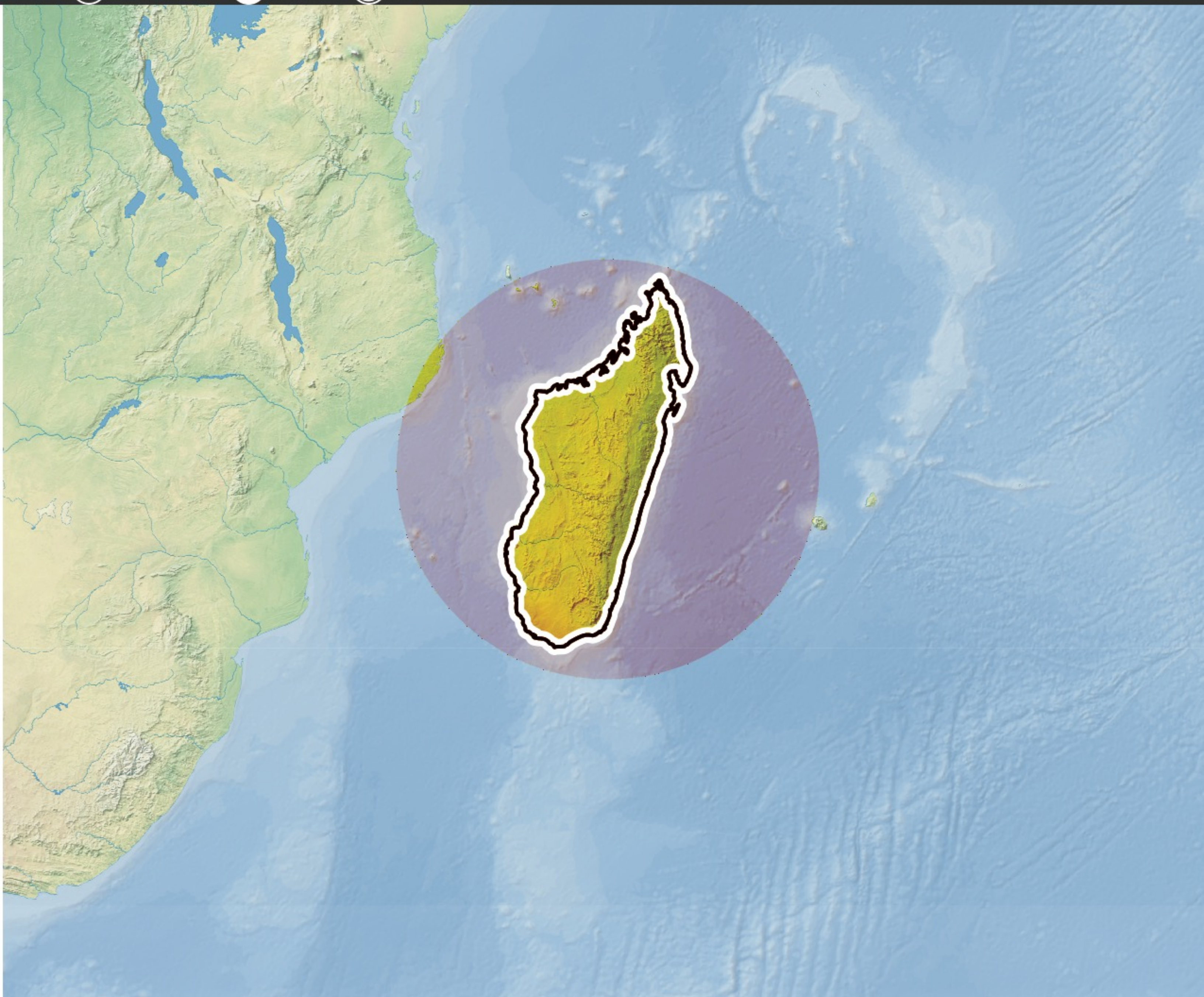
DISASTER RISK PROFILE

Madagascar

Earthquake Flood Tropical Cyclone



Southwest Indian Ocean Risk Assessment and Financing Initiative

WORLD BANK GROUP

GFDRR
Global Facility for Disaster Reduction and Recovery

Building Disaster Resilience in Sub-Saharan Africa

An initiative of the African, Caribbean and Pacific Group of States funded by the European Union

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Africa Disaster Risk Profiles are co-financed by the EU-funded ACP-EU Natural Disaster Risk Reduction Program and the ACP-EU Africa Disaster Risk Financing Program, managed by the Global Facility for Disaster Reduction and Recovery.

The SWIO RAFI Project

The Southwest Indian Ocean Risk Assessment and Financing Initiative (SWIO RAFI) seeks to provide a solid basis for the future implementation of disaster risk financing through the improved understanding of disaster risks to participating island nations. This initiative is in partnership with the Ministries of Finance, National Disaster Risk Management Offices and Insurance sector representatives from The Comoros, Madagascar, Mauritius, Seychelles, and Zanzibar, and carried out in coordination with the Indian Ocean Commission (IOC) ISLANDS Project, the United Nations Office for Disaster Risk Reduction (UNISDR), and the French Development Agency (AFD). The SWIO RAFI supports the ISLANDS project's Islands Financial Protection Program (IFPP), which is also supported by the European Union (EU), UNISDR, and AFD. Africa Disaster Risk Profiles are co-financed by the EU-funded ACP-EU Natural Disaster Risk Reduction Program and the ACP-EU Africa Disaster Risk Financing Program, managed by the Global Facility for Disaster Reduction and Recovery.

SWIO RAFI complemented the ongoing work of the IOC to reduce vulnerability to natural disasters in accordance with the Mauritius Strategy for the Further Implementation of the Program of Action for the Sustainable Development of Small Island Developing States (SIDS) 2005–2015. More broadly, this initiative offers support to long-term, core economic, and social development objectives.

The risk modeling undertaken through SWIO RAFI focused on three perils: tropical cyclones, floods produced by events other than tropical cyclones, and earthquakes. Three hazards associated with tropical cyclones, wind, flooding and storm surge were considered in the risk assessment. In addition, as part of the earthquake risk assessment, tsunami risk zones were identified for each country.

The SWIO RAFI included the collection of existing hazard and exposure data, and the creation of new hazard and exposure data, that were used in the development of a risk assessment and risk profiles for The Comoros, Madagascar, Mauritius, Seychelles, and Zanzibar.

The exposure data includes detailed information on building construction for a variety of occupancy classes including: residential; commercial; industrial; public facilities such as educational facilities and emergency facilities; and infrastructure such as roads, airports, ports, and utilities. Finally, risk information that is determined through a combination of data on hazard, exposure, and vulnerability is provided at the national level and at several administration levels for each peril and for all perils combined, and broken down into occupancy classes.

In addition to the information provided in the risk profiles, the hazard and exposure data and the results of the risk analysis will be collated and stored on open data geospatial risk information platforms, or GeoNodes, in each country and will be available to a wide range of end-users. The results will be available in the form of geospatial files, text files, and detailed final reports and can be used for sector specific development planning and implementation.

MADAGASCAR

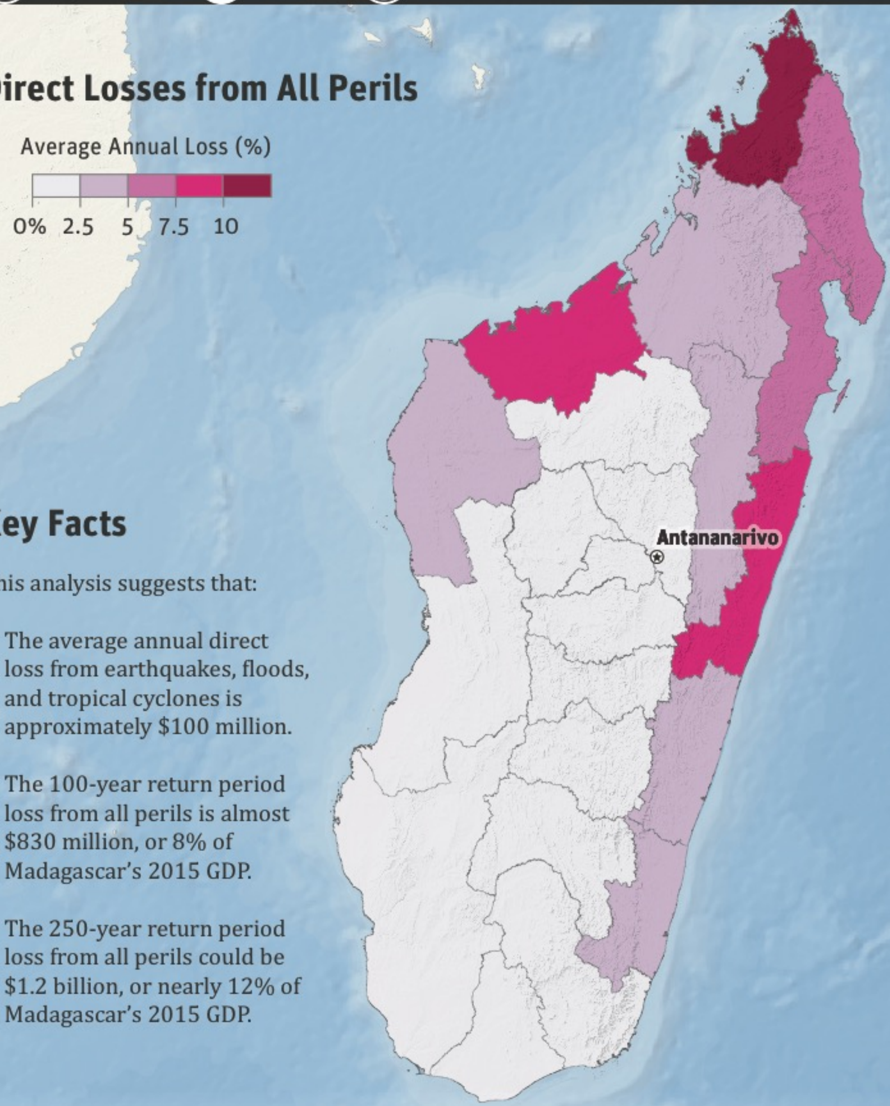
Earthquake Flood Tropical Cyclone

This analysis suggests that, on average, Madagascar experiences over **US$100 million** in combined direct losses from earthquakes, floods, and tropical cyclones each year. However, a specific event such as a **severe tropical cyclone** can produce **significantly larger losses**. For example, results suggest that a **100-year** return period tropical cyclone event would produce direct losses of **$810 million** and require approximately $190 million in emergency costs.

Tropical cyclones are by far the **most significant risk** in this study, causing approximately **85 percent** of the annual average loss from all three perils. Flooding is the next largest risk, accounting for nearly 13 percent.

In this analysis the residential sector experiences nearly **75 percent** of the combined losses, the commercial sector over 9 percent, and the public sector more than 8 percent. The **highest loss** takes place in the **Toamasina region**, which experiences nearly 30 percent of the average annual losses from the three perils combined. In addition to the direct losses, an annual average of nearly **$23 million** is estimated for **emergency costs**.

Direct Losses from All Perils

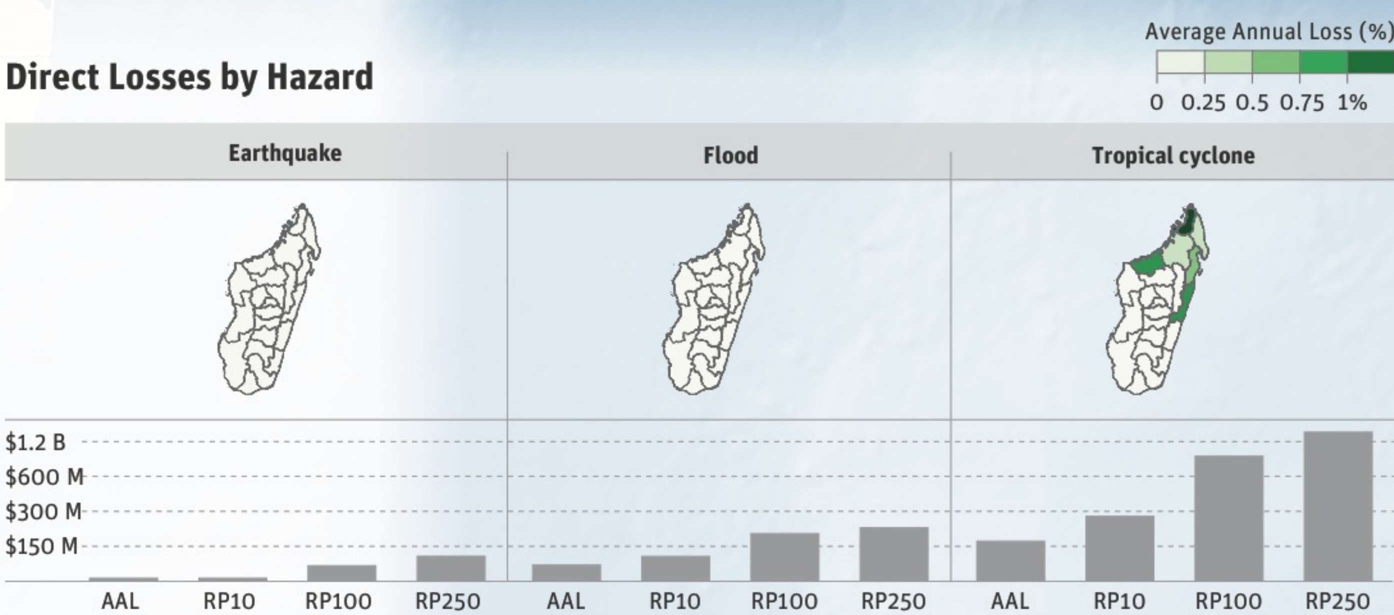


Key Facts

This analysis suggests that:

- The average annual direct loss from earthquakes, floods, and tropical cyclones is approximately $100 million.
- The 100-year return period loss from all perils is almost $830 million, or 8% of Madagascar's 2015 GDP.
- The 250-year return period loss from all perils could be $1.2 billion, or nearly 12% of Madagascar's 2015 GDP.

Direct Losses by Hazard



RISK SUMMARY

MADAGASCAR

GDP $10.3 billion **Population 23 million**

Madagascar's **population** in 2015 was approximately **23 million**. The most populous regions are around Antananarivo and along the coastline. Nearly 22 percent of Madagascar's population lives in metropolitan or urban areas (more than 2,000 people per square kilometer) and slightly more than 76 percent in rural areas (fewer than 1,600 people per square kilometer). In 2015, Madagascar's **gross domestic product** (GDP) was approximately **$10.3 billion** ($34 billion in purchasing power parity), and the per capita GDP was $420.

For 2015, the estimated **total replacement value** for all residential, commercial, industrial, and public buildings and other infrastructure is estimated to be nearly **$35 billion**. The largest concentration of replacement value is the Antananarivo region.

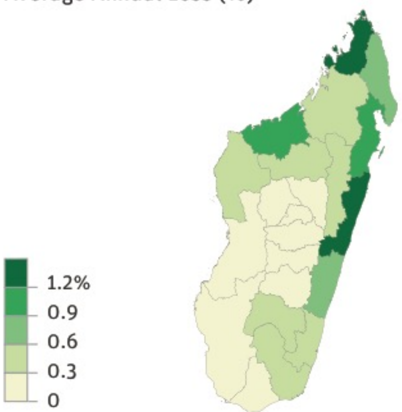
To assess risk better, replacement values and loss are often categorized according to occupancy and construction types. In terms of occupancy type, the **residential sector** accounts for over **55 percent** of the total replacement value. In terms of construction type, buildings with **masonry** and **concrete** wtall construction account for nearly **62 percent** of the **total replacement value**.

Peril	Average Annual Loss		100-Year Return Period Loss	
	Total Direct Losses	Emergency Costs	Total Direct Losses	Emergency Costs
Earthquakes	$1.3 million	$200,000	$15 million	$2.3 million
Floods	$13 million	$3.1 million	$120 million	$27 million
Tropical Cyclones	$87 million	$20 million	$810 million	$190 million

Direct Losses by Building Type for All Perils

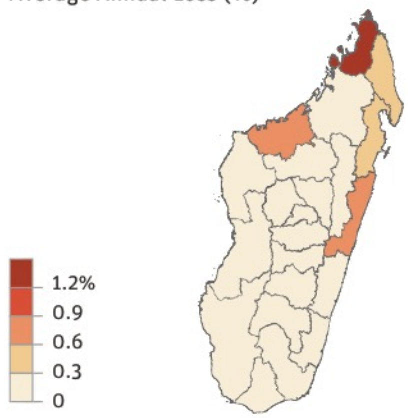
Residential

Average Annual Loss (%)



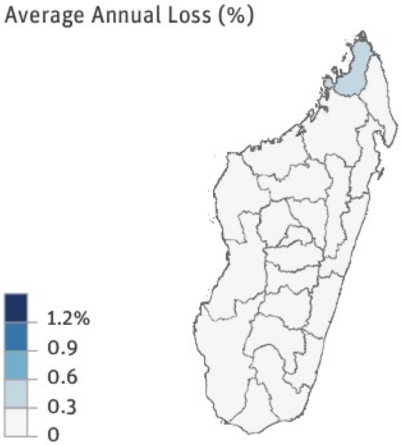
Commercial/Industrial

Average Annual Loss (%)



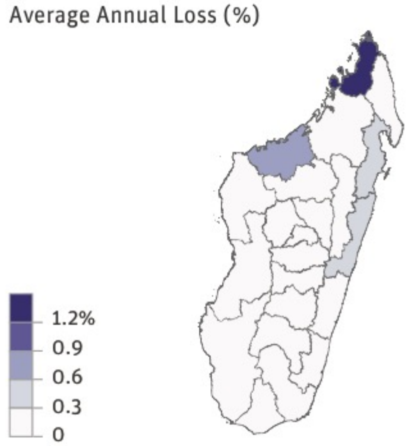
Infrastructure

Average Annual Loss (%)



Public*

Average Annual Loss (%)



*Education, Healthcare, Religion, Emergency

TROPICAL CYCLONE
MADAGASCAR

Tropical cyclones are common in the Southwest Indian Ocean region, and Madagascar often experiences **multiple landfalls each year**. The wind, rain, and storm surge associated with tropical cyclones all contribute to losses.

A recent example of a tropical cyclone affecting Madagascar is **Chedza**, which made landfall in Madagascar on **January 16, 2015**. The cyclone caused around **68 fatalities** and affected over **80,000 people**.[2]

This analysis suggests that, on average, Madagascar will experience around **$87 million** in **direct losses annually** from winds, flooding, and storm surge associated with tropical cyclones. This is **86 percent** of the country's total annual direct losses from earthquakes, floods, and tropical cyclones. The results suggest that almost **73 percent** of the loss from tropical cyclones originates from the **residential sector**. On average, **emergency costs** for tropical cyclones are estimated at nearly **$20 million** annually.

Tropical cyclones generate wind, flood, and storm surge hazards. On average in this analysis, **winds** cause over **68 percent** of the **loss** from the three hazards, while storm surge causes around 20 percent and inland flooding around 12 percent of the remaining damage.

Return Period	Total Modeled Losses
AAL	$90 million
RP10	$200 million
RP100	$810 million
RP250	$1 billion

Modeled Direct Losses

		Average Annual Loss
Residential	AAL	$65 million
	RP10	$150 million
	RP100	$550 million
	RP250	$750 million
Commercial/ Industrial	AAL	$8 million
	RP10	$20 million
	RP100	$100 million
	RP250	$150 million
Public	AAL	$7.5 million
	RP10	$20 million
	RP100	$100 million
	RP250	$150 million
Infrastructure	AAL	$2 million
	RP10	$4 million
	RP100	$30 million
	RP250	$45 million

Key Facts

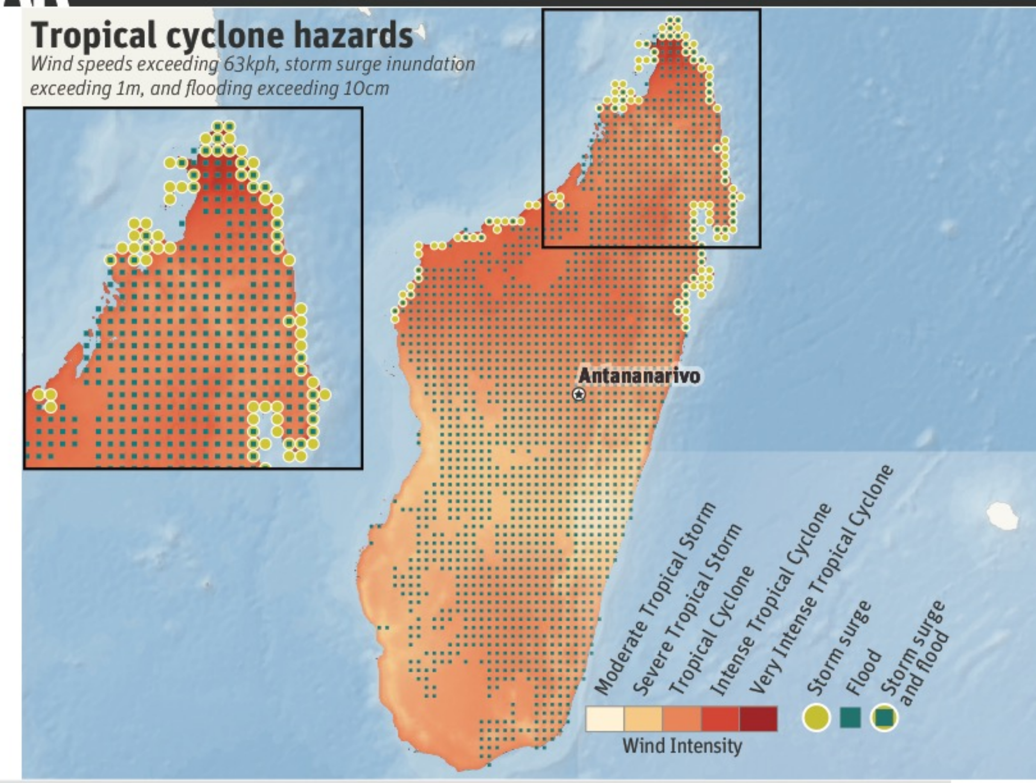
This analysis suggests that:

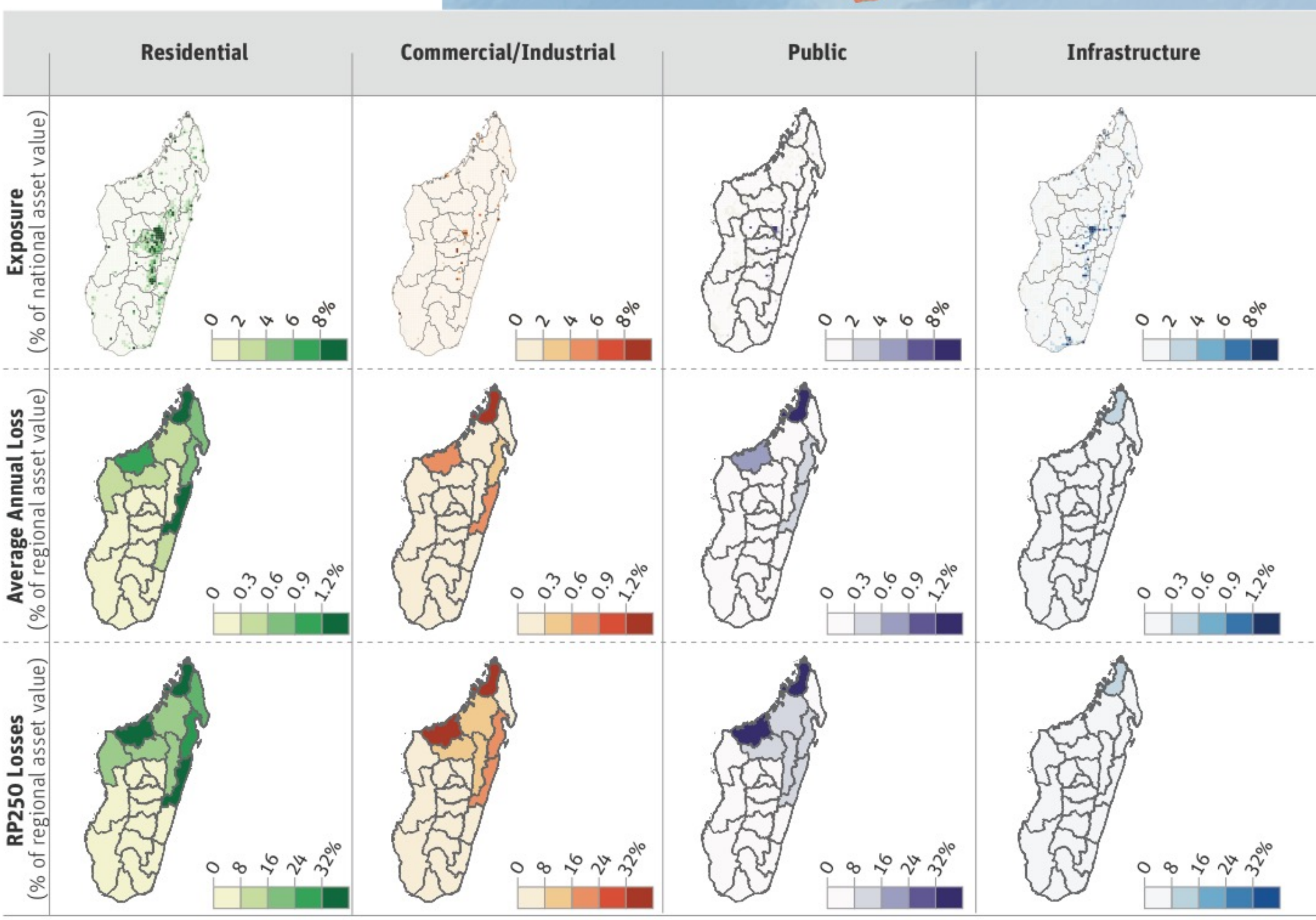
- The average annual direct loss from tropical cyclones is $87 million.
- Toamasina has the greatest risk of direct loss from tropical cyclones with an average annual loss of $20 million.
- The 100-year direct loss to Madagascar from tropical cyclones is $810 million.

TROPICAL CYCLONE
MADAGASCAR

Three hazards produced by tropical cyclones are: wind, storm surge, and flooding produced by excessive rainfall. For Madagascar, this analysis suggests that the **greatest wind hazard** occurs on the **northern half** of the country, particularly in coastal regions. Modeled winds associated with the 100-year tropical cyclone can exceed **200 kph**.

These results suggest that there is potential for **flooding** from tropical cyclone rainfall **over much of Madagascar**. Storm surge hazard is **greatest** along the **northern end** of Madagascar where storm surge can exceed **2m** in some locations.





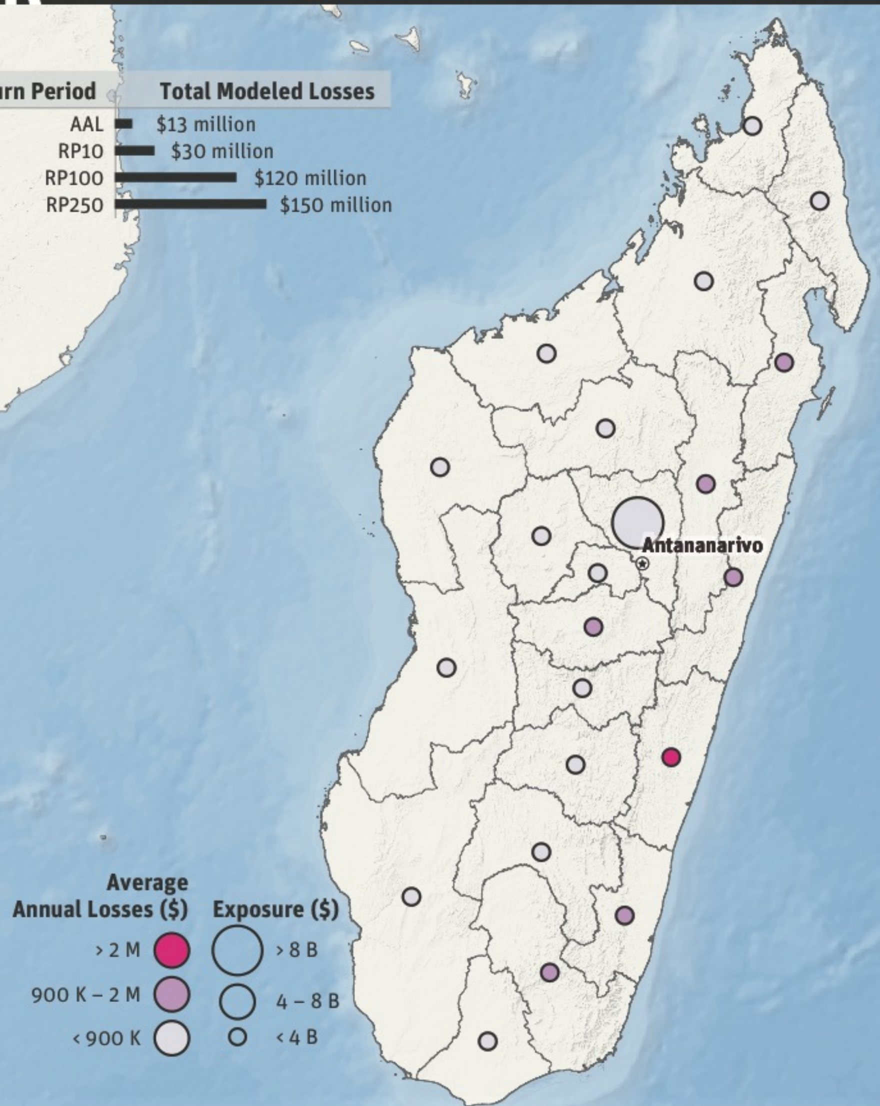
FLOOD
MADAGASCAR

This analysis suggests that, on average, Madagascar will experience around **$13 million** each year in **direct losses** from flooding, amounting to nearly 13 percent of the country's total annual direct losses from earthquakes, floods, and tropical cyclones. It is estimated that nearly **86 percent** of the direct losses from flooding are from the **residential sector. Emergency costs** for floods are estimated at over **$3.1 million** each year, on average.

The results suggest that **Fianarantsoa** is at **greatest risk** for flood loss, with an average loss per year of **$4.9 million** from flooding resulting from events other than tropical cyclones—nearly 36 percent of the total flood loss. Flood risk in Antananarivo is $1.6 million, one-third that of Fianarantsoa, despite assets in Antananarivo having more than three times the total replacement value of assets in Fianarantsoa ($16 billion vs. $5 billion).

Significant flood losses can **occur frequently.** For Madagascar as a whole, direct losses from a 10-year flood are estimated to be $31 million, and direct losses from the **100-year flood** event are estimated to be almost **$120 million**.

Return Period	Total Modeled Losses
AAL	$13 million
RP10	$30 million
RP100	$120 million
RP250	$150 million



Modeled Direct Losses

		Average Annual Loss
Residential	AAL	$10 million
	RP10	$25 million
	RP100	$95 million
	RP250	$100 million
Commercial/ Industrial	AAL	$500,000
	RP10	$1.5 million
	RP100	$5.5 million
	RP250	$7 million
Public	AAL	$600,000
	RP10	$1.5 million
	RP100	$6 million
	RP250	$7.5 million
Infrastructure	AAL	$350,000
	RP10	$850,000
	RP100	$5 million
	RP250	$6.5 million

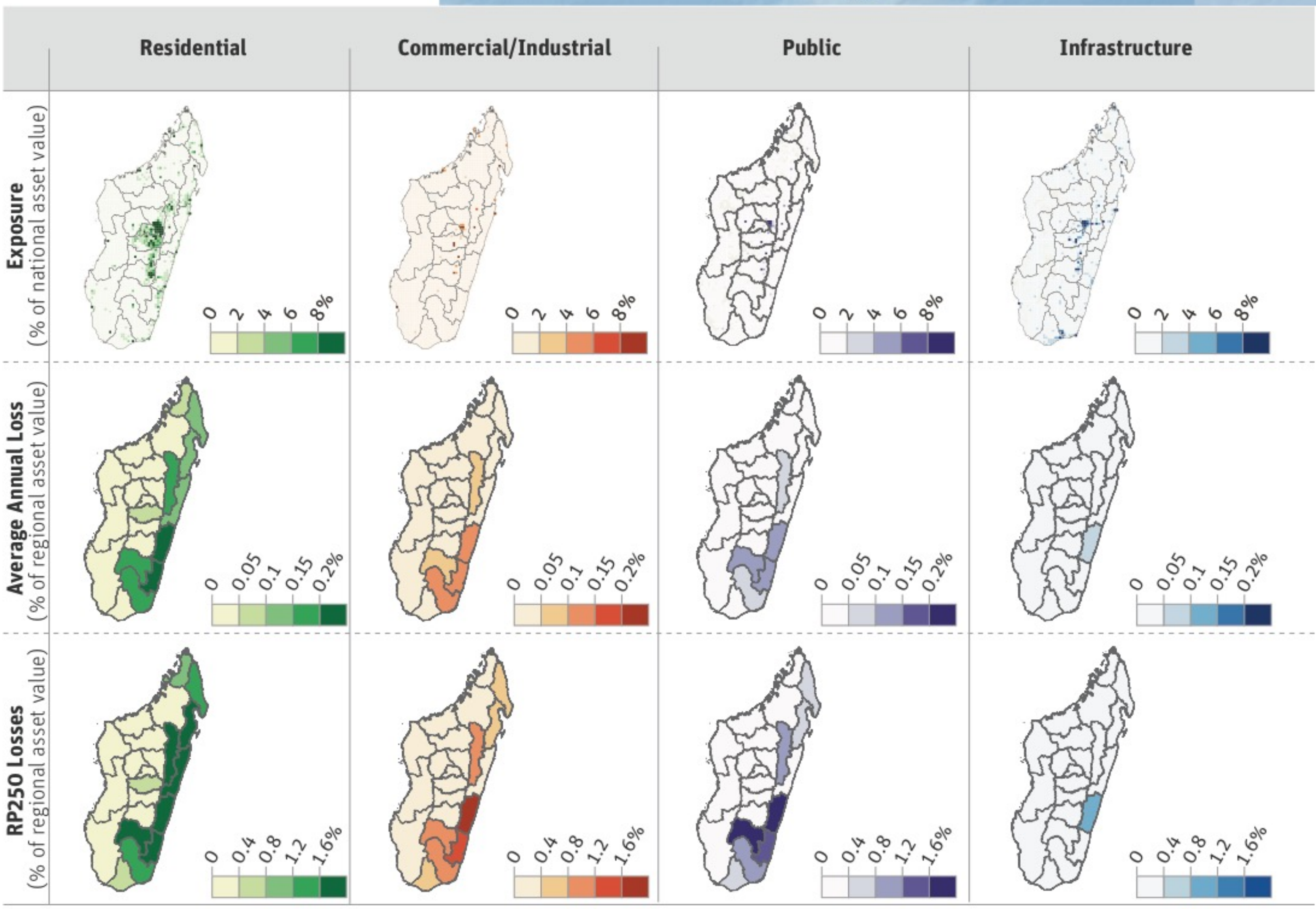
Key Facts

This analysis suggests that:

- The average annual direct loss from flooding is $13 million.
- Fianarantsoa has the greatest risk of direct loss from flooding with an average annual loss of $4.9 million.
- The 100-year direct loss to Madagascar from flooding could be nearly $120 million.

For this analysis, five hydro-climatological zones are used to represent the rainfall characteristics of Madagascar. The regions are roughly delineated by rapid changes in topography and include the extreme north of the country, another northern section, a southern zone, and then long eastern and western sections. The annual average rainfall from non-tropical cyclone events is 1,310 mm with a minimum of 849 mm and a maximum of 1,764 mm.

In this analysis, flood depths tend to be **highest** on the **eastern side** and **northern end** of Madagascar. Modeled flood depths can exceed 10 m.



MADAGASCAR

Earthquakes are common in the Southwest Indian Ocean region, but the **major seismic sources** in the region are **far from Madagascar.** The two major sources of seismic activity are the Mid-Indian Ridge in the Indian Ocean and the East-African Rift system. Earthquakes in these regions are **frequent** but usually of **low to moderate magnitude**.

In addition to these regional-scale sources of seismic activity, Madagascar experiences local seismic activity related to its **slow separation** from the **African continent** and, as a result, has **more local earthquakes**. For example, two magnitude 5.5 events occurred relatively recently, one on **October 4, 1985**, near Toamasina, approximately 100 kilometers northeast of Antananarivo, and the other on **April 21, 1995**, 150 kilometers northwest of Antananarivo. Neither produced significant losses.

This analysis suggests that earthquakes account for around **1 percent** of Madagascar's **total annual direct losses** from earthquakes, floods, and tropical cyclones, amounting to an estimated $1.3 million on average each year. The region with the **greatest absolute risk of loss** from earthquakes is **Antananarivo**, with an expected loss per year of $870,000. In Madagascar, the analysis suggests that over **65 percent** of the loss from earthquakes is from the **residential sector** and around 11 percent each from the commercial and public asset sectors. Losses to industrial assets contribute approximately 8 percent to the total of direct losses. Annual **emergency costs** for earthquakes are estimated at around **$200,000** on average.

Losses from earthquakes that are **greater than the annual average** are expected to occur **relatively frequently**. For example, direct losses for earthquakes with a 25-year return period are $3.5 million and with a **100-year** return period are **$15 million.**

Return Period	Total Modeled Losses
AAL	$1 million
RP10	$1 million
RP100	$15 million
RP250	$35 million

Modeled Direct Losses

		Average Annual Loss
Residential	AAL	$850,000
	RP10	$800,000
	RP100	$10 million
	RP250	$20 million
Commercial/ Industrial	AAL	$150,000
	RP10	$55,000
	RP100	$1.5 million
	RP250	$4 million
Public	AAL	$150,000
	RP10	$65,000
	RP100	$1.5 million
	RP250	$3.5 million
Infrastructure	AAL	$35,000
	RP10	$10,000
	RP100	$650,000
	RP250	$2 million

Key Facts

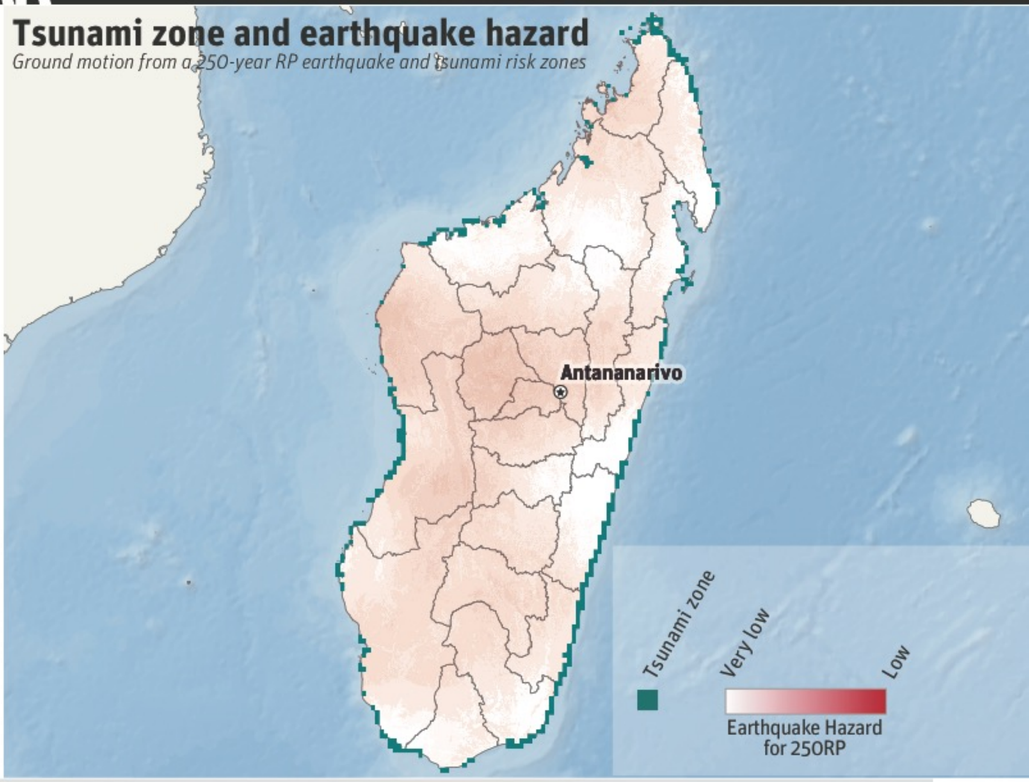
This analysis suggests that:

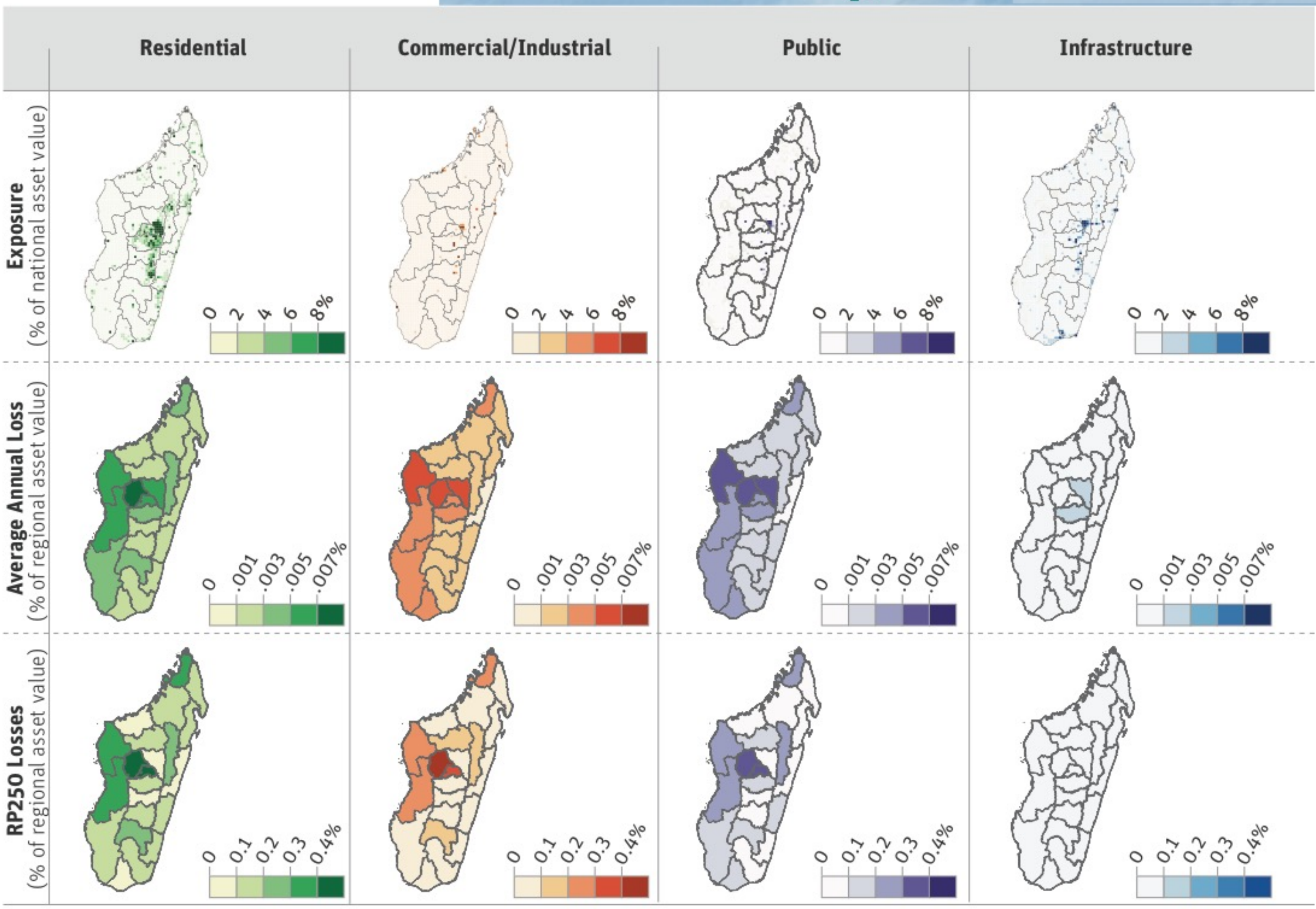
- The average annual direct loss from earthquakes is $1.3 million.
- Antananarivo has the greatest risk of direct loss from earthquake with an average annual loss of $570,000.
- The 100-year direct loss to Madagascar from earthquakes could be $15 million.

Earthquake hazard varies throughout Madagascar. This analysis suggests that the areas with the highest hazard are Antananarivo, Mahajanga, and Toliary, along with coastal areas in the northwest of Antsiranana.

Tsunamis usually result from high-magnitude, subduction-zone earthquakes. The Southwest Indian Ocean region does not experience many high-magnitude earthquakes, nor does it contain major subduction zones. The entire region is at risk, however, of tsunamis generated by subduction zones elsewhere in the Indian Ocean.

A recent tsunami event that affected the Southwest Indian Ocean region was the **2004 Indian Ocean tsunami**. Some locations along the eastern coast of Madagascar experienced inundation of over **5 meters** above sea level, while others were not affected.[1]





METHODOLOGY

Risk

These risk profiles have been developed from a multi-hazard risk assessment using a variety of exposure data and vulnerability functions. Modeled perils include earthquake, flood, and tropical cyclone. The results for individual and aggregated perils are available in several formats, including geospatial data and text files. The risk profile results are presented in terms of average loss per year and for selected return periods. For details on the development of the risk profiles, see the final report "Southwest Indian Ocean Risk Assessment Financing Initiative (SWIO RAFI): Component 4 – Risk Profiles". Brief explanations of the exposure and hazard data and the vulnerability functions are given below.

Hazard

This study encompasses three perils: earthquake, flood, and tropical cyclone. One or more hazards are associated with each peril. For example, the hazards associated with tropical cyclones include strong winds, storm surge, and flooding. A catalog representing 10,000 years of simulated events was constructed using empirical and theoretical principles and information derived from historical observations. A variety of statistical characteristics derived from the events in the catalogs are consistent with the historical record for each peril. The catalog (which is proprietary) includes information such as the intensity—for example, central pressure for a tropical cyclone and moment magnitude for an earthquake—and location of each peril event. This information is then coupled with peril-specific empirical and theoretical considerations to describe the spatial distribution of hazard intensity for each simulated peril event in the catalog, at a grid spacing of about one kilometer. The information is used to determine the hazard intensities expected at each return period.

EARTHQUAKE

This analysis suggests that there is a low likelihood of earthquakes in the SWIO region. The catalog of synthetic earthquake events is developed using characteristics based on the historical record of 1,228 earthquakes with moment magnitudes 5.0 or greater that occurred in the SWIO basin between 1901 and 2014 and the slip rates and geometries of known faults in the region. Ground motion prediction equations are used to determine the spatial distribution of ground motion (such as peak ground acceleration, or PGA) produced by each earthquake event.

FLOOD

The risk assessment indicates that floods from rainfall not associated with tropical cyclones are a significant hazard in the SWIO region, particularly for the areas closer to the equator. Flood hazard statistics in this analysis are ultimately based on satellite-derived rainfall estimates from the years 1998–2013. The satellite-derived data are used with a rainfall model to develop a catalog of daily rainfall produced by events other than tropical cyclones. A flood model then dynamically distributes the rainfall throughout the affected region and calculates flood depths.

TROPICAL CYCLONE

This analysis suggest that the most costly catastrophic hazard in the SWIO basin is tropical cyclone. The historical record of tropical cyclones in the region includes 847 events that took place between the 1950 and 2014. The event catalog is developed using characteristics of the historical catalog, such as annual tropical cyclone frequency, landfall frequency, seasonality, genesis location, forward speed, central pressure, and radius of maximum winds. Three tropical cyclone hazards are considered: wind, flooding from rainfall, and storm surge.

Tropical cyclone wind speeds are calculated using an equation that includes parameters such as the difference between the tropical cyclone's central pressure and the surrounding environment, a storm's forward motion and its asymmetry, and account for surface features such as land use.

Rainfall produced by modeled tropical cyclones is calibrated using satellite-derived rainfall estimates and used as a boundary condition to force a flood model that accounts for factors such as hourly rainfall, elevation, and soils.

Storm surge is derived from a variety of tropical cyclone characteristics that include central pressure, forward motion of the storm, maximum wind speed, and radius of maximum winds. For a tropical cyclone in the Southern Hemisphere, the highest storm surge generally occurs near the radius of maximum winds on the left side of the storm track.

Exposure

The methodology used to develop the exposure data is illustrated in figure A1. The exact process varies by country because of differences in available data. The exposure database for each island nation is constructed from various data sources, including government censuses, local agencies, satellite imagery, publicly available spatial statistics, and previous regional investigations. The end result is datasets that represent the built environment of each island nation and include nationally appropriate replacement values (that is, the estimated cost to rebuild a structure as new), construction characteristics, and occupancy classes.

The exposure data are divided into eighteen different occupancy classes spanning different types of residential, commercial, industrial, public facility, and infrastructure assets. The residential occupancy class includes single and multifamily residences. The commercial class includes general commercial buildings and accommodation. The exposure groups in the public occupancy class are health care services, religion, emergency services, primary educational, university educational, and general public facilities. The infrastructure occupancy classes are road/highway, bus/rail, airport, maritime port, electrical utility, and water utility. An "unknown" occupancy class is also assigned.

In addition to their categorization by occupancy class, the exposure data are categorized according to thirteen construction classes. Seven of these are specific to infrastructure occupancies and include structures such as roads, railroads, and bridges. Five represent common construction classes, such as single-story traditional bamboo and earthen buildings and single and multistory traditional wood, wood frame, masonry/concrete, and steel frame buildings. As with occupancy class, an "unknown" construction class is assigned.

The exposure data for residential, commercial, and general industrial assets are provided on a grid of 30 arc-seconds (approximately one kilometer). When high-resolution government and infrastructure data are available, these assets are captured at their individual exposure locations. When location-level information is not available, government and infrastructure assets are distributed to the one-kilometer grid.

Vulnerability

Vulnerability functions appropriate to the construction and occupancy classes most commonly found in the SWIO region are used to estimate loss from a hazard. The functions calculate the average level of damage to the structures using the hazard intensity and information on their occupancy and construction. The damage level represents the fraction of the total building replacement value that has been damaged. Vulnerability functions used in this study have been developed specifically for the SWIO region based on research on local building practices, applicable building codes, engineering analysis, historical damage reports, and expert judgment.

Vulnerability functions for earthquake ground shaking, non-tropical cyclone flooding, tropical cyclone flooding, and tropical cyclone storm surge are assumed to be uniform throughout the SWIO region for all occupancies other than infrastructure. Except for infrastructure, the tropical cyclone wind damage functions for Mauritius and Seychelles are modified to be less vulnerable than the SWIO base functions used for the other island nations because of their history of more stringent construction practices relative to the other three nations. All damage functions for infrastructure occupancy classes are assumed to be uniform for all perils throughout the SWIO region.

** All dollar amounts are U.S. dollars unless otherwise indicated.*

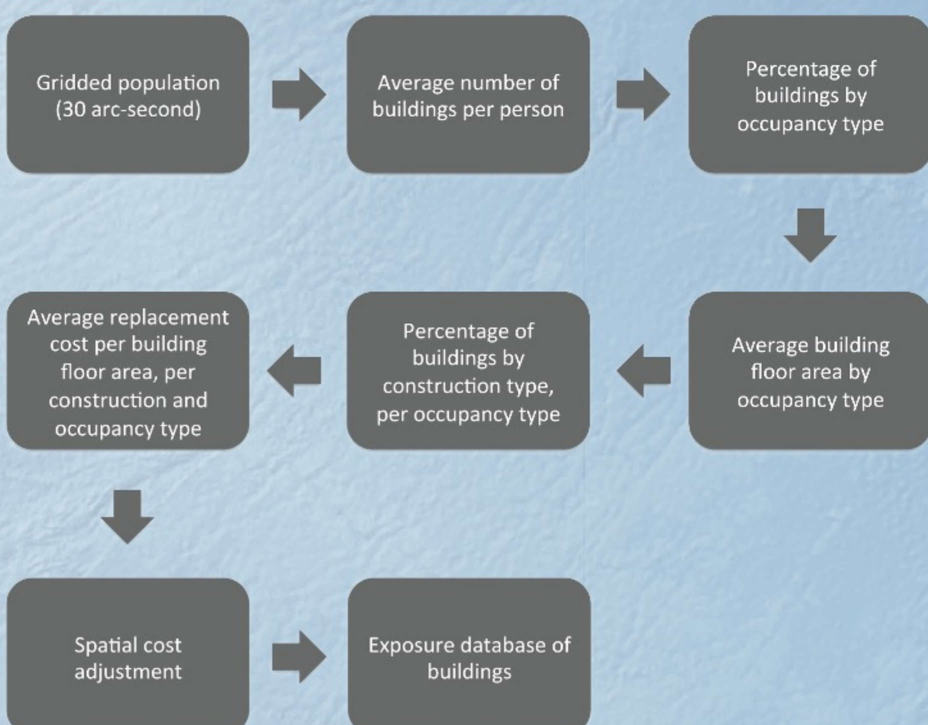


Figure A1. Schematic diagram illustrating the methodology used to develop the SWIO-RAFI exposure data

GLOSSARY

Average Annual Loss

The modeled average annual loss (AAL) is equal to the total of all impacts produced by a hazard (e.g. earthquake) in a specified time period (e.g. 10,000 years) divided by the number of years in that specified time period (e.g. 10,000 years).

Building Construction Class

Building Construction Class is used to classify an asset's construction, which determines an asset's vulnerability to a certain hazard, contributing to a risk estimate. For example, a traditional wood building is more vulnerable (i.e. likely to be damaged or destroyed) by a tropical cyclone than a building made of steel-reinforced concrete. Thus an area with traditional wood buildings is likely to experience more damage and larger losses from a tropical cyclone than an area with steel-reinforced concrete buildings. Building Construction Class is one of the factors used to determine vulnerability (see below).

Building Type

Building Type, or Occupancy Class, specifies the usage of a given building, which contributes to a building's vulnerability. The building types used in these profiles are: residential, commercial, industrial, infrastructure, and public.

Each building type has subtypes:

- Residential: single, multi-family (e.g. apartment)
- Commercial: accommodation (e.g. hotel), commercial (e.g. shop)
- Industrial: general industrial (e.g. factory)
- Infrastructure: bus terminals, rail terminals, airports, maritime ports, utilities, roads, highways
- Public: healthcare, education, religious, emergency services, general public facilities

Building Type is one of the factors used to determine vulnerability (see below).

Exposure / Exposed Assets

Exposure refers to assets such as buildings, critical facilities and transportation networks, which could be damaged by a hazard. A variety of attributes associated with the exposure, such as location and occupancy and structural characteristics, help determine the vulnerability of the exposure to a hazard.

Hazard

Hazard refers to the damaging forces produced by a peril, such as inundation associated with flooding, or winds produced by a tropical cyclone. A single peril can have multiple hazards associated with it. Those associated with a tropical cyclone, for example, include strong winds, storm surge and flooding.

Impact

Impact refers to the consequences of a hazard affecting the exposure, given the exposure's vulnerability. The impact on structures is usually quantified in terms of direct monetary loss.

Replacement Value

Replacement value refers to the estimated amount it would cost to replace physical assets.

Return Period (RP)

Throughout this profile 10-year (RP10), 100-year (RP100), and 250-year (RP250) events are referenced. These events have intensities that (on average) are expected to occur once during a "return period". A return period is based on the probability that an event could happen in a given year. The larger the return period for an event, the less likely its occurrence, and the greater its intensity. The probability of an event occurring in any given year equals 1 divided by the number of years named in the "X-year event", e.g. for a 10-year event (an event with a 10-year return period), the probability is 1/10 or 10%; for a 100-year event, the probability is 1/100 or 1%.

Risk

Risk is a combination of hazard, exposure, and vulnerability. It is quantified in probabilistic terms (for example, average annual loss) using the impacts of all events produced by models.

Vulnerability

Vulnerability accounts for the susceptibility of the exposure to the forces associated with a hazard. Vulnerability accounts for factors such as the materials used to build the asset (as specified by the Building Construction Class) and the asset's use (as specified by the Building Type).

NOTES

[1] Emile A. Okal, Hermann M. Fritz, Ranto Raveloson, Garo Joelson, Petra Pančošková, and Gérard Rambolamanana, "Madagascar Field Survey after the December 2004 Indian Ocean Tsunami," *Earthquake Spectra* 22, no. S3 (2006): 263–83.

[2] ReliefWeb, "Madagascar: Cyclone Chedza Emergency Plan of Action (EPoA) Operation No. MDRMG011," http://reliefweb.int/report/madagascar/madagascar-cyclone-chedza-emergency-plan-action-epoa-operation-n-mdrmg011.

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