAGEMENT

Increased river flooding
Floodplain expansion
Increased flooding from storm surges and sea level rise

TRANSPORT INFRASTRUCTURE

Damage to roads, airports, seaports and railways
Disruption of travel during cyclones

SCHOOLS, HEALTH FACILITIES & PUBLIC

Loss and damage of structures
Overheated buildings
Power outages
Water supply shortages or contamination

SOLID WASTE MANAGEMENT

Increased air and water pollution
Increased vector-borne disease

ELECTRICITY INFRASTRUCTURE

Damage to power generation and distribution infrastructure
Water scarcity for hydropower production and thermal power cooling

As the climate becomes more variable and extreme events happen with greater frequency or duration, already chronic food insecurity will deepen and likely affect growing numbers of people. In rapidly expanding urban centers, climate risk exacerbates problems of inadequate water supply, sanitation and wastewater management. A poor transportation network, limited electricity supply and a lack of reliable infrastructure in general combine to further hinder economic development and the ability of urban populations and institutions to plan for and respond to climate stressors.

CLIMATE SUMMARY

Madagascar's climate is tropical with two distinct seasons: (1) a warm and rainy season (summer) from November to April, with the highest rainfall during December and January; and (2) a cool, dry season (winter) from May to October, with the lowest rainfall in September and October (GERICS 2015). The north and northwestern regions are characterized by a tropical monsoon and savannah climate, the eastern coast by a tropical rainforest climate, and the southwest by hot arid desert and steppe climates. The highland regions in the country's center have humid subtropical to temperate highland tropical climates (GERICS 2015).

Annual average precipitation countrywide is 1,500 mm but amounts vary from less than 400 mm in the extreme south, to 1,400 mm in the highlands, to 3,000 mm along the east coast (PPCR 2017, World Bank 2011b). Average annual temperatures are 23–27°C along the coast and 16–19°C in the highlands. There is relatively little seasonal temperature variability along the east coast and high seasonal variability (GERICS 2015, World Bank 2011b). Meteorological observations show increasing climate variability, such as longer dry periods, increasing intensity of heavy rainfall events and higher maximum temperatures in recent decades (GoM 2010).

Table 1: Climate trends and projections
Sources: GERICS 2015, GoM 2015, World Bank 2011b, Yoshida et al. 2017, Fitchett and Grab 2015

Parameter	Observed trends (since 1960s)	Projected changes (2040–2069)
Temperature	• Increased temperature of 0.27°C per decade for 30 years (1983–2013)	• Increase in average annual temperature of 1.2–2.1°C by 2050 • Increase in annual maximum temperature of 1.4–2.3°C by 2050 • Increase in heat wave duration of 7 to 20 days by 2050
Rainfall	• Decreased rainfall of 8 percent over 30 years (1983–2013)	• Likely decrease in annual average precipitation, with a range of -8 percent to +1 percent by 2050 • Likely decrease in core dry season (June to October) precipitation, with a range of -55 percent to +10 percent • Precipitation models for the core wet season (January to March) are less clear, ranging from -10 percent to +18 percent • Likely increase in duration of dry spells, with a range +0–5 days by 2050 • Likely increase in the intensity of heavy rainfall events, with a range of 0–7 percent by 2050
Sea level rise	• Increased sea level by 0.6 cm per year from 1994 to 2008	• Increasing sea levels of 19 cm to 47 cm by 2056 (near Ambanja, high emissions scenario)

Cyclones	• No trend detected; considerable interannual variability	• Increased cyclone intensity but stable or decreased frequency of landfall (due to reduced genesis and changes in cyclone tracking) when global temperature increases by 4°C

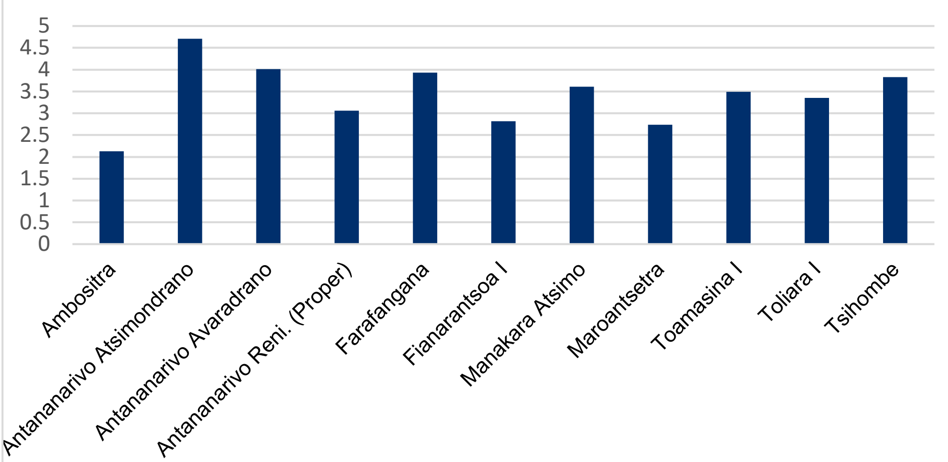
Climate risk in urban Madagascar involves sudden onset shocks such as cyclones, floods, drought and heatwaves and gradual onset stressors, such as average temperature increase, long-term changes in rainfall patterns and sea level rise. Cyclone Enawo in 2017, for example, affected 14 of the country's 22 regions (USAID 2017). Between 1990 and 2015, Madagascar recorded 65 major climate-related disasters, including more than 50 cyclones and 5 severe droughts (PPCR 2017).

URBANIZATION AND CLIMATE RISK IN MADAGASCAR

A confluence of climate and urbanization trends in Madagascar is paving the way for new hazards, particularly in urban areas. Development in low-lying areas, for example, leads to greater exposure to the growing flood risks associated with increasing intensity of heavy rainfall, cyclone events and sea level rise. Development programming in Madagascar faces a range of climate risks, including drought in the southwest, cyclones and floods in the center and north, sea level rise and storm surges along the coasts, and heat stress in low-elevation inland areas (World Bank 2016b).

With annual urban growth of 4.7 percent, rapidly changing demographics and settlement patterns pose a significant challenge for urban climate risk management. Of the country's 25 million residents, 36.4 percent live in urban areas, with that number increasing due to rural-to-urban migration and population growth (World Bank 2017). While internal seasonal migration was historically common in Madagascar, more permanent migration has increased in recent years. Each year 100,000 to 150,000 people move to Antananarivo alone, with most settling in areas of high flood risk (PPCR 2017). This migration strains already limited urban management infrastructure and services. In turn, vulnerable migrants and residents bear a disproportionate impact of shocks and stressors as they are often unable to avoid hazardous areas with poor infrastructure and services.

Figure 1. Percent urban population growth per year, 1993-2014
(for selected urban areas by district population)



Source: Institut National de la Statistique Madagascar.

Rural-to-urban migration in Madagascar is driven by push and pull factors. Push factors drive people out of rural areas and include climate impacts (mainly drought in the south), environmental degradation, resource shortages and actual or perceived insecure land rights. A 2017 IOM survey identified a range of coping strategies employed by populations affected by the recent severe drought in the south, including seeking alternative sources of income, changing their food consumption, selling household goods and migrating to urban areas as a final resort (IOM 2017). Pull factors include urban economic opportunities and access to services, including health and education, which, although limited, are markedly better than in rural areas.

With rapid urbanization still a relatively new phenomenon, only a small fraction of the country's potential urban space has been developed. Opportunity exists now for new developments to benefit from improved information on climate vulnerabilities to build more resilient urban spaces. This opportunity hinges on proactive investment in resilient urban planning and infrastructure development that is underpinned by community and stakeholder engagement, economic development, disaster risk management and equity of service provision.

Municipalities generally lack the resources and capacity to plan for and manage urban growth, however, leading to inadequate urban infrastructure and services, notably water and sanitation. Most urban residents live in informal settlements with limited services (USAID 2010). Urban unemployment and underemployment have put increasing pressure on natural resources surrounding urban centers, as residents depend on these for livelihood activities, including cutting forest for charcoal making. Rapid urbanization combined with a lack of employment opportunities has led to high levels of urban poverty, with 36 percent of urban populations countrywide (66 percent in Antananarivo) below the national poverty line (World Bank 2017). While the urban poverty rate is substantially lower than in rural areas, new migrants are highly vulnerable, often facing unstable housing and employment situations that can persist for many years (IOM 2017).

Land shortages and the proliferation and expansion of informal settlements are common across Madagascar's urban areas (UNHabitat 2012). Laws exist to govern land use, ownership and transferability (i.e., Order 60-146, Law 2008-014 and Decree 63-192), but given the lack of government capacity and resources, much of the urban land market operates outside a legal or regulatory framework (World Bank 2011a). While the central government has undertaken decentralization efforts to increase local government authority, much decentralization has not been accompanied by adequate municipal budgets and the requisite institutional and technical capacity (UNHabitat 2012). Municipalities are thus often unable to keep pace with the ever-changing, expanding and increasingly crowded urban landscape. Decentralization efforts have also led to confusion for landowners attempting to formalize their landownership, as legal authority for taxation, land registration, and issuance of land titles and building permits is divided among regional and municipal government entities (World Bank 2011a).

While urban land tenure will likely remain challenging for decades, the Ministry at the Presidency in charge of Presidential Projects, Regional Planning, and Equipment (M2PATE) is implementing land reform in cooperation with the World Bank and other donors. While much of the effort is in rural areas, low-income urban and rural residents can use the state system, *Opérations domaniales concertées* (Odoc), to secure a legal land title. Further, the Law on Land Use Planning (2015) mandates local governments to identify private, untitled and communal lands and to ensure these are reflected in local plans.

WHERE URBANIZATION AND CLIMATE RISKS COLLIDE: CASE STUDIES

Major urban centers like Antananarivo and Tulear, as well as rapidly urbanizing rural population centers like Maroantsetra and Tsihombe, will need to consider the potential impacts of climate risks that may be compounded as a result of rapid expansion. The following figures highlight points of vulnerability where urban and climate-related pressures are being compounded in Madagascar's cities.

Figure 2. Points of vulnerability in Tulear

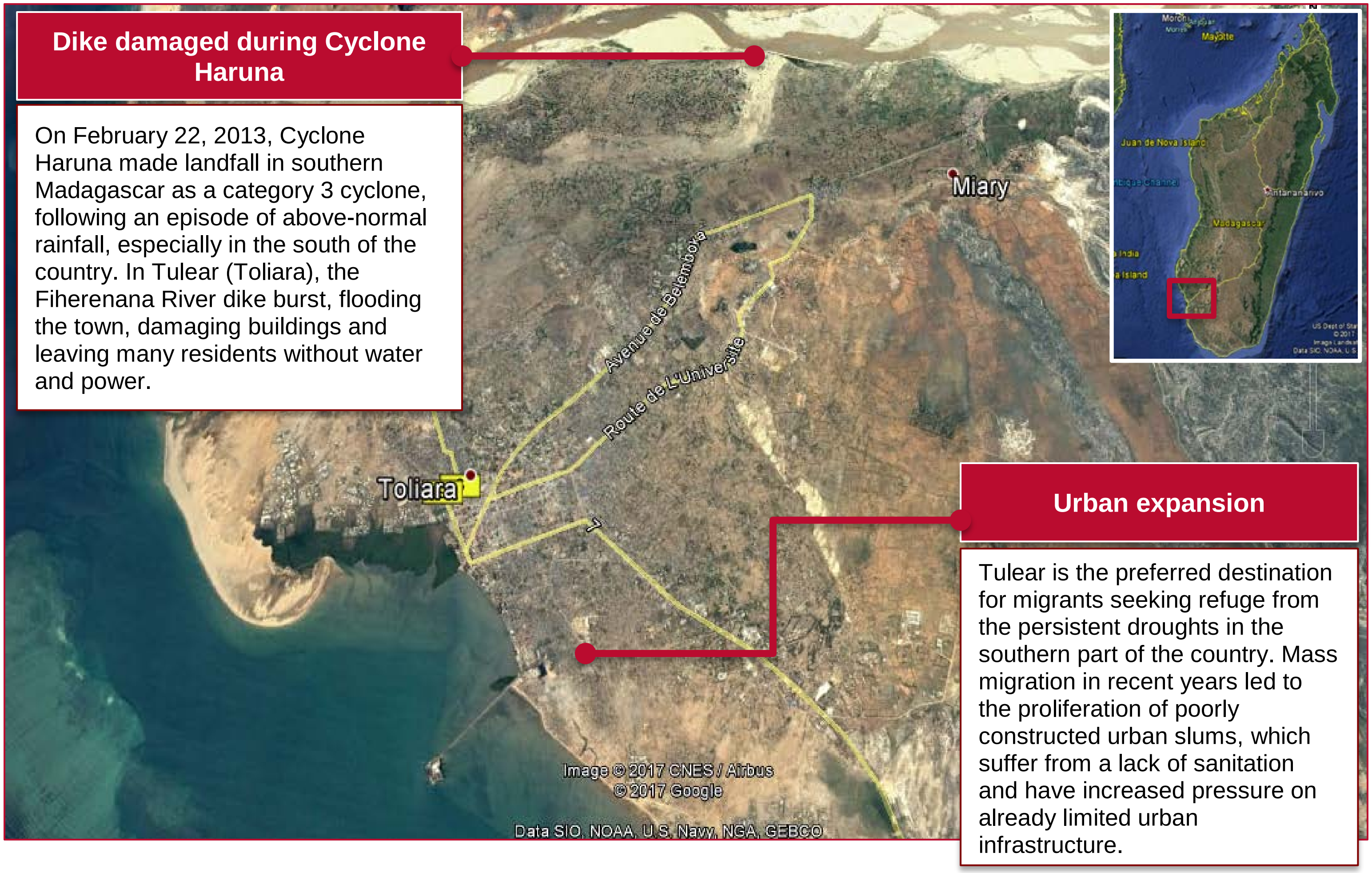
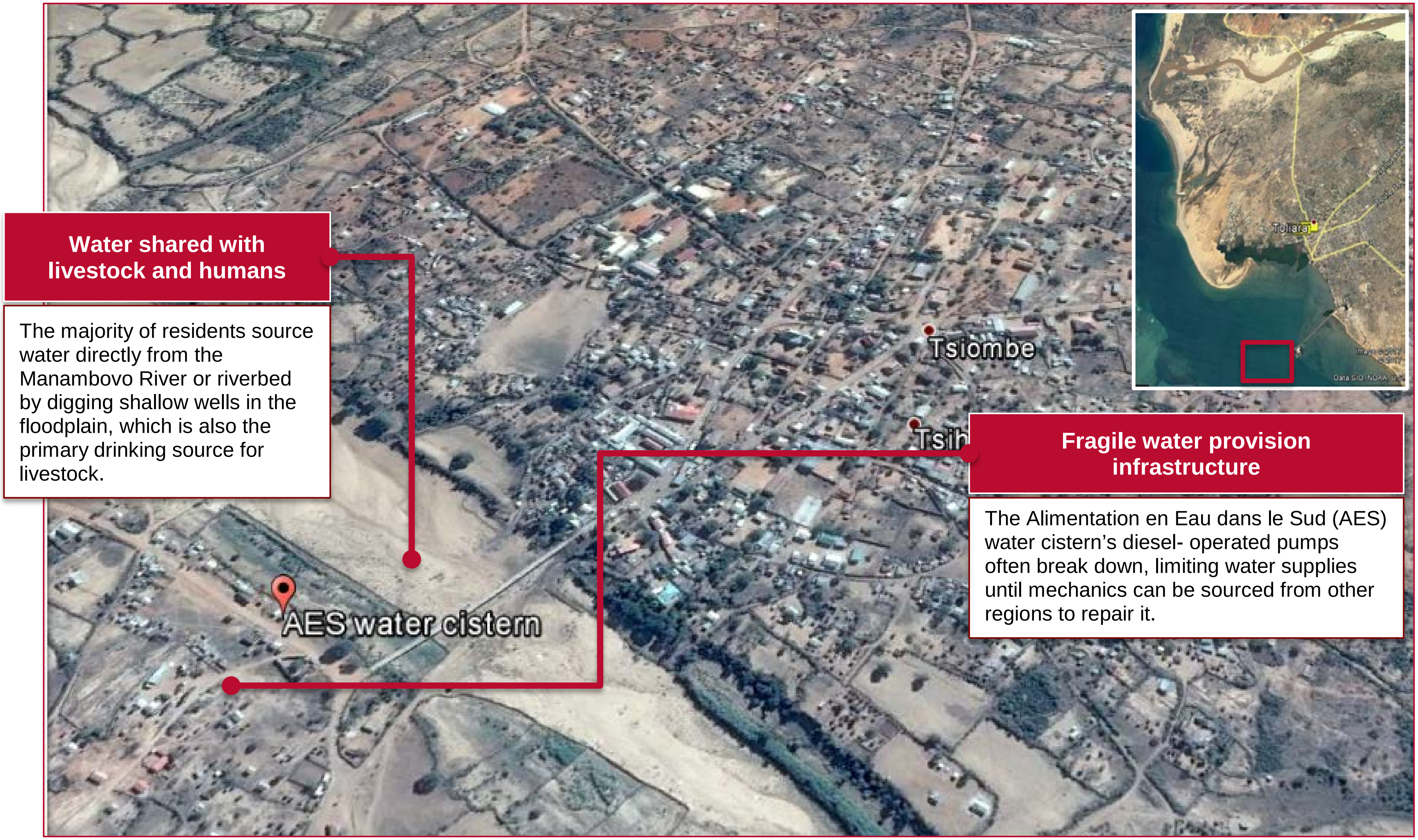


Figure 3. Points of vulnerability in Tsihombe



Source: Google Earth 2017.

Figure 4. Points of vulnerability in Maroantsetra

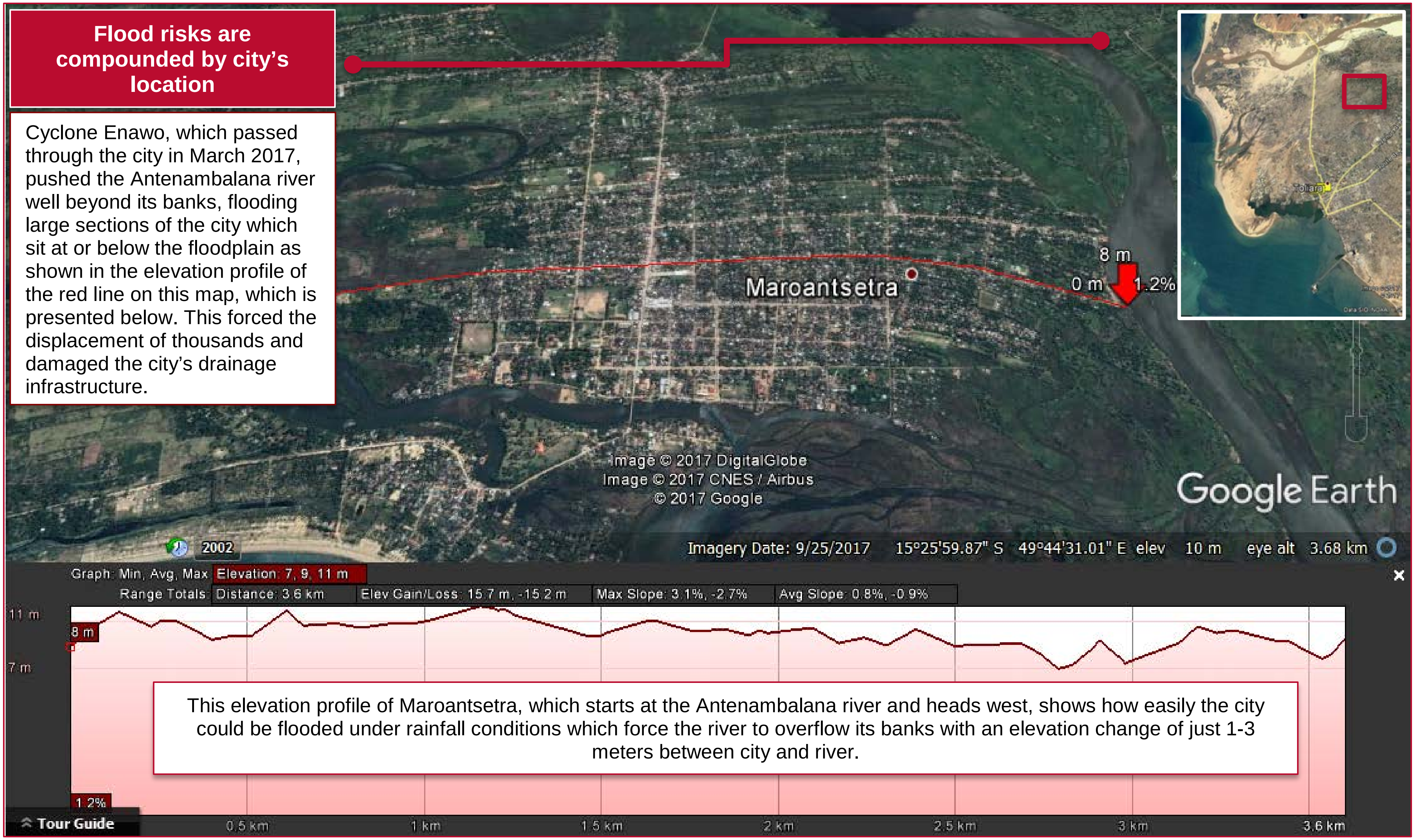
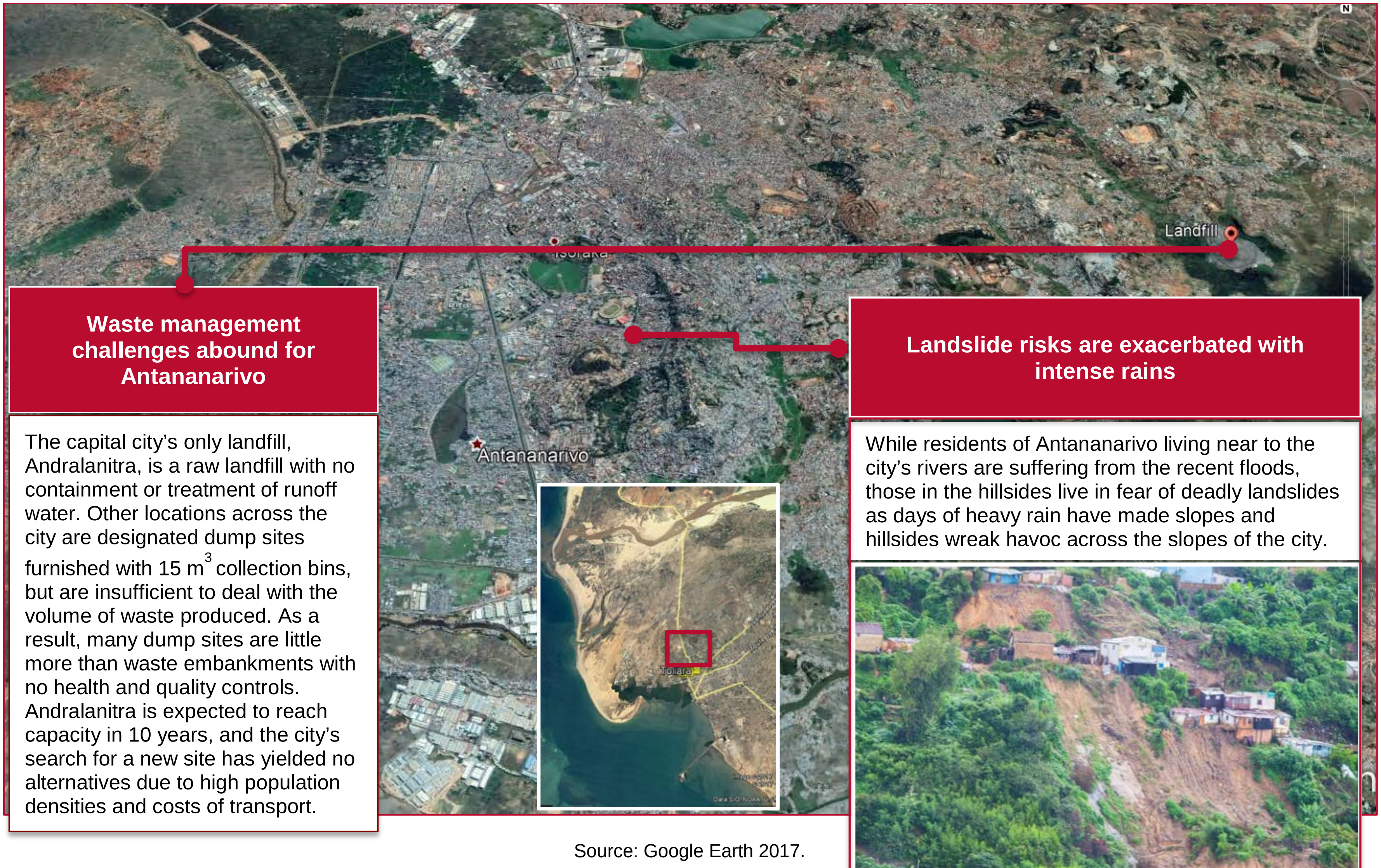


Figure 5. Points of vulnerability in Antananarivo



Waste management challenges abound for Antananarivo

The capital city's only landfill, Andralanitra, is a raw landfill with no containment or treatment of runoff water. Other locations across the city are designated dump sites furnished with 15 m^3 collection bins, but are insufficient to deal with the volume of waste produced. As a result, many dump sites are little more than waste embankments with no health and quality controls. Andralanitra is expected to reach capacity in 10 years, and the city's search for a new site has yielded no alternatives due to high population densities and costs of transport.

Landslide risks are exacerbated with intense rains

While residents of Antananarivo living near to the city's rivers are suffering from the recent floods, those in the hillsides live in fear of deadly landslides as days of heavy rain have made slopes and hillsides wreak havoc across the slopes of the city.

Source: Google Earth 2017.

MUNICIPAL SERVICE DELIVERY IMPACTS, VULNERABILITIES AND ADAPTATION OPTIONS

Increasing climate variability and more frequent extremes projected for the coming decades will impact long-lived, fixed public and private assets and infrastructure. Madagascar's rapidly growing cities and rural towns are exposed to flooding, storms, drought and heat stress that impact human health and safety, economic activities, and urban infrastructure and services. Beyond urban areas, projected climate variability and change will disrupt transport infrastructure, power networks, supply chains and ecosystem services (i.e., water conservation and flood mitigation) on which urban populations rely. These climate stressors exacerbate existing social, economic and environmental weaknesses, and compound risks to urban populations. Consistent with trends across Africa, vulnerability levels are very high among rapidly growing urban populations in Madagascar (Niang et al. 2014).

Sea level rise, heat stress and drought each pose considerable risk to Madagascar's urban and urbanizing population centers. Cyclones, with their associated high winds, storm surges, flooding and landslides, have proved the most damaging to date, calling for climate-sensitive disaster risk management as a key component of adaptation efforts. Catastrophic risk modeling suggests that the country experiences, on average, over $100 million in direct losses from cyclones and floods each year (PPCR 2017). Cyclone Enawo in 2017 caused an estimated economic loss equivalent to 4 percent of GDP and damaged or destroyed more than 104 health facilities, 3,300 classrooms and 250 water systems and contaminated more than 1,300 wells (World Bank 2017, UNOCHA 2017). While intensifying cyclones will likely continue to cause the most damage in urban areas, drought-induced migration may be an equally significant stressor. The drought of 2013–2016 led to food insecurity for 1.1 million people in the country's south (World Bank 2017).

A city's adaptive capacity depends on the quality and coverage of its infrastructure and services, capacity for land use management, and integration of adaptation into all planning and investment efforts. Building adaptive capacity may involve both incremental and transformative (often post-disaster) change, creating more resilient development by addressing basic service deficits, reducing poverty, managing risk, aligning policies and incentives to resilience objectives, and working with the private sector to share the financial and technical burden of these efforts (Revi et al. 2014).

Table 2: Drivers of major climate hazards in Madagascar			
Climate Hazard	**Risk**	**Anthropogenic Drivers**	**Climate Drivers**
Floods and cyclones	Heavy rainfall and storm surges overwhelm cities' limited drainage systems, leading to flooding and infrastructure damage Cyclone winds damage buildings, power lines and other infrastructure Heavy rainfall destabilizes slopes, leading to landslides that damage infrastructure and block natural and constructed drainage channels	• Development in flood-prone areas • Limited and aging drainage infrastructure • Waste that obstructs drainage network • Increased runoff from lands cleared for urban expansion • Interruption of or building over natural drainage channels • Lack of conventional and green flood protection infrastructure • Lack of cyclone-resistant infrastructure	• Increased intensity of heavy rainfall events • Increased intensity of cyclones and associated storm surges
Droughts	Water shortage affects urban water supplies, hydropower production, cooling systems for thermal power production and water-dependent waste systems Surface water is more readily polluted at low water levels Reduced recharge and/or increased withdrawal in coastal aquifers leads to saline intrusion; subsidence above depleted aquifers damages infrastructure	• Inadequate water supply system capacity and coverage • Aging power production infrastructure with limited coverage • Lack of integrated water resources management • Deforestation and land clearing for urban and agricultural expansion	• Likely decreased annual rainfall • Increased duration of dry spells • Likely decrease in core dry season (June to October) precipitation
Sea level rise	Inundation of or storm surge damage to coastal infrastructure occurs Coastal erosion damages or washes away infrastructure	• Development in high-risk coastal zones • Lack of infrastructure resilient to sea level rise • Mangrove deforestation	• Sea level rise • Increased magnitude of storm surges
Heat stress	Buildings overheat and road surfaces are compromised	• Urban heat island effect • Lack of heat-resilient design standards for buildings and roads	• Increased average temperatures • Increased heat wave duration

WATER, SANITATION AND HYGIENE INFRASTRUCTURE

The most pressing climate risk for Water, Sanitation and Hygiene (WASH) infrastructure in increasingly urbanized Madagascar is flood damage and water supply contamination associated with increased intensity of cyclones and heavy rainfall events. Already, cyclones and flooding routinely contaminate urban wells and increase incidence of waterborne disease. In the country's urban areas, 71 percent of people have access to a public or private water tap and just 40 percent have access to at least a basic or shared sanitation facility (JMP 2017). Across the country, open defecation and unimproved latrines are common and increase the risk of downstream water pollution during cyclones and heavy rainfall events.

Longer dry periods, sea level rise and higher temperatures pose additional WASH risks. The successive drought years in southern Madagascar (2013–2016), for example, reduced clean water access. In the southern city of Tsihombe, rivers, wells and water tanks dry up during drought (UNOCHA 2016, UNICEF 2016), creating a major water supply and sanitation challenge. Coastal aquifers already experience substantial saline intrusion (BGS 2002) that could be exacerbated by sea level rise and reduced rainfall or longer dry periods, leading to increased withdrawals and reduced recharge. Coastal populations in the south are particularly dependent on coastal aquifers due to the lack of surface water. Finally, higher water temperatures lead to increased pathogen growth (bacteria and viruses) that diminishes water quality.

Water supply in Tsihombe

Water scarcity, especially in times of prolonged, extreme drought, limits agricultural productivity, threatens food security and severely constrains the resource base available to support the city's inhabitants. Deep-rooted cultural practices mean livestock (especially Zebu) have priority to these limited resources. Less than 1 percent of Tsihombe's population has access to safe, reliable water sources. Instead, the majority of the city's 46,000 residents source water directly from the Manambovo River or riverbed by digging shallow wells in the floodplain. Although a series of diesel operated water pumps* are available to supplement the city's water resources they suffer malfunctions regularly, reducing water availability and increasing costs. Costs are further increased when the diesel pumps fail, and water must be provided via truck.

*Two water operators, JIRAMA and Alimentation en Eau dans le Sud (AES), supply water to Tsihombe. JIRAMA operates communal taps supplied through groundwater underflow captured from the Manambovo River, while AES operates a cistern that relies on water piped from a pumping station in Ampotaka in Beloha commune).

Water contamination from flooding and pollution of scarce water resources during drought combined with increased temperatures threaten to increase transmission of some of Madagascar's most deadly and prevalent diseases. Nationally, diarrhea and malaria are both leading causes of mortality in children under five, accounting for 10 percent and 6 percent of mortality, respectively (Path 2014). A lack of clean water and poor hygiene are estimated to be responsible for causing 90 percent of the country's diarrhea cases (GoM 2016). Additionally, 86 percent of the population is exposed to high rates of malaria (>1 case per 1,000 people) (WHO 2015).

Addressing all risks to water security, including flooding, water scarcity and water quality, requires consideration of all elements of the water supply system from the source (watershed or aquifer) to the point of delivery. Source water protection may require new collaborative approaches among urban and rural government and nongovernment entities, utilities and rural landowners and users.

Table 3: WASH – Climate stressors, risks and responses

Climate stressors	Climate risks	Potential adaptive responses
Increased intensity of heavy rainfall **Increased cyclone intensity** **Sea level rise** **Increased length or intensity of dry periods**	Flooding that leads to contaminated water supplies (wells and surface sources) and increased incidence of waterborne diseases	• Extend, maintain and improve water supply infrastructure for flood resilience (e.g., sealed wells, treated and piped surface water) • Improve on-site excreta disposal systems and extend coverage of sewerage systems • Reduce flood risk through conventional, green and blue flood-mitigation infrastructure and land management options (see Table 4, Stormwater and Wastewater Systems, for additional detail)
	Water scarcity due to drying water sources during longer or more severe dry periods	• Extend, maintain and improve water supply infrastructure for drought resilience, including accessing groundwater where sustainable extraction is possible (e.g., sealed wells connected to aquifer-supplied water towers)

Higher temperatures		• Reduce water losses (e.g., leaks, illegal takings) from existing storage and distribution water supply infrastructure • Increase rain- and floodwater harvesting, storage capacity, treatment and utilization technologies for utilities (i.e., JIRAMA and AES), businesses and public facilities, including small- and large-scale reservoirs and cisterns • Manage and restore upstream water catchments for water conservation • Establish/improve water supply system monitoring processes as a basis for more efficient and equitable use, including pro-poor access to water • Increase water conservation measures (e.g., reuse grey water at user level, monitor public water taps for efficient use) • Establish utility-level infrastructure to recycle wastewater to potable standards
	Saline intrusion into coastal aquifers	• Enhance aquifer recharge through watershed conservation measures • Establish or strengthen surface, rain and flood water harvesting, storage, treatment and utilization
	Increasing temperature combined with standing water after flooding, leading to expanded ranges of disease vectors (i.e., mosquitos)	• Establish or strengthen infectious disease surveillance and early warning systems

STORMWATER AND WASTEWATER SYSTEMS

Increasingly intense heavy rainfall events and cyclones are expected to exacerbate flood risk in urban communities. In coastal areas, storm surges from increasing cyclone intensity combined with sea level rise will put urban infrastructure at high risk of inundation and coastal erosion. Inadequate capacity and extent of urban storm- and wastewater systems already lead to urban flooding. The catastrophic 2015 floods in greater Antananarivo, for example, affected an estimated 93,000 people and caused losses equivalent to 1.1 percent of GDP (PPCR 2017). Further, extreme events are straining flood protection infrastructure. In February 2013, Cyclone Haruna caused a dike along on the Fiherenana River in Tulear (built 2003) to rupture, leading to severe flooding that damaged roads, schools, agricultural infrastructure, water supplies and more than 15,000 homes within a 70-mile radius (WFP 2015).

Storm- and wastewater management in Tulear (Toliara)

Floods and stagnant water are a frequent occurrence in Tulear and can pose a risk to the city's population by providing ideal conditions for the spread of waterborne diseases. At its highest point, the city of Tulear rests just 8 meters above sea level, which brings special challenges to flood- and wastewater management. As of 2004, the city's drainage network consisted of 4 km of conduits, a 700-meter main wastewater collector, and leaching pits. These resources are subject to flooding and damage during the rainy season (Commune Urbaine de Tulear 2004). To make matters worse, dense pockets of vulnerable populations reside in low-lying flood zones along the coast – in the Tsimenatse I, Mahavatse I and Mahavatse II neighborhoods in particular – where access to sanitation services is limited to nonexistent.

Table 4: STORMWATER AND WASTEWATER SYSTEMS – Climate stressors, risks and responses		
Climate stressors	**Climate risks**	**Potential adaptive responses**
Increased intensity of heavy rainfall **Increased cyclone intensity** **Sea level rise** **Higher temperatures**	Increased flooding, overwhelming local drainage systems	• Extend, maintain (clean, fix, reinforce) and improve storm- and wastewater drainage infrastructure • Employ green and blue infrastructure, including maintaining or increasing urban green spaces and tree cover and protecting, restoring and enhancing natural drainage channels, wetlands and floodplains • Manage and restore upstream water catchments to mitigate floodwater before it reaches urban areas • Establish or retrofit upstream reservoirs (attenuation facilities) designed and operated for flood control • Build upstream river spillways to divert water from rivers during major flood events • Build flood protection infrastructure such as levees and bunds • Require new developments to retain all stormwater on-site • Update floodplain mapping with climate information and use in land use planning • Acquire properties at risk of flooding, transition the land to green infrastructure and help affected residents resettle in the community
	Increased flooding from rising sea level and increased magnitude of storm surges	• Implement hard (sea walls, groynes, dikes, etc.) and soft (beach nourishment, dune stabilization, mangrove restoration) engineering methods to minimize coastal erosion, flooding and infrastructure damage • Update coastal flood zone mapping with climate information and use to guide land use planning

SOLID WASTE MANAGEMENT

Increasingly intense heavy rainfall and cyclone events, sea level rise and warming temperatures complicate solid waste management. Uncollected solid waste disturbed and dispersed by heavy rain and high winds leads to air and water pollution and can attract disease-carrying insects and rodents (Hoornweg and Bhada-Tata 2012). In turn, uncollected solid waste exacerbates flooding by obstructing drainage systems. Climate extremes, including sea level rise, further threaten solid waste disposal sites with leaks and breaches, leading to the same problems associated with uncollected waste but in higher concentrations and the additional threat of groundwater contamination. With municipal solid waste generation increasing alongside urbanization and climate trends, there is increased risk of waste impacting public health through respiratory ailments, diarrhea, dengue and plague. Bubonic plague, endemic in the country, is carried by rodents and most commonly transmitted to humans through flea bites. The 2017 plague outbreak included bubonic and pneumonic plague, with cases reported in 35 districts and 10 cities, including the country's largest cities, Antananarivo and Toamasina (as of October 2017) (UN Children's Fund 2017).

Currently, just 18 percent of municipal solid waste in Madagascar is collected, with most of this going into landfills (97 percent) (Hoornweg and Bhada-Tata 2012). By 2025, it is estimated that urban residents in the country will each generate 1.1 kg of municipal solid waste per day, for a total of 12,485 tons per day, creating a large need for solid waste management (Hoornweg and Bhada-Tata 2012). The country's WASH sector key results framework (2016–2019) targets developing urban solid waste management to improve sanitation and reduce solid waste obstruction of drainage systems (GoM 2016). About half of the country's solid waste is organic and an opportunity exists to further develop composting options.

Table 5: SOLID WASTE MANAGEMENT – Climate stressors, risks and responses		
Climate stressors	**Climate risks**	**Potential adaptive responses**
Increased intensity of heavy rainfall **Increased cyclone intensity** **Sea level rise** **Higher temperatures**	Uncollected solid waste dispersed by heavy rain and high winds, obstructing drainage channels, polluting air and water and attracting disease-carrying insects and rodents	• Establish/maintain a regular solid waste collection system • Enforce restrictions on dumping waste in drainage channels • Clear solid waste from drainages and waterways
	Solid waste disposal sites that leak or are destabilized as a result of heavy rainfall, flooding, landslide, high winds or sea level rise	• Improve solid waste disposal practices (e.g., proximity to water sources, stable containment) to prevent leaking or spreading solid waste • Develop composting options to reduce pressure on landfill sites

SCHOOLS, HEALTH FACILITIES AND OTHER PUBLIC BUILDINGS

Public buildings in urban and urbanizing areas are at risk from flooding, high winds, landslides and temperature increase associated with projected climate variability and climate change. During Cyclone Enawo, for example, flooding and landslides damaged health facilities and schools across the country's northern regions and indirectly impacted these facilities through contaminated water supplies and electricity cuts (BNGRC 2017). Along the coast, buildings also face sea level rise, storm surges and coastal erosion. Structures in the towns of Morondava and Mahajanga on the west coast are particularly vulnerable to rising sea levels (GoM 2010). Increasing temperatures, combined with the urban heat island effect, are elevating the risk of overheated buildings, which adversely impacts human health and increases cooling and refrigeration costs where these services exist.

Well-located, hazard-resistant public buildings will minimize exposure to climate risks. National law provides good guidance for resilient development; however, implementation is a challenge for urban governments that often lack the technical expertise, work force and systems to address infrastructure deficits and rapid population growth. In Antananarivo (pop. ~1.4 million), for example, the city's "urban division" has just 10 inspectors and 5 engineers (USAID 2018). The city has attempted to streamline its system for construction permit applications and approvals but is unable to keep pace with rapid expansion, particularly in vulnerable, low-lying neighborhoods.

Public buildings in Maroantsetra

Maroantsetra's communal development plan for 2004–2008 acknowledges cyclones, floods and intense rainfall as risks that threaten residents' safety, livelihoods and assets. The focus of the investment plan, however, is on the construction of public buildings (e.g., primary schools, administrative buildings). Within the last decade, there has been an observed change in hydrology around Maroantsetra. The occurrence of flooding at shelter sites in March 2017 following the passage of Cyclone Enawo suggests a shift in flood patterns, with floodwaters extending far into areas previously untouched. These hydrological changes may, at least in part, be due to the proliferation of "artificial islands" built by local residents for planting in the Antenambalana River. This emerging phenomenon highlights the need to not only consider best practices for cyclone-resistant construction of public buildings but also to evaluate building codes for storm surge and flood risk when identifying potential sites and building specifications for key public buildings.

Table 6: SCHOOLS, HEALTH FACILITIES AND OTHER PUBLIC BUILDINGS– Climate stressors, risks and responses		
Climate stressors	**Climate risks**	**Potential adaptive responses**
Increased intensity of heavy rainfall **Increased cyclone intensity** **Sea level rise** **Higher temperatures** **Increased length or intensity of dry periods**	Loss and damage due to flooding, landslide, high winds, rising sea level and increased height of storm surges	• Establish or strengthen multi-hazard early warning systems at national and subnational levels, including detailed warning response plans • Implement flood- and cyclone-resistant buildings and structural retrofitting • Designate resilient buildings as community shelters with design features that can withstand water and power outages • Protect and maintain tree cover on landslide-prone slopes that threaten public buildings • Implement climate-resilient land use planning (i.e., land use restrictions in floodplains) • Relocate key infrastructure under serious and recurring threat of flooding, landslide, storm damage or sea level rise • Reduce flood risk through conventional, green and blue flood mitigation infrastructure and land management options (see Table 4, Stormwater and Wastewater Systems, for additional detail)
	Overheated buildings	• Implement passive cooling for buildings (i.e., ventilation, shading, insulation, white reflective roofs) • Maintain or increase urban green spaces and tree cover to reduce urban heat island effect • Implement heat warning systems
	Water shortage and/or contamination in facilities	• Increase on-site water collection and storage through rain- and floodwater harvesting, storage capacity, treatment and utilization technologies • Increase water conservation measures (e.g., reuse grey water at user level, monitor public water taps for efficient use) • Improve municipal water supply system from source to point of delivery, including watershed restoration and management and water supply infrastructure (see Table 3, WASH Infrastructure for additional detail)
	Power outages in facilities	• Establish backup power generation capacity for critical buildings (e.g., hospitals) • Address weaknesses in the power generation, transmission and distribution system through elevating, retrofitting, relocating, upgrading and maintaining infrastructure in light of climate risk (see Table 8, Electrical Infrastructure, for additional detail)

TRANSPORT INFRASTRUCTURE

Madagascar's road network is limited in coverage, poorly maintained and highly vulnerable to cyclones, flooding and sea level rise and increasing temperatures. The national network is ramified (branching) but not interconnected, such that an impassable road in one area can cut off access to whole regions of the country. Madagascar has 18,214 km of road, of which 6,077 km are paved (UNISDR 2015). Much of the road network is in poor condition and prone to flooding, leading to regular disruptions in the movement of goods and people. The Global Competitiveness Index ranks the quality of the country's roads at 2.2 on a scale of 1 to 7 (World Bank 2017). In urban areas, roads are often aging and congested. Inadequate and poorly maintained culverts along Route Nationale 5 on the outskirts of Maroantsetra, for example, caused part of the road to wash away in the wake of Cyclone Enawo in 2017. Farm-to-market routes are commonly unpaved and highly susceptibility to degradation from increasing flooding and erosion.

Road, port, rail and air transportation are all at risk of disruption during intense cyclones and heavy rainfall events. Ports are particularly sensitive to cyclones, storm surges and sea level rise and to disruptions to water and electric service caused by climate and non-climate stressors. The larger of the two Antalaha ports, for example, was inaccessible for a week after Cyclone Enawo (BNGRC 2017). Toamasina, the nation's largest port, is located on the east coast and is crucial for the country's economy. The country has two unconnected railway systems. The northern railway (TCE) consists of three lines and the southern railway, Fianarantsoa-Côte Est (FCE), a single line. The entire network is 875 km long, entirely single track and vulnerable to flooding, landslides and erosion. The country's airports are at risk of damage to runways from increasing temperatures that can cause pavement to buckle and from flooding, as well as to disrupted service due to extreme weather events (Baglin 2012).

Table 7: TRANSPORT INFRASTRUCTURE – Climate stressors, risks and responses

Climate stressors	Climate risks	Potential adaptive responses
Increased intensity of heavy rainfall **Increased cyclone intensity** **Sea level rise** **Higher temperatures**	Disruption of road, port, rail, and air transportation during cyclones and heavy rainfall	• Enhance redundancy of critical transportation routes
	Damage or destruction of roads, bridges, culverts, rail lines and airport runways due to surface or seawater flooding, landslides, wash-outs and coastal erosion	• Implement transportation design standards that address flood, landslide and storm surge risks • Improve road, rail and airport runway drainage and flood protection in key at-risk areas • Rehabilitate transport lifeline infrastructure, including key points along national roads RN7, RN4, RN6, RN 12 and RN25 • Redesign or relocate transportation routes under serious and recurring threat of flooding, storm damage or sea level rise
	Damage to ports due to storm surge, sea level rise and high winds	• Implement hard (e.g., sea walls, groynes) and soft (e.g., beach nourishment, dune stabilization) engineering methods to minimize coastal erosion, flooding and infrastructure damage from coastal flooding • Design seaport terminals to withstand sea level rise, increasing wave loads and high winds
	Thermal expansion of paved surfaces and compromised pavement integrity (buckling, softening, rutting, cracking, etc.)	• Establish transportation design standards that address temperature risks

ELECTRICAL INFRASTRUCTURE

A likely future drying trend combined with more intense heavy rainfall events and more frequent and intense cyclones create operational risks for Madagascar's electricity production and transmission and distribution systems. The country's electrical production comprises 60 percent hydropower and 40 percent thermal (fossil fuel) generation (AfDB 2016). Hydropower production faces the pressure of water scarcity due to longer dry spells and likely overall reduced precipitation. Thermal generation also requires large volumes of water for cooling and is sensitive to water shortages. Water scarcity will exacerbate competition for water resources between the agriculture and power sectors. Meanwhile, heavy rainfall-associated flooding and landslides threaten to damage dams and electricity transmission and distribution infrastructure. Cyclone winds also damage powerlines and other grid infrastructure, causing power outages. Cyclone Enawo, for example, disrupted electrical service throughout northern Madagascar for weeks, including the hard-hit Antalaha commune (BNGRC 2017). Cyclones may further disrupt fossil fuel imports through the Toamasina port, temporarily restricting thermal generation.

Climate stressors on electrical supply come in addition to the strains from rising demand (increasing by 5 percent per year) and limited transmission and distribution capacity (USAID 2016). In urban areas, electricity access is just 57 percent, leaving many urban residents reliant on burning of unhealthy and inefficient biomass (coal and wood) for fuel (AfDB 2016). Regular outages in electric service occur, as do long waiting periods for new connections. The lack of electricity has numerous impacts, including hampering health facilities' operations, creating indoor air pollution from burning biomass and encouraging deforestation. Drying trends, and flood and storm damage, may exacerbate the lack of electricity, further impacting urban businesses and urban services (water supply and treatment, emergency services, etc.) and the urban residents who rely on both.

The country does have extensive renewable energy potential, including hydropower (7,800 MW, only 1.6 percent harnessed), solar (2,000 kWh/m2/year) and wind (2,000 MW) (AfDB 2016). A new electricity policy (2015) has a goal of increasing renewable energy to 85 percent of electricity production and providing access to electricity to 70 percent of the population.

Table 8: ELECTRICAL INFRASTRUCTURE – Climate stressors, risks and responses

Climate stressors	Climate risks	Potential adaptive responses
Increased intensity of heavy rainfall **Increased cyclone intensity** **Increased length or intensity of dry periods** **Sea level rise** **Higher temperatures**	Power generation, transmission and distribution infrastructure damaged by high winds, flooding, coastal erosion and storm surges, leading to outages or shortages	• Elevate, retrofit or relocate key infrastructure under serious and recurring threat of flooding, storm damage, coastal erosion or sea level rise • Upgrade distribution infrastructure with stronger materials and structural support • Manage vegetation around distribution systems • Establish backup power generation capacity for critical buildings (e.g., hospitals) • Establish renewable energy-fueled micro-grids (with ability to separate from main grid during disturbance) • Reduce flood risk through conventional, green and blue flood mitigation infrastructure and land management options (see Table 4, Stormwater and Wastewater Systems, for additional detail)
	Water shortage and tradeoffs among water availability for power production, irrigation and domestic use	• Improve coordination among water users, including plans for water distribution during scarcity • Increase rain- and floodwater harvesting, storage capacity, treatment and utilization technologies for utilities (i.e., JIRAMA and AES), businesses and public facilities, including small- and large-scale reservoirs and cisterns • Increase water conservation measures (e.g., reuse grey water at user level, monitor public water taps for efficient use) • Improve municipal water supply system from source to point of delivery, including watershed restoration and management and water supply infrastructure (see Table 3, WASH Infrastructure for additional detail)

	Heightened electricity demand for increased indoor cooling and refrigeration	• Increase electricity production from renewable sources, including small-scale wind and solar energy production • Identify options for increasing energy efficiency among energy users • Implement passive cooling for buildings (i.e., ventilation, shading, insulation, white reflective roofs) • Maintain or increase urban green spaces and tree cover to reduce urban heat island effect

OPPORTUNITIES FOR ENGAGEMENT IN URBAN AND RAPIDLY URBANIZING AREAS

Preparing urban communities for hotter and more extreme weather will reduce the costs associated with climate-induced infrastructure damage, diminished public health and loss of life. Critical components of urban climate risk management include robust risk assessment, effective land use planning, resilient infrastructure, quality and coverage of basic services, early warning systems and emergency response. Urban adaptation is an iterative process and requires ongoing integration of climate information into policy, planning and budgeting processes. Adaptation initiatives are most effective when grounded by local climate risk assessment and aligned with government efforts, including the Plan National de Développement 2015–2019.

Urban adaptation management is complex, particularly in the context of rapid growth. Key to adaptation is steering new investment and migration flows away from areas of high climate risk through urban planning, disaster risk management and infrastructure investments (Revi et al. 2014). In urban areas, adaptation efforts also can involve difficult choices between resilient infrastructure investments and relocation when risks are too large to mitigate (e.g., low-lying coastal developments). Stakeholder engagement, including community groups and broad public participation, focused on increasing equity and sustainability is critical to effective adaptation.

Many adaptation actions, particularly those related to water supply and flood mitigation, must be coordinated across multiple jurisdictions with differing capacities, interests and directives. In Tsihombe, for example, addressing chronic water supply challenges in the context of increasingly long and intense dry spells requires looking upstream and across jurisdictions. Water utilities (JIRAMA and AES), governments in water source and end-user communes (i.e., Ampotaka and Tsihombe for the AES water pipeline) and residents each have a role in managing water supply. Roles for donors in infrastructure and management investments must also be assessed. Geologic surveys are needed to determine sustainable groundwater extraction rates. These types of efforts require local governments to build relationships and negotiate management arrangements outside of their traditional spheres.

Opportunities for engaging with the governments of large or growing population centers include addressing climate information needs, strengthening municipal governance for climate risk management and resilience, and investing in conventional infrastructure and nature-based approaches, such as urban green space. Support to urban governments may come in the form of training, tailored decision support tools for planning and management, opportunities for shared learning nationally and internationally, facilitation of access to resources and finance, and more. Support to urban governments may be most effective in places where local government entities have already begun to strengthen their capacity through initiatives that improve the effectiveness of their planning and financial management. Specific opportunities are described in more detail for each of these areas, as follows.

CLIMATE INFORMATION NEEDS

An evidence base is essential for effective urban adaptation. This includes completing local risk and vulnerability assessments and improving climate science and urban adaptation expertise that can inform adaptation options. In Madagascar, this evidence base is being developed through:

- Commune-, district- and regional-level disaster risk management committees (in some areas)
- National entities such as the Direction Générale de la Météorologie (DGM), Bureau National de Coordination des Changements Climatiques (BNCCC) and Bureau National de Gestion des Risques et Catastrophes (BNGRC)
- International initiatives such as the Famine Early Warning Systems Network (FEWS NET), Pilot Program on Climate Resilience (PPCR), USAID-NASA SERVIR and Enhancing National Climate Services (ENACTS)

While these efforts are significant, most local governments have limited access to relevant climate information and a lack of experience with how to put this information to use in urban management. Available information is often difficult for local governments to interpret and is not tailored for a particular urban area. The inability to access and use relevant climate information restricts local government capacity to anticipate and act on emerging climate risks to urban infrastructure, services and populations. Climate information is essential for both identifying risk and demonstrating the benefits of investing in adaptation over time.

To address these information gaps, it is recommended to:

- **Promote the generation of locally usable weather and climate information for municipalities** by facilitating discussion among local government, DGM and other climate information providers about developing understandable and tailored information products.
- **Support local government in accessing reliable climate information** to inform decision making. Where information is lacking, support risk assessment and information collection on climate risk and the changing demographics that influence levels and areas of vulnerability. Encourage work with *fokontany* (neighborhood organizations) leaders, community groups and vulnerable populations to identify area-specific risks and population trends.
- **Build local government capacity to use climate information** in urban planning and management (including updating land use maps), improving service delivery and screening new investments with emphasis on the long-term approach needed to adapt to evolving climate conditions.
- **Increase local support and demand for adaptation solutions by raising residents' awareness** of climate risks and adaptation options among women, men and vulnerable groups.

STRENGTHENING MUNICIPAL GOVERNANCE FOR CLIMATE RISK MANAGEMENT AND RESILIENCE

Municipal governments are responsible for leading economic, social, cultural and spatial development, including developing a master urban plan and a three-year public investment plan.

Local governments have additional responsibilities for public safety, service provision (particularly sanitation and waste management) and public infrastructure (i.e., commune roads, schools and health centers) (Law on Decentralization 2014, Law on Decentralized Local Authorities 2014). In addition to the commune government, *fokontany* serve as a forum for public participation in governance and can encourage compliance with local plans and regulations.

Local government capacity to fulfill its mandated roles varies among communes but is generally low and a major obstacle to adaptation. Urban governments are often constrained by limited authority, weak or nonexistent supporting institutions and a lack of the requisite training, tools and resources to manage and plan urban spaces. The land use policies and zoning that do exist are often outdated and inadequate and planning tools to operationalize planning efforts are lacking. Urban governments typically consist of an elected mayor, the chief executive and a communal council. Council members oversee designated commune functions such as tax collection, communal police service, and public records. Some communes also have committees that focus on disaster risk management, water and sanitation, health or development. Officials from regional or national structures (e.g., M2PATE, Ministry of Agriculture, Ministry of Health) are occasionally deployed to districts and communes to provide technical assistance.

Disaster risk management and urban adaptation

Integrating adaptation into urban disaster risk management provides a ready opportunity to address changing exposure to climate risks. The growing concentration of people in high-risk urban areas combined with climate variability and extremes can create new hazards, exposure and vulnerability. Madagascar has a large and active disaster risk management community (government, donors and NGOs) that is increasingly interested in disaster risk reduction and climate change adaptation. The Disaster and Risk Management Act (amended 2016) and National Plan for Disaster Risk Management guide efforts. Supporting urban adaptation through disaster risk management efforts involves integrating locally relevant climate information as well as:

- Planning for post-disaster recovery before a disaster strikes, including a resilience-building post-disaster redevelopment plan and adopting a post-disaster redevelopment ordinance that encourages increasing resilience through disaster recovery.
- Supporting emergency preparedness for more extreme weather emergencies, including heat waves.
- Investing in multi-hazard early warning systems and communication infrastructure and strategies within and beyond the urban area to share critical information before and during emergencies.

Urban planning tools, including comprehensive plans, zoning, developer incentives and building codes, are critical for building urban resilience. These tools can shift development away from high-risk areas, create safe commercial and residential areas, guide sustainable transit networks and more. Urban communes are mandated to develop master plans, *Plan d'urbanisme Directeur* (PUDi) with public consultation (Law on Urban Planning and Housing 2015). These plans have potential to provide important guidance for adaptation; however, few urban areas have them in place. National law also guides zone-level planning (e.g., industrial zones) through *plans d'urbanisme de détaille* (PUDe). A number of other national laws are applicable to adaptation, including the Urbanization and Habitation Code which includes building and infrastructure codes (revised 2010 and 2015), the Disaster and Risk Management Act (amended 2016) and the Decree on the Construction of Cyclone-Resistant Buildings (2010). Lack of awareness of these laws and capacity to implement them, however, has led to weak compliance (IFRC 2014).

To develop municipal capacity for planning and prioritizing adaptation:

- **Support municipalities in prioritizing and designing adaptation actions,** including grey (i.e., conventional hard infrastructure) and green infrastructure and management options. Encourage robust community and stakeholder engagement, including vulnerable populations. Adaptation solutions may include promoting *fady* (taboos) designed to protect water quality, conserve green spaces and more through communication and behavior change campaigns.
- **Support integrating prioritized adaptation actions into urban plans and planning processes** with an emphasis on projects that address the most vulnerable areas and provide multiple benefits (e.g., green infrastructure that reduces flooding and heat stress and provides a public park).
- **Support local government in understanding and complying with national laws** related to urban planning, building and infrastructure codes, and disaster risk reduction. Include climate information and consideration of demographic pressures in efforts to comply with national laws. Addressing development in flood-prone areas deserves particular attention.

To develop municipal capacity in financial management for adaptation:

- **Support local governments to develop budgets for prioritized adaptation** efforts and prepare technically sound investor-ready projects.
- **Support local government in building relationships with regional and national government, nongovernment, private sector and donor entities** that may have resources to support urban adaptation.
- **Promote access to a range of finance mechanisms and resources** for adaptation (*see next section*).

To encourage support for urban adaptation among national government entities:

- **Work with national government entities to establish leadership, cooperation and respective roles for supporting urban adaptation**, including M2PATE, BNGRC, the Emergency Prevention and Management Unit (CPGU), BNCCC and the Ministry of Public Works.
- **Support M2PATE staff dedicated to working with regional and district governments on land use planning** (about 50 staff) and the National Planning and Habitat Committee (established through the Law on Urban Planning and Housing 2015) to integrate climate risk considerations and adaptation options into urban planning.
- **Support BNGRC to integrate climate information** into its disaster-specific plans (*plans particuliers*, PPI) for cyclones and flooding and support its cooperation with BNCCC.
- **Support BNCCC in its efforts toward comprehensive regional adaptation plans** with relevant information and planning tools.

INVESTMENTS IN NATURE-BASED AND CONVENTIONAL ADAPTATION INFRASTRUCTURE

Key adaptation investments are building, maintaining and retrofitting conventional infrastructure to withstand more extreme weather and conserving or increasing natural areas and green and blue infrastructure to address flood and heat stress risks. Infrastructure and nature-based investments are most effective when guided by comprehensive urban planning, resilient building and infrastructure codes and standards, and sustainable management practices.

Supporting cities in identifying options for accessing resources and financing is a critical part of investing in urban resilience. Local government financial resources are scarce across the country as local governments collect only about 30 percent of their potential revenues due to an unclear legal framework, poor awareness and enforcement of tax and nontax revenue regulations, and challenges in collecting revenues (World Bank 2016a). Additionally, mandated intergovernmental

Green and blue infrastructure

Climate risk is exacerbated by both inadequate conventional infrastructure and the loss of ecological (green) infrastructure to facilitate adaptation. Expanding and retrofitting conventional wastewater systems is often expensive, leading many cities to integrate green infrastructure approaches to ease the pressure on existing drainage systems (Buurman and Klaassen 2015). Green infrastructure aims to capture rainwater where it falls, intercepting water before it can overwhelm conventional drainage systems, or temporarily store water on land to lower peak discharge. The approach preserves or restores the functionality of green spaces to absorb and treat stormwater at its source. Blue infrastructure, including constructed wetlands or retention ponds, may supplement green and grey infrastructure. Examples of green infrastructure include rainwater harvesting, rain gardens (bioretention), bioswales, urban tree canopy and land conservation, particularly for steep hillsides, natural drainage channels and floodplains. Green and blue infrastructure can also lower temperatures and improve air quality, among other social and ecological benefits.

transfers from the central treasury are often insufficient and unreliable. The central government collects more than 95 percent of the country's revenue and the small disbursements available to municipalities are irregular, posing a substantial challenge for local budgets (World Bank 2017).

To promote infrastructure investment:

- **Bring together government, local service provider, community, NGO and donor expertise and cooperation to design and implement strong adaptation investments**. Encourage coordination to implement projects at the appropriate scale and with all available resources. Ensure green and blue infrastructure options in addition to conventional infrastructure. Support cost-benefit analyses of adaptation interventions.
- **Support local governments to consider where adaptation aligns with currently funded activities** and integrate adaptation to optimize funding.
- **Support municipalities to partner with upstream management entities** to implement watershed conservation and restoration, flood protection measures and water supply infrastructure maintenance and upgrades.
- **Work with municipalities to employ national hazard-resistant building codes** in areas vulnerable to cyclones and flooding. The cyclone-resistant building code factors in climate trends, including higher wind speeds.
- **Work with local service providers to increase resilient infrastructure and management practices** for water, sanitation, waste and electric services (i.e., JIRAMA, AES), including options such as adapting key infrastructure to withstand weather extremes and addressing water losses.
- **Support local government to work with *fokontany* leaders and community groups to orient new residents** to the area's climate risks and enforce local land use plans.
- **Use community service days or cash-for-work programs for conventional and green infrastructure efforts** such as rehabilitating drainage systems or establishing rain gardens.
- **Support local governments to identify a range of financial mechanisms and resources** available to support urban adaptation, including:
    - **Public-private partnerships and private sector investment,** with support from organizations with expertise in these mechanisms such as Fondation TELMA.

- **Options to increase own-source revenue** (tax and nontax) and improve fiscal management.
- **Small-scale investment grants** from the government-administered Local Development Fund (FDL) or Development Intervention Fund (FID) for activities such as retrofitting education and health infrastructure.
- **Development agreements** where developers assume the cost of service infrastructure upgrades, offset development impacts through conserving or restoring green infrastructure and/or manage stormwater on site.
- **Facilitation of intergovernmental financial flows** to address issues impeding the effective and efficient transfer to local government.

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