Antananarivo: assessment and pre-feasibility study of green infrastructure solutions and disaster evacuation planning and design to mitigate flood risk and strengthen resilience between Nature-based Solutions and Disaster Evacuation Planning

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PROJECTS DEVELOPMENT

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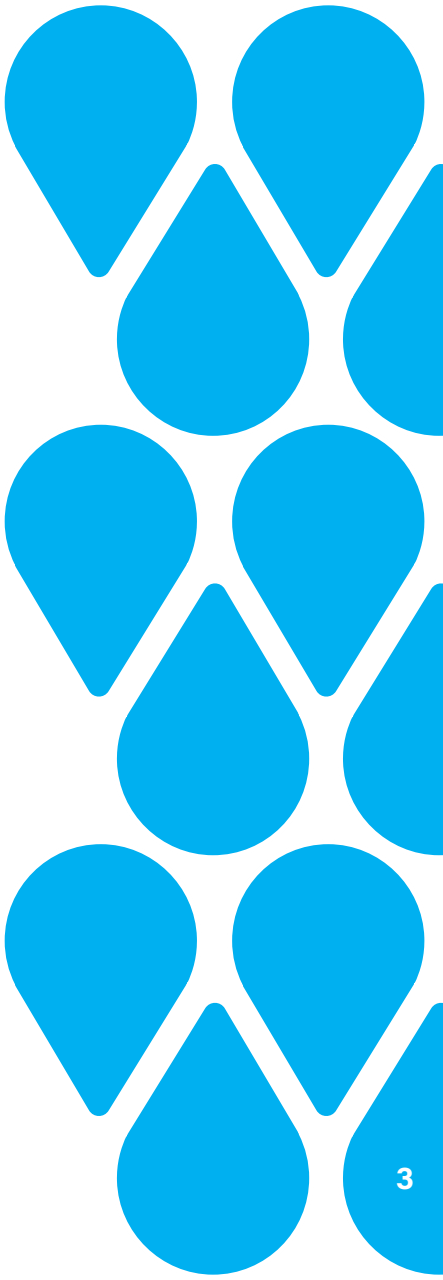
1. Introduction

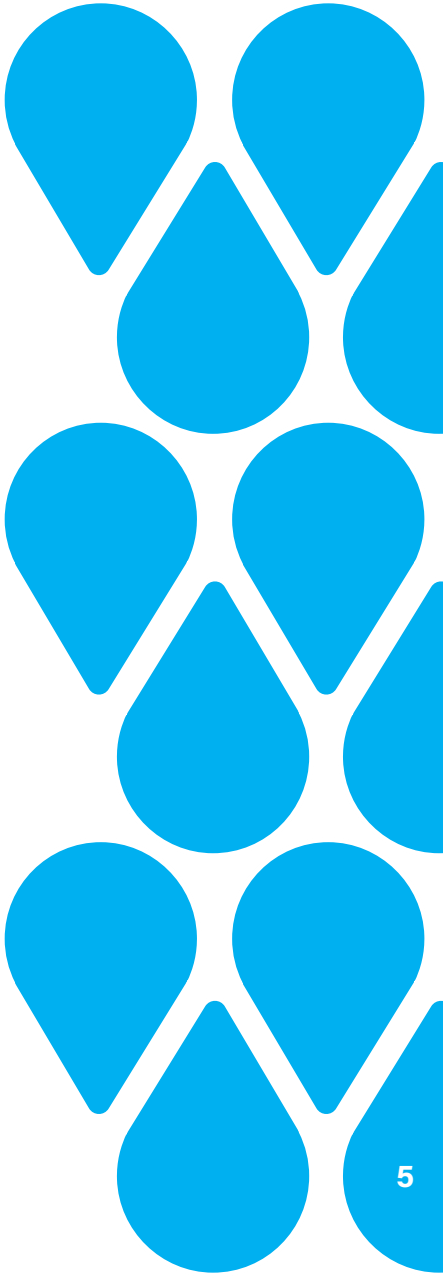


Introduction

- Antananarivo faces several **water-related urban challenges**, such as urban floods and water pollution, with high social, economic and ecological impact.
- They commonly affect some of the **most vulnerable communities** in the city
- Nature-based Solution (NbS) present an opportunity to address these challenges in a **resilient and inclusive way**.
- During a disaster, **NbS can potentially contribute to an efficient and safe evacuation** and refuge for affected communities.
- The Integrated Urban Development and Resilience Project (PRODUIR) is being implemented between 2018 and 2023 to **enhance urban living conditions and flood resilience** in selected low-income neighborhoods of the Greater Antananarivo.
- Our project contributes to this objective by focusing on the **design and assessment of NbS for disaster evacuation and flood risk reduction**.

2. The setting

- Landscape analysis
- Overview of existing challenges



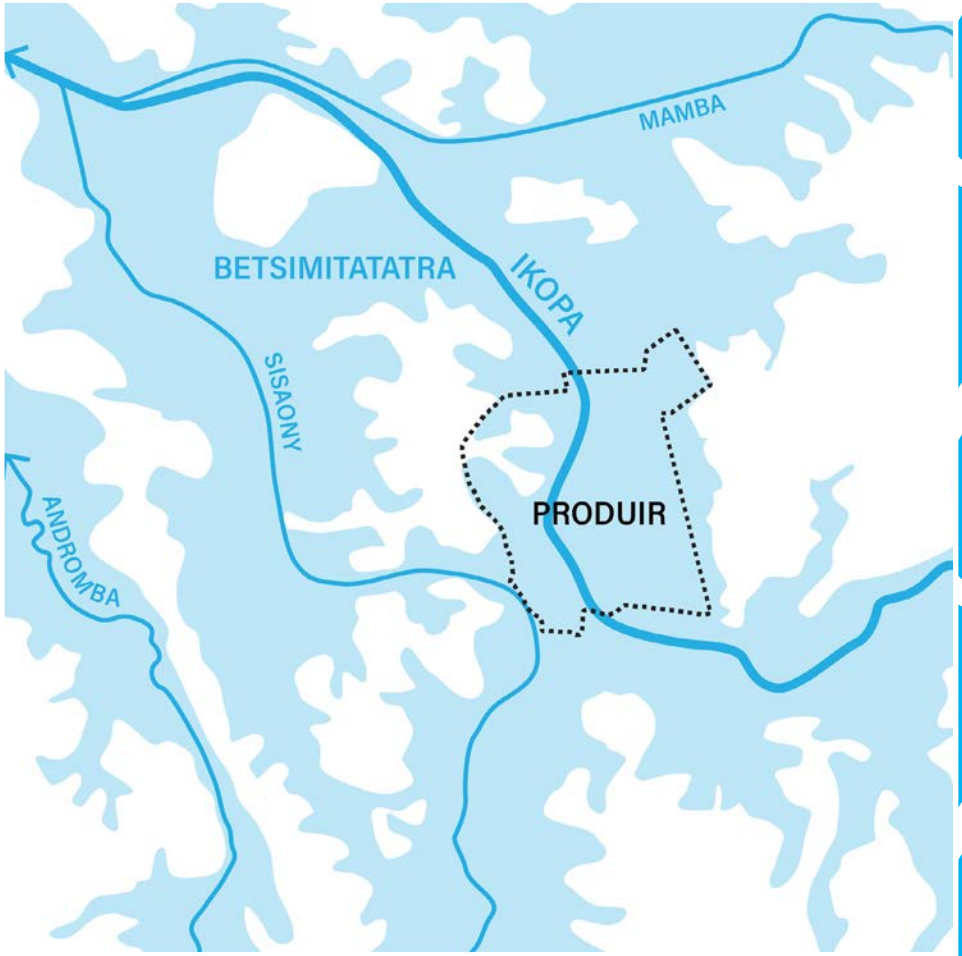
“See how a wonderful landscape has become
This huge rice field
This plain located west of Antananarivo
Neither low nor high, but only one level
The Ikopa is there for its fertility
For easy transport of rice
What will become of us if the field does not produce,
If there is no Betsimitatatra?”

“Voyez comme est devenue un merveilleux paysage
Cette immense rizière
Cette plaine située à l’Ouest de T ananarive
Ni basse , ni haute , mais d’un seul niveau
Vlkopa est là pour sa fertilité
Pour le transport facile de son riz
Que deviendrons-nous si le champ ne produit pas ,
S’il n’y a pas de Betsimitatatra”

Hildebert, 1955

Landscape analysis

The Ikopa River, that crosses Antananarivo from south east to north west, and its tributaries – the Mamba, the Sisaony and the Andromba – are embraced by the **Betsimitatatra, the swampy large plain of Antananarivo.**



Legend

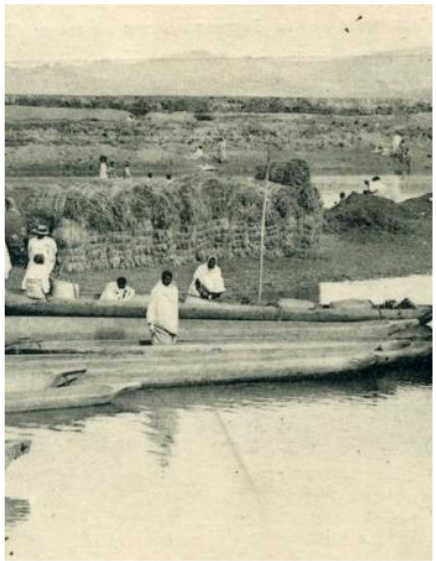
- Floodplains
- PRODUIR area
- Main rivers

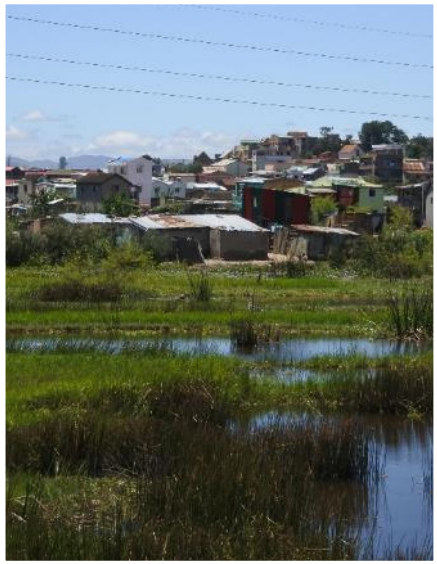
The plain of Antananarivo - Betsimitatatra - and the main rivers that cross the city. The PRODUIR area is located within the Betsimitatatra. Adapted from The plains of Antananarivo and their mountainous surroundings (Hildebert, 1955)

Landscape analysis

Historical background

- During the XVII century, the first **dike along the Ikopa river** was built (Ankadimbahoaka) to protect the lower land between the river and the hills.
- The system was later improved with the construction of four **additional dikes**, which ensured the protection of both the north and the south of the city.
- The **reservoirs** of Anketsa and Manampisoa were created to use the water for the irrigation of the rice fields during the dry season
- A series of **canals** ensured the supply and irrigation of water to the rice fields. and the transport of the harvest.





(left) Port of pirogues in Antananarivo, at the beginning of the XX century. Cartepostale, Geneanet; (right) Rice field on the east of the Ikopa River

Landscape analysis

Historical background

- There was an **organization responsible for the maintenance and operation** of the canals, dikes and other hydraulic infrastructure.
- In the event of the dike rupture, the men in this organization could **quickly respond to minimize the damages** of the flood (communicating the danger to the population, closing waterways, etc.)
- **Understanding of the landscape and the involvement of the community** played an important role in the efficient and effective functioning of this system.
- Local laws stated that **water was a common good**, that should circulate freely and not be diverted from its natural course.

Landscape analysis

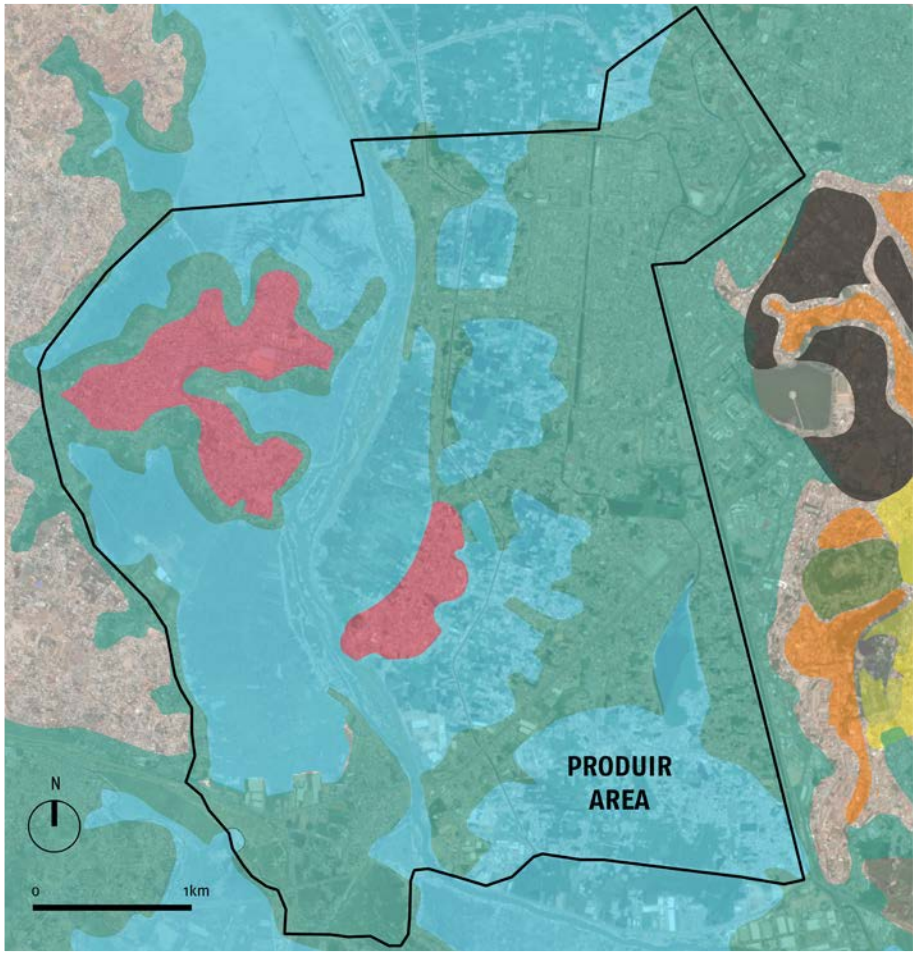
Historical background

- Rural-urban migration has led to urban growth and the **urbanization of the floodplains** of the Ikopa with informal settlements.
- Encroachment has causeed stress in this area and accelerated the changes that have been taking place (e.g. pollution)

Informal settlements in antananarivo

Landscape analysis

From landscape types to urban typologies: the Green Plan (Plan Vert) classified the landscape of Antananarivo according to different landscape types, with their own abiotic, biotic and anthropogenic characteristics.



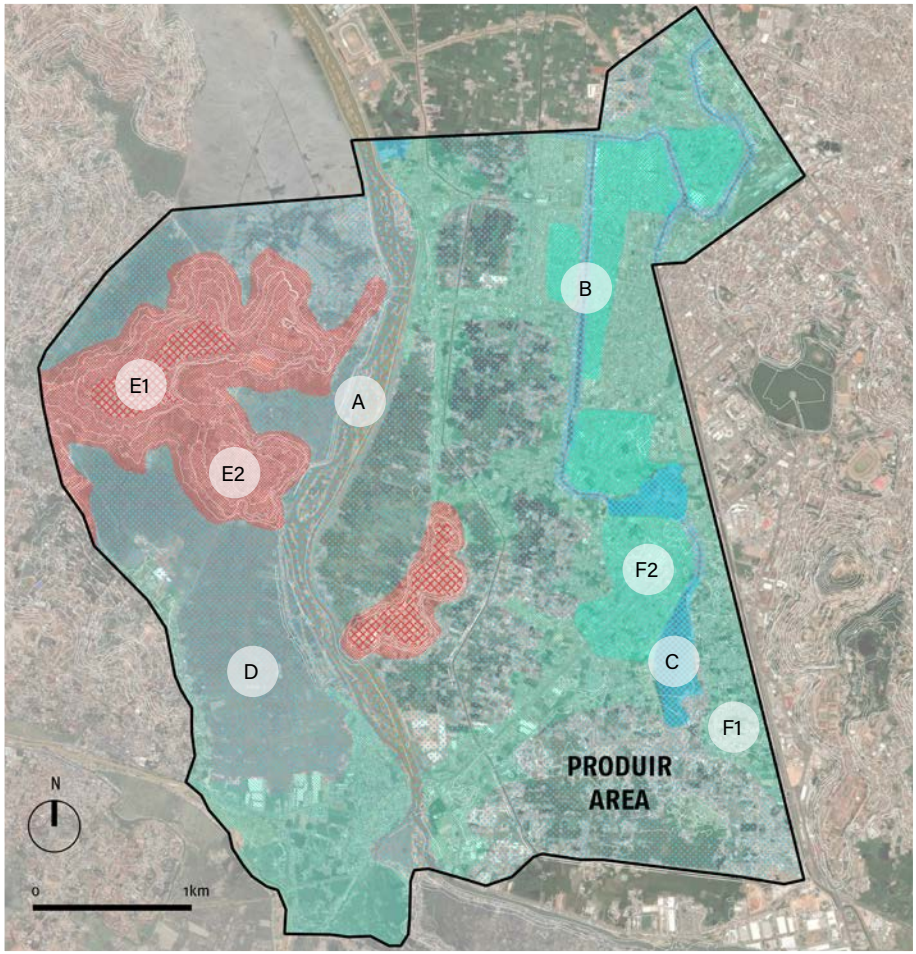
Legend
Landscape types

- The island city
- Informal city
- The plain and the river
- Colonial city
- The urbanized hills
- The valleys
- The urbanized valleys
- The forest hills

Landscape types, adapted from Plan Vert (2007). The landscape types from the communes at the East of the Ikopa were extrapolated from the original classification.

Landscape analysis

Based on the different landscape types, in the PRODUIR area we identified **8 urban typologies**: (A) The river and embankments, (B) The canals, (C) The water basins, (D) The rice fields, (E1) The island cities (first occupation), (E2) The island cities (latest occupation), (F1) Informal city less densely built, (F2) Informal city densely built.



Legend

Urban typologies

- A - The river & embankments
- B - The canals
- C - The water basins
- D - The rice fields
- E1 - The island cities (1st occupation)
- E2 - The island cities (latest occupation)
- F1 - Informal city less densely built
- F2 - Informal city densely built

Landscape analysis

A - The river and embankments

- **Biotics**. Within the riverbed weeds and small shrubs can be found. The dike embankment is covered by grass.
- **Infrastructure network**. East of the Ikopa river, the National Route 4 is situated on the dike. The river space is hardly used as a transport route
- **Occupation pattern**. There are some buildings inside the riverbed or on the embankment, which are under great risk of floods.

(upper) Satellite image of the Ikopa River. Retrieved from Google Earth; (lower)Views of the Ikopa River

Landscape analysis

B - The canals

- **Biotics**. There are trees and natural embankment along some part of the C3 canal, which provide shade and enrich the urban quality.
- **Infrastructure network**. Along the canals there are either unpaved pedestrian paths or roads for vehicles. The canals are not used for transport.
- **Occupation pattern**. Basic constructions along canals, which are not protected from floods.

(upper image) Satellite image of the canal. Retrieved from Google Earth; (lower) Views of the settlements along the canal.

Landscape analysis

C - The water basins

- **Biotics**. Water hyacinth which makes the basin look like a green field. Along the water basins a few lost trees can be found.
- **Infrastructure network**. Basins are used as transportation routes, and have small unpaved roads on the side that both pedestrians and cars use.
- **Occupation pattern**. Informal settlements and small street shops are situated along the basins.

(upper image) Satellite image of a retention basin next to the C3 canal, retrieved from Google Earth; (lower) View of the Anosibe basin.

Landscape analysis

D - The rice fields

- **Biotics**. Agricultural use. Small dikes are used as footpaths, separation between different lots and to keep water in.
- **Infrastructure network**. Dikes used as pedestrian routes. More important routes are elevated by tires and plastic. There are no roads for vehicles.
- **Occupation pattern**. Low occupation density, with few farmhouses in the rice fields.

(upper image) Satellite image of rice fields, retrieved from Google Earth; (lower) View of the rice fields in the south of the city.

Landscape analysis

E1 - The island cities (first occupation)

- **Biotic.** Trees and greenery in private gardens, some open spaces between building blocks (mostly privately owned)
- **Infrastructure network**. Paved main roads, and mostly unpaved smaller roads.
- **Occupation pattern**. Upper houses made of brick are often detached surrounded by some open space, lower houses.

Satellite image of settlements in Bemasoandro, retrieved from Google Earth

Landscape analysis

E2 - The island cities (latest occupation)

- **Biotics**. Scarce open green areas, mostly only trees in private gardens. Elevation differences in the landscape
- **Infrastructure network**. Few paved roads, smaller unpaved roads and pedestrian paths between houses where open sewage runs towards the main roads.
- **Occupation pattern.** High occupancy, with informal settlements between brick houses on the border of higher and low-lying areas.

Satellite image of settlements in Anosimasina, retrieved from Google Earth

Landscape analysis

F1 - Informal city less densely built

- **Biotics**. Limited amount of green areas, except for rice fields and trees on private gardens. Open spaces exist but are underused.
- **Infrastructure network**. Wide vehicular network, pedestrian network of small alleys between houses where open sewage runs towards the main roads.
- **Occupation pattern**. Mainly informal settlements and precarious constructions under risk of floods.

Satellite image of settlements in Andavamamba Anjezika II, retrieved from Google Earth

Landscape analysis

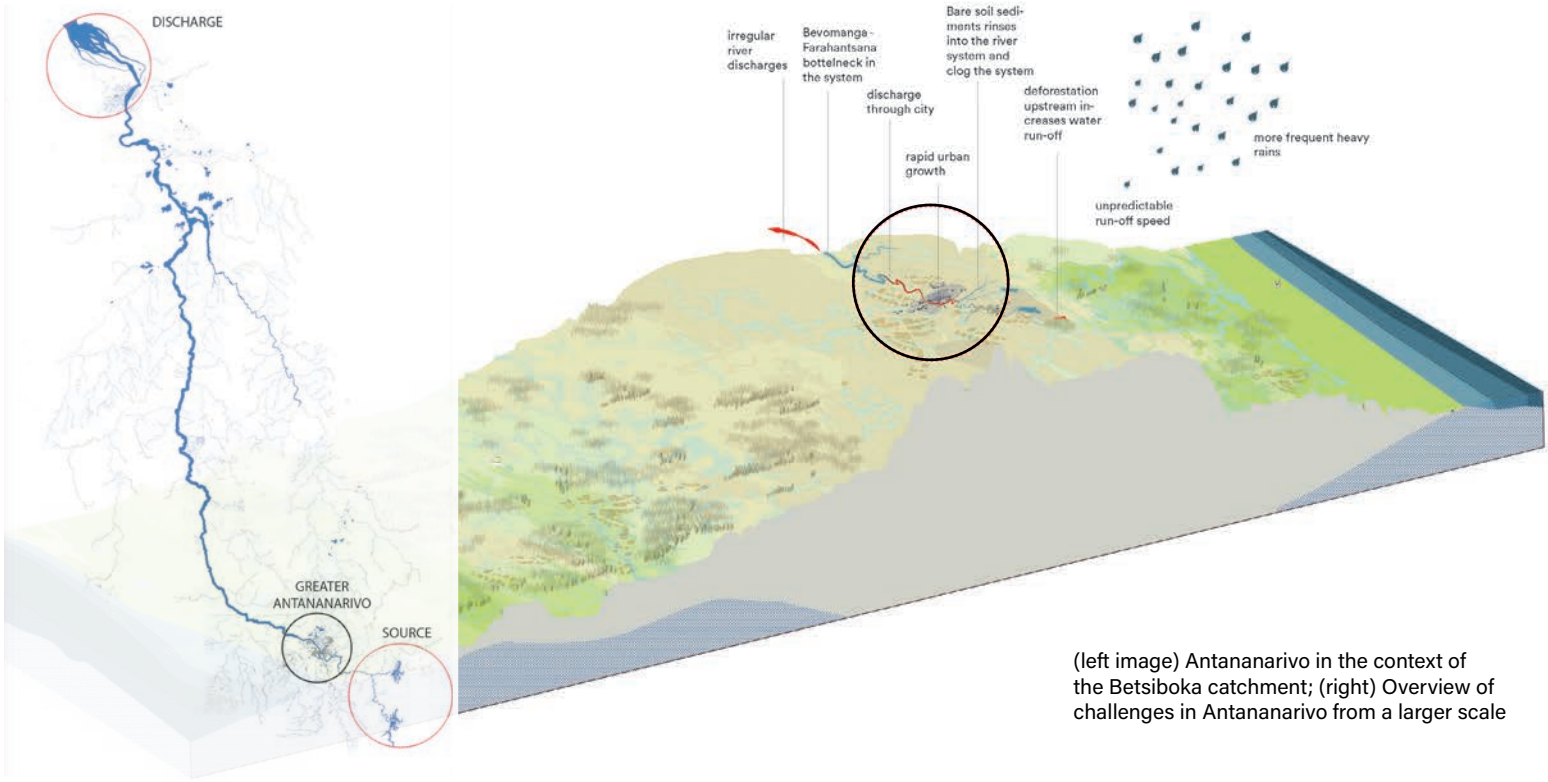
F2 - Informal city densely built

- **Biotics**. There are hardly any green areas in this landscape entity.
- **Infrastructure networ**k. Main vehicylar route is paved, while secondary roads are mostly unpaved and used by all transport forms. Pedestrian network of small alleys between houses where open sewage runs towards the main roads.
- **Occupation pattern**. High occupation density with mostly informal settlements.

Satellite image of an area along the National Route 1, retrieved from Google Earth

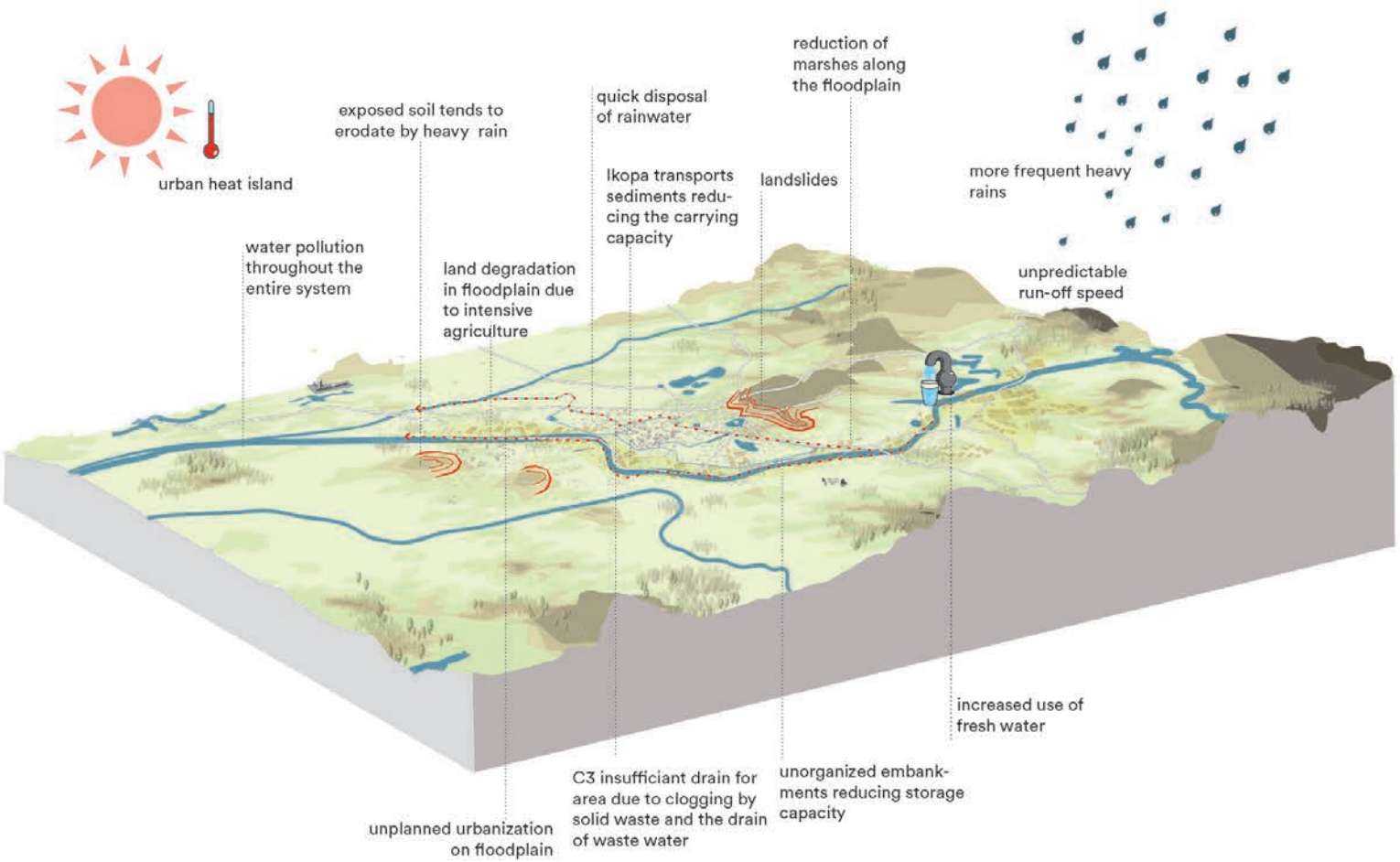
Overview of existing challenges

Antananarivo faces several challenges that, if not addressed, will continue hindering the development of this culture and nature-rich city. This project focuses predominantly on **urban floods**, where city-scale and smaller-scale interventions can have a great impact by **managing storm water locally**.



(left image) Antananarivo in the context of the Betsiboka catchment; (right) Overview of challenges in Antananarivo from a larger scale

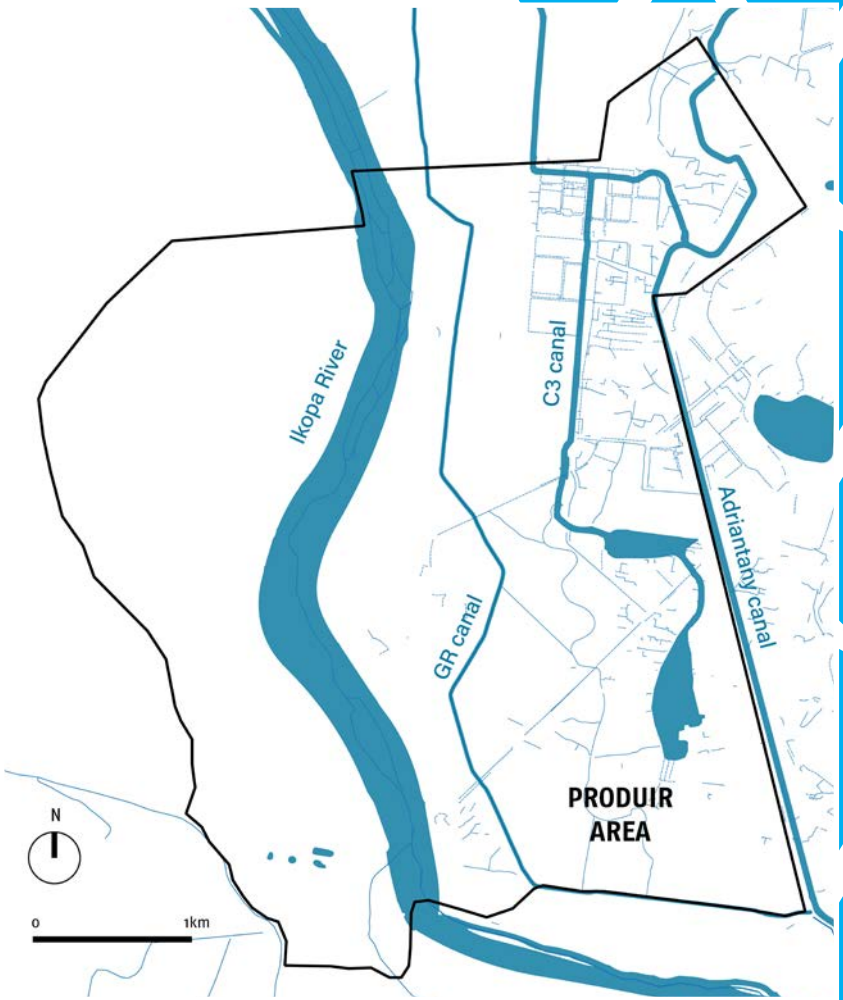
Overview of existing challenges



Overview of challenges in Antananarivo on a city scale.

Floods

- Antananarivo has a water infrastructure system based on three main canals: Andriantany, C3 and GR canals, plus a series of smaller channels, ditches and underground stormwater drainage pipes.
- The system is designed to **quickly drain the excess of water from the city into the Ikopa river** downstream.

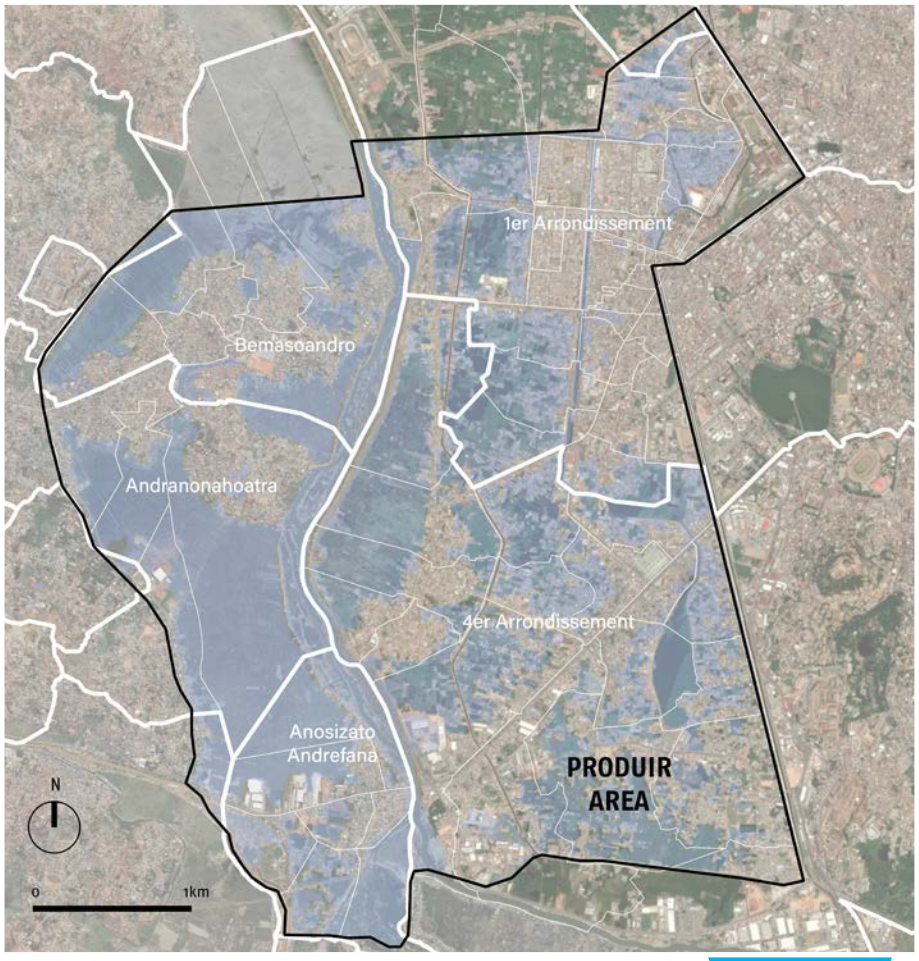


Legend
- River
- Canals
- Channels
- Underground pipes

Main elements of the urban water drainage infrastructure in Antananarivo

Floods

- However, the **existing infrastructure is not enough to prevent floods**
- There is a **lack of drainage capacity** due to the under-performance of the drainage network caused by lack of maintenance and solid waste
- Lack of space for the water due to the **urbanization of the floodplains**



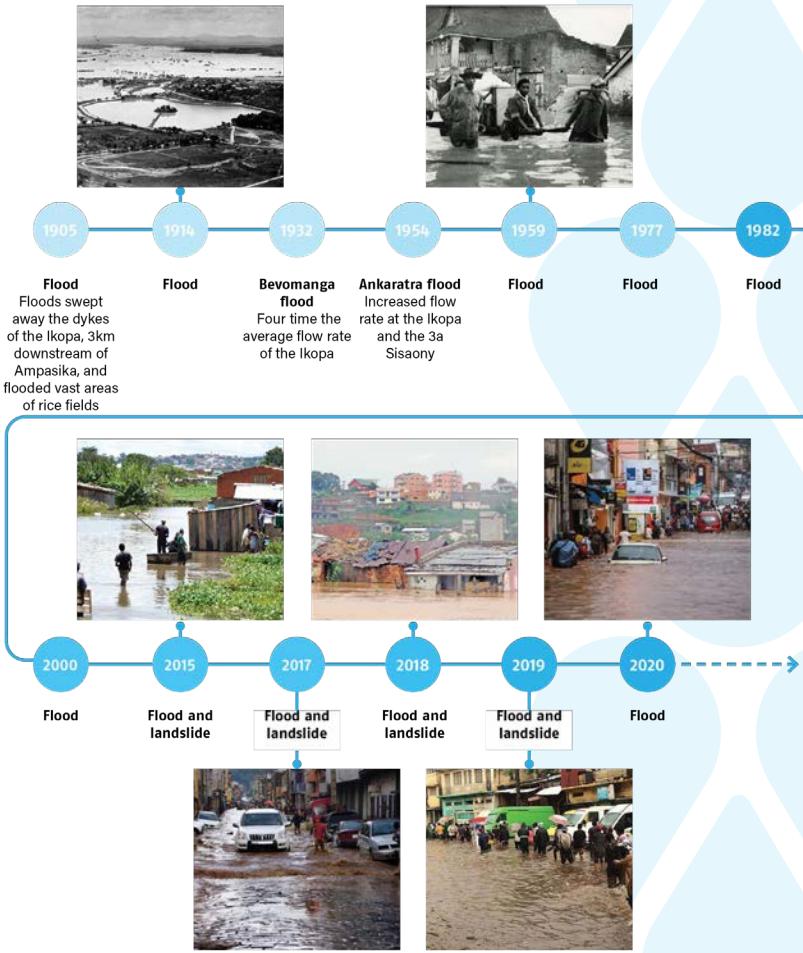
Legend

Flood extension (PRODUIR)

Fokontany

Floods

Antananarivo has been facing floods for some time, but the increased urbanization and densification of the city have stressed this situation even further.



Overview of floods in the last 100 years

Other related challenges

- Landslides
- Water pollution
- Unplanned urbanization
- Informal economy
- Heat stress

Landslide on the east of the city. Credits BNGRC

Solid waste in canals and basins

Informal settlements

Lack of green areas

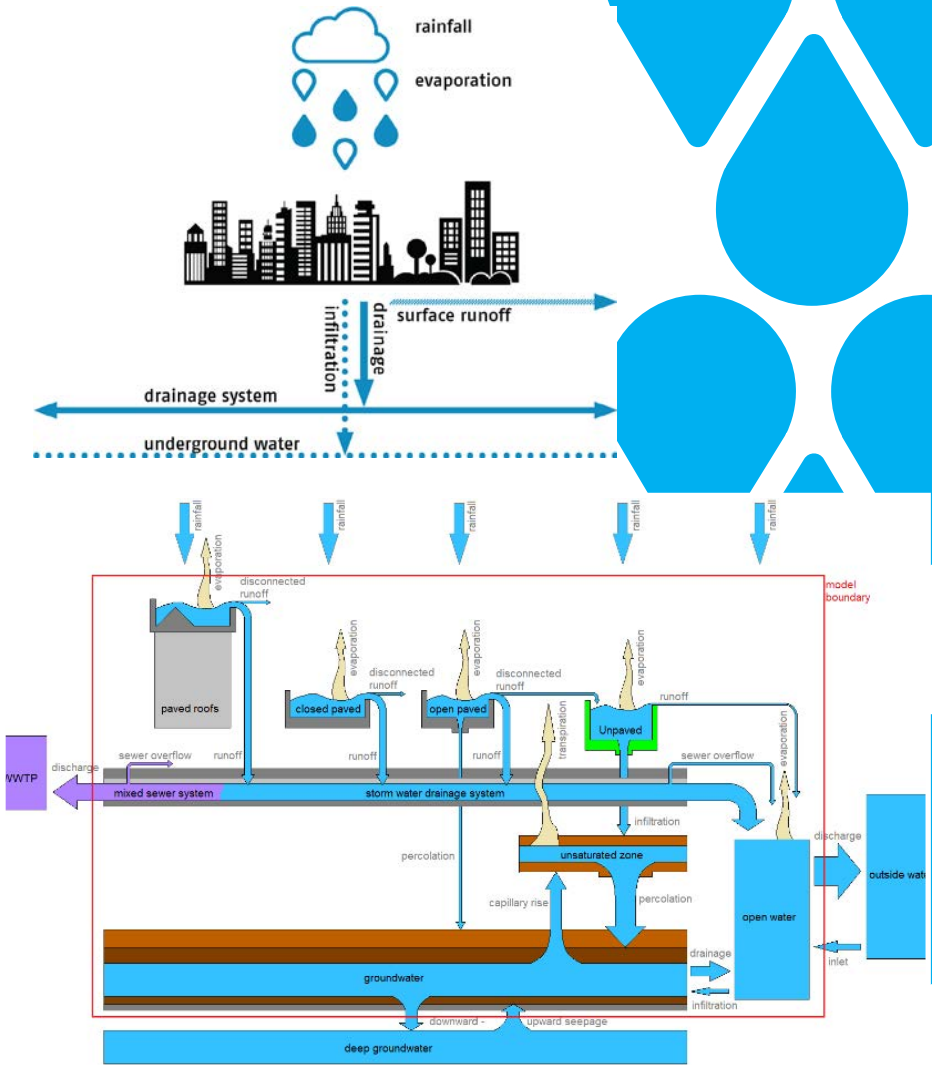
Informal wood selling

3. Analysis of the problems & possible solutions

- Flood risk
- Evacuation planning
- Nature-based Solutions (NbS)

Flood risk

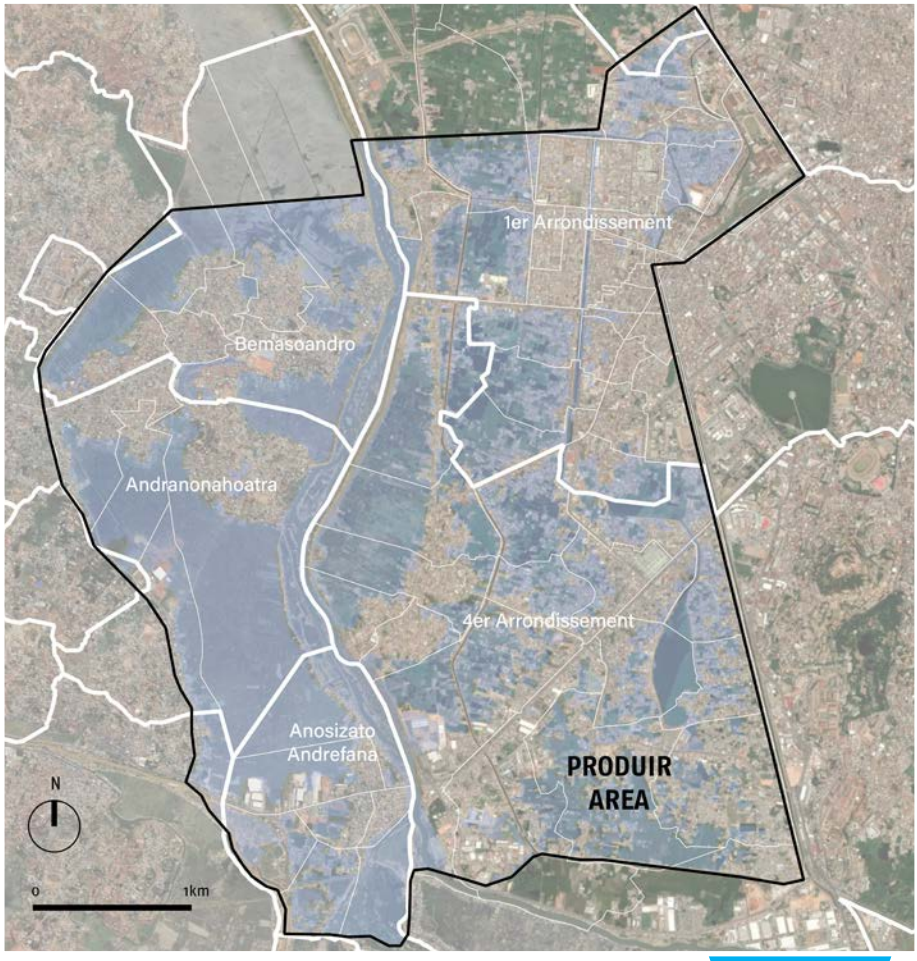
- Urban pluvial floods are one of the most pressing water-related challenges, since the occur often.
- **Pluvial flood hazards** could be prevented by managing the rainfall locally
- We quantified the pluvial flood hazard by focusing on **water storage capacity**, using the urban water balance model (UWM)
- Depending on the type of surface, water storage capacity will be different



UWM conceptual model indicating all the reservoirs and fluxes between them

Flood risk

- Most of the PRODUIR area covers the floodplains of the Ikopa river
- The floodplains have the lowest elevation (around 1250m), and are very exposed to floods, both fluvial and pluvial
- Settlements located in the floodplains are at high risk, since they are exposed to the hazard and the population is mostly vulnerable



Legend

Flood extension (PRODUIR)

Fokontany

Evacuation planning

We analyzed both on-site and off-site evacuation opportunities in the PRODUIR area, to preselect a series of 10 locations.

Methodology

- **Assessment of the capacity** of local authorities and communities **to evacuate** persons living in this disaster-prone area.
- **Assessment of the effectiveness** of response to floods and the related displacement of vulnerable communities including access to safe shelter, essential food, basic services and other relief measure's appropriate to local needs.
- **Identification and assessment of evacuation sites** (on-site and off-site) evaluated for suitability against basic criteria

Evacuation planning

Evaluation criteria for site suitability for evacuation & refuge

- Proximity to roads/tracks
- Elevation
- Proximity to water/sanitation
- Proximity to clinics
- Ease of access for provision of relief
- Areas of facility
- Suitable for longer term occupancy
- Safe (not crime hotspot)
- Suitability for vulnerable persons
- Pre-existing infrastructure (e.g. community facilities)
- Ready for occupancy in short/medium term
- Potential for air evacuation

Evaluation criteria for site suitability for NbS

- Land use
- Slope angle
- Soil type
- Space in subsurface
- Groundwater depth

- Elevation and accessibility are relevant but were included as part of the on on-site and off-site evacuation opportunities.
- Urban typologies were considered when making the final selection, so they were representative of the main urban typologies in the study area.

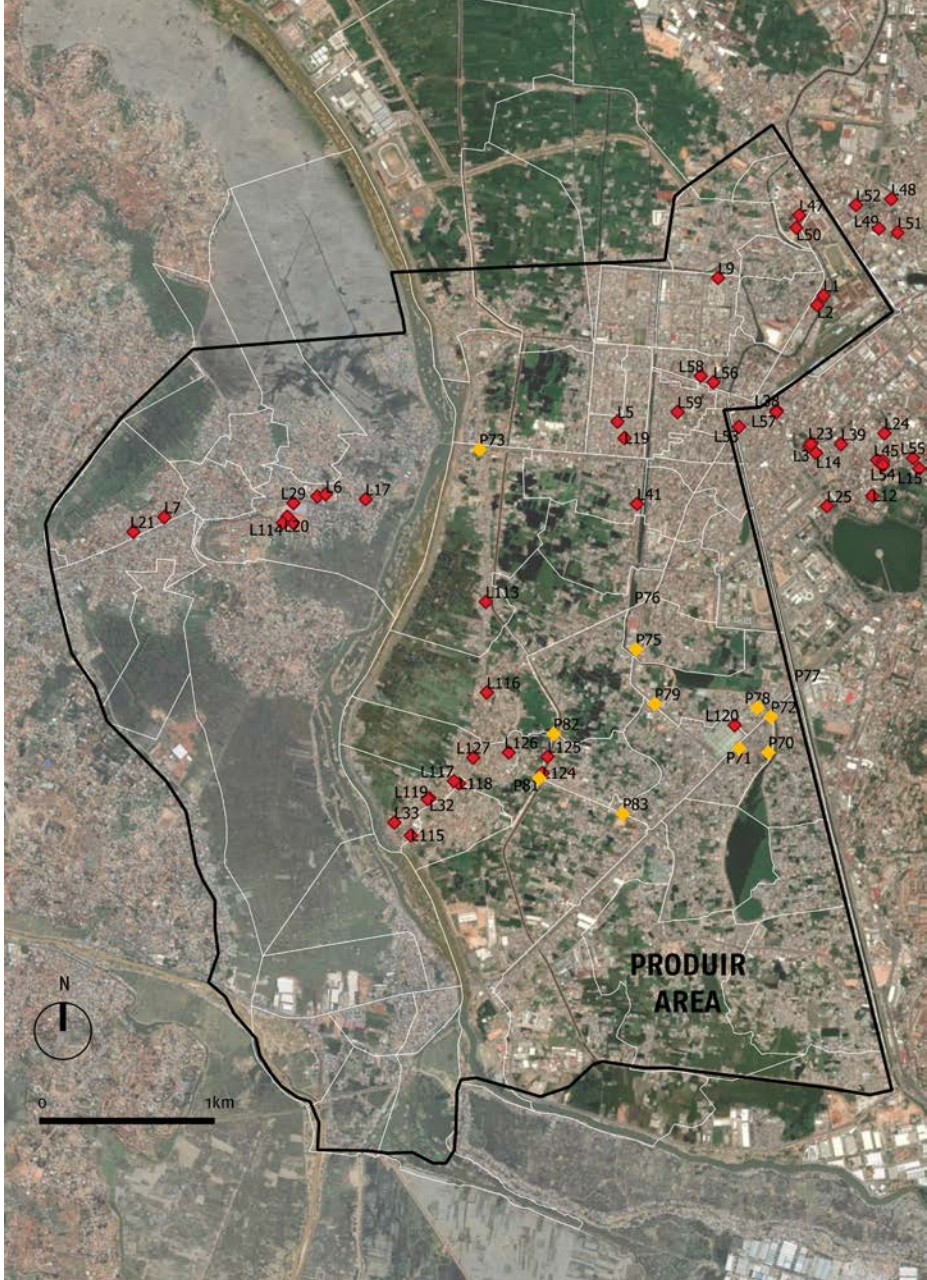
Evacuation planning

Starting point

Existing disaster evacuation plan for the urban area of Antananarivo, from UNOCHA and BNGRC (2015)

2 types of sites identified:

- Refuge sites (L)
- Assembly points (P)



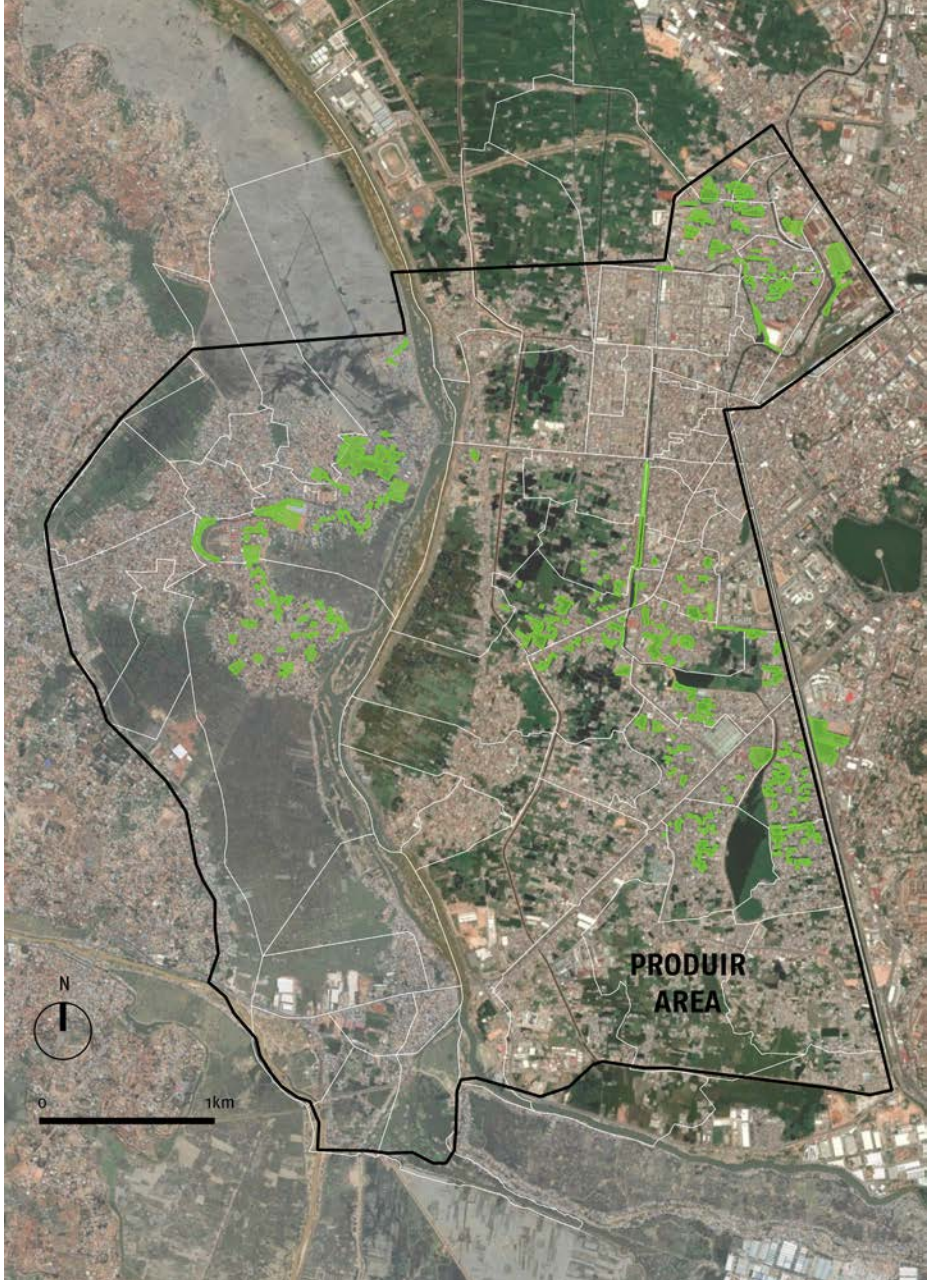
Legend

Refuge sites UNOCHA
Assembly points UNOCHA
Fokontany in PRODUIR area

Plan d'Evacuation District Tana IV (2015) contains evacuation routes, assembly points, and refuge sites. For the districts 1e arrondissement and Bemasoandro, only refuge sites are available. For districts Andranonahoatra and Anosizato Andrefana, there is no information available, because the plan does not cover these rural areas.

Evacuation planning

Open areas around the fokontany where the surveys were conducted. They were mapped manually from Bing Aerial (April 2020). These areas are not part of the swamp, wetland and agricultural areas, or water bodies. These areas could be potentially used to integrate NbS and disaster refuge.



Legend

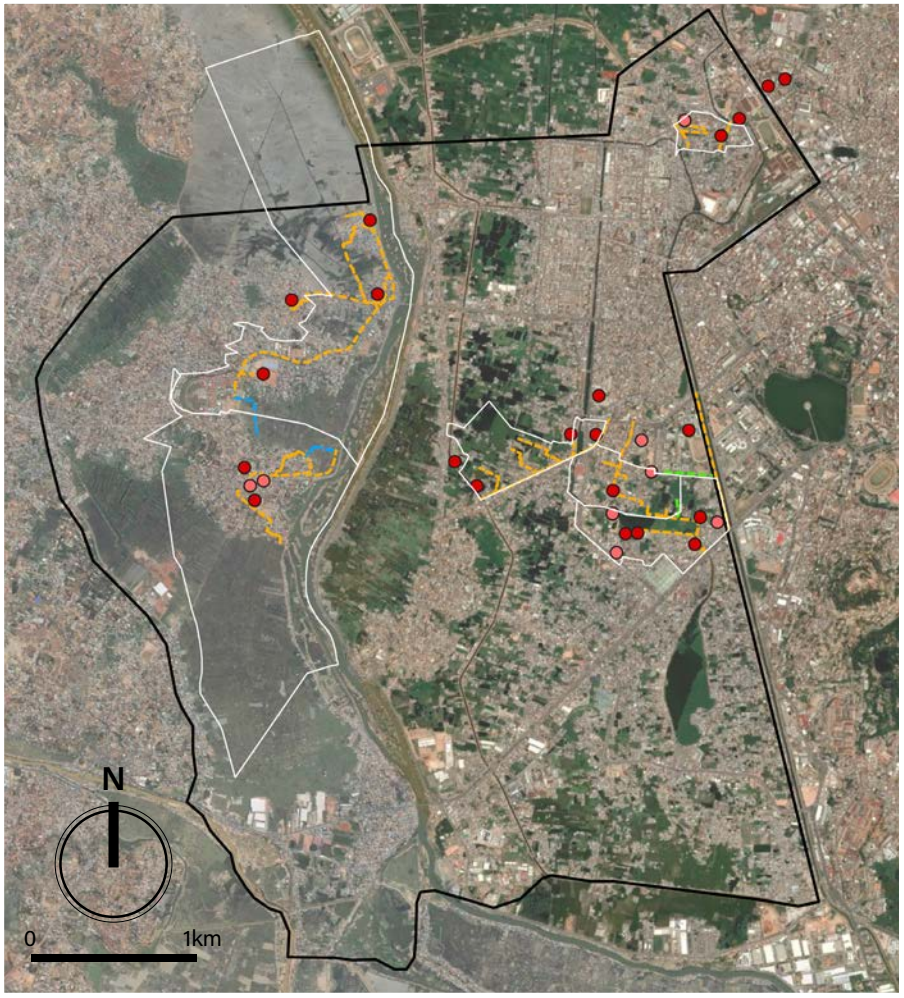
Open areas
Fokontany in PRODUIR area

Swamp, wetland, and agricultural areas, as well as water bodies extension were based on: Land use in 2007, from PRODUIR; Open Street Map; Water Shapes CUA and CR

Evacuation planning

The **community survey** provided the following input:

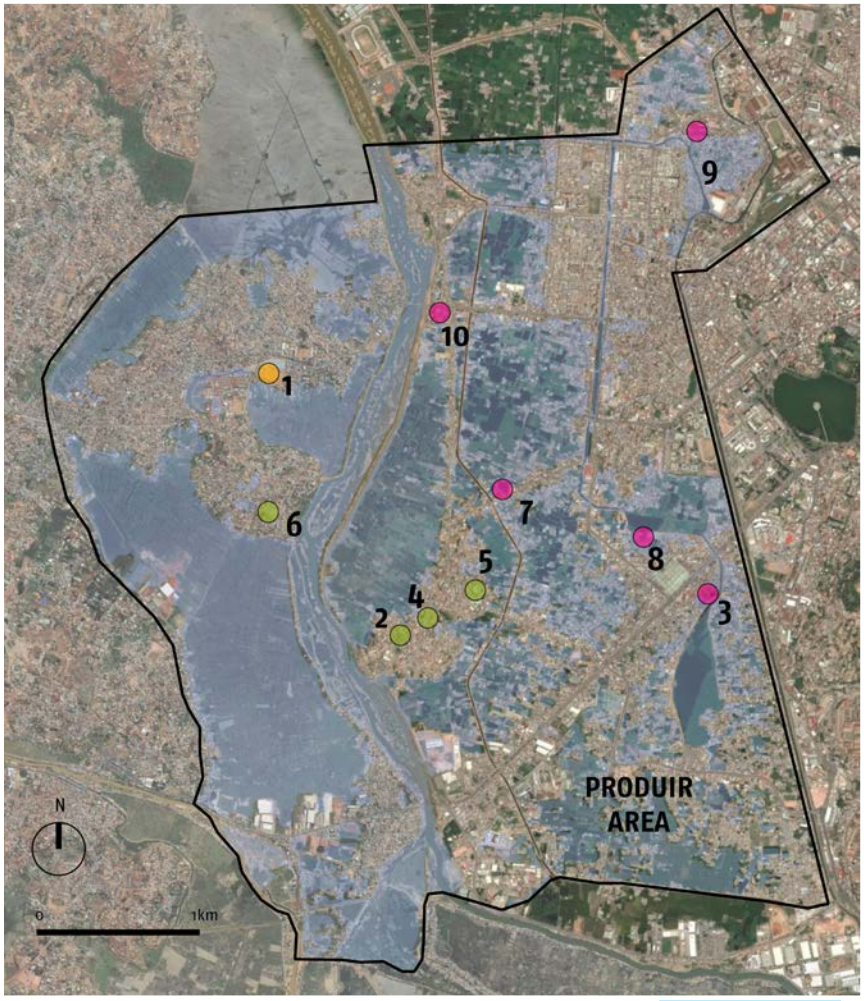
- Existing refuge sites are correspond to official refuge sites in certain locations.
- Proposed refuge sites and evacuation routes seem to respond to the necessities of the community, and are not necessarely the safest option
- The proposed refuge site and evacuation route in Antohomadinika Anfovoany are located closely to site 9.



Evacuation planning

Preselected sites

Site 1 - Antanikatsaka football field
Site 2 - Anosipatrana free land
Site 3 - Open field near buffer tank
Site 4 - Anosipatrana
Site 5 - Anosipatrana asphalt field
Site 6 - Community survey (Ambaniala)
Site 7 - Community survey (Andavamamba Anjezika II)
Site 8 - Community survey (Anosibe Andrefana I)
Site 9 - Community survey (Antohomadinika Afovoany)
Site 10 - Red Star Hotel



Legend
Site elevation
High
Medium
Low

Evacuation planning

The main **role of authorities** during evacuation are:

- **Fokontany leader**. Works closely with the higher authority, which is the Commune. He also has the role of ensuring risk and disaster management at the level of their constituency.
- **Military authorities**. Relevant for the implementation of activities and especially enforcing laws and ensuring the safety of the people.
- **Local monitoring committees and the RF2**. The committees are responsible for the sensitization of the population regarding evacuation. They work closely with the RF2, in pre-collection, sorting and recovery waste through the support of NGOs.
- **Commune**. It is part of the political decision-makers and has the role of ensuring the well-being of the inhabitants through both economic and social projects. In addition, mayors also play a role in flood prevention through urban planning and the implementation of adequate infrastructure.

Nature-based Solutions (NbS)

Good practices worldwide

There are several good practices from around the world to inspire and use as reference in Antananarivo. We focused on **flood risk reduction by strengthening evacuation planning** in combination with NbS, keeping in mind the other challenges.

The main types of good practices are:

- Nature-based Solutions
- Disaster evacuation & refuge
- Combination of Nature-based Solutions and disaster evacuation & refuge
- Complementary solutions

Nature-based Solutions (NbS)

Some examples of good practices are:

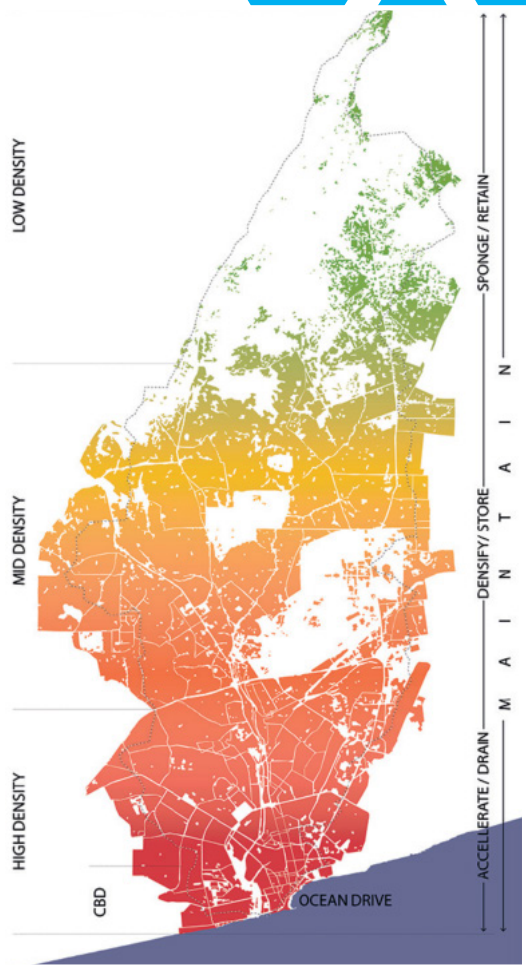
Accra Urban Plan. Ghana. 2017-2018

Problem addressed: urban pluvial floods

NbS: swales on neighborhood scale

Lessons learned:

- Analyze the natural system. When you know how it works, you can work along it.
- You need the courage to think big but also have the guts to act small
- Change from drain as quick as possible to retain and store as long as possible, drain only when no other option is left.
- Increase storage capacity along main roads by changing drains into swales
- Use flood protection as a means to create better livelihoods within the city



Overview of the multiscale strategy for Accra

Nature-based Solutions (NbS)

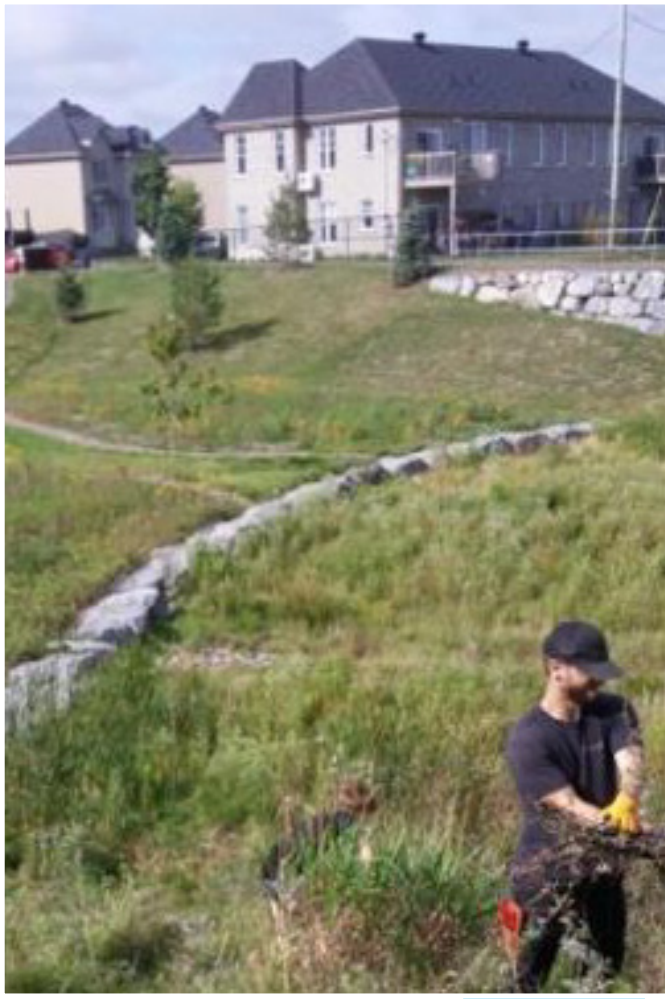
Too Small to Fail. Canada. 2018

Problem addressed: floods

NbS: rain gardens, swale, bioswale, retention basin

Lessons learned:

- Small-scale community-based measures and activities can be easily implemented with limited resources, as long as the community is involved and motivated
- No-regret NbS and other complementary measures can be part of a longer-term strategy for flood risk reduction.



Volunteers from the community working in the implementation of a detention basin. Feltmate and Fluder (2018)

Nature-based Solutions (NbS)

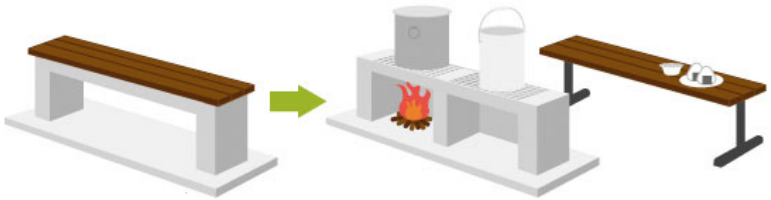
Disaster Prevention parks. Japan

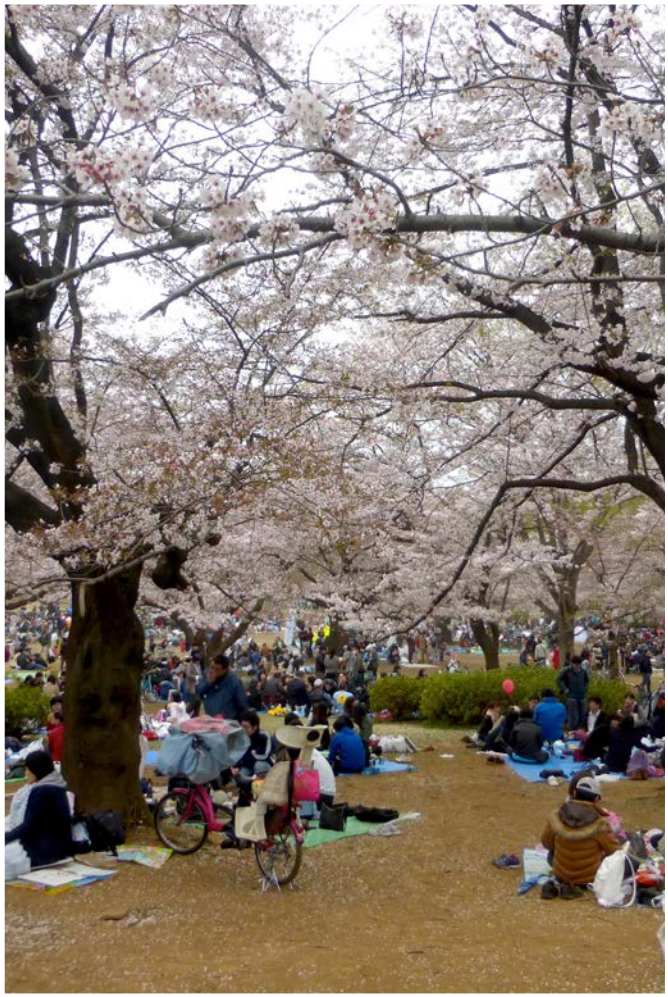
Problem addressed: urban floods, fires, earthquakes, cyclones

NbS: urban parks, urban forest

Lessons learned:

- Visibility of the park helps to conduct a smoother disaster evacuation, because people are already aware of where is safe to go
- A park network can provide a robust evacuation and refuge network





(left image) Detail of a kamado bench (stove bench), one of the facilities present in the park, credits Tokyo-Park ; (right) Hikarigaoka Park being used by the community in a normal day, credits Wikiwand

Nature-based Solutions (NbS)

Bridging the gap Africa. Kenya. 2003 - to date

Problem addressed: safe mobility of pedestrian across rivers

NbS: use of vetiver for land stabilization of river banks, especially around the areas where footbridges are built.

Lessons learned:

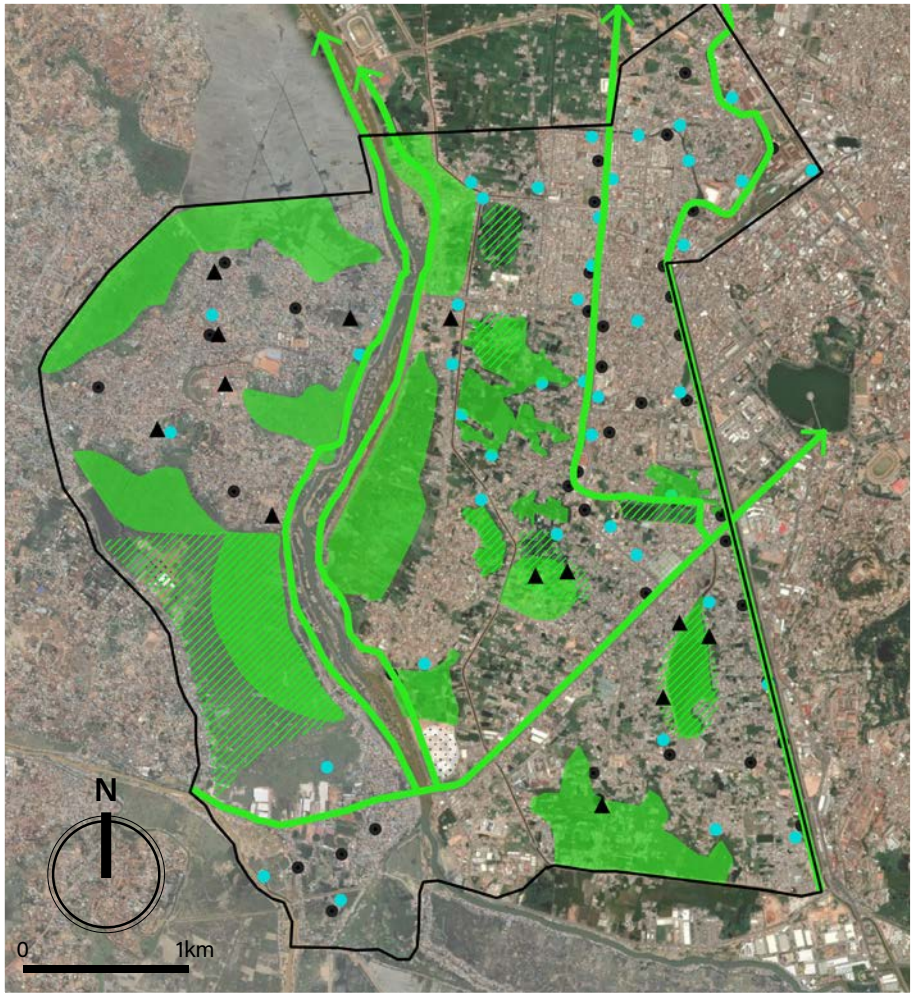
- Collaborative planning and implementation of measures leads to successful solutions that are accepted by the community
- A clear plan of action for the implementation and maintenance of the footbridge ensures the adequate maintenance over time
- Sense of ownership of the community that participated in the implementation.
- Use of native non-invasive species for NbS

Vetiver system project. Credits Bridging the gap Africa

Nature-based Solutions (NbS)

During **workshop 1**, stakeholders identified multiple potential NbS:

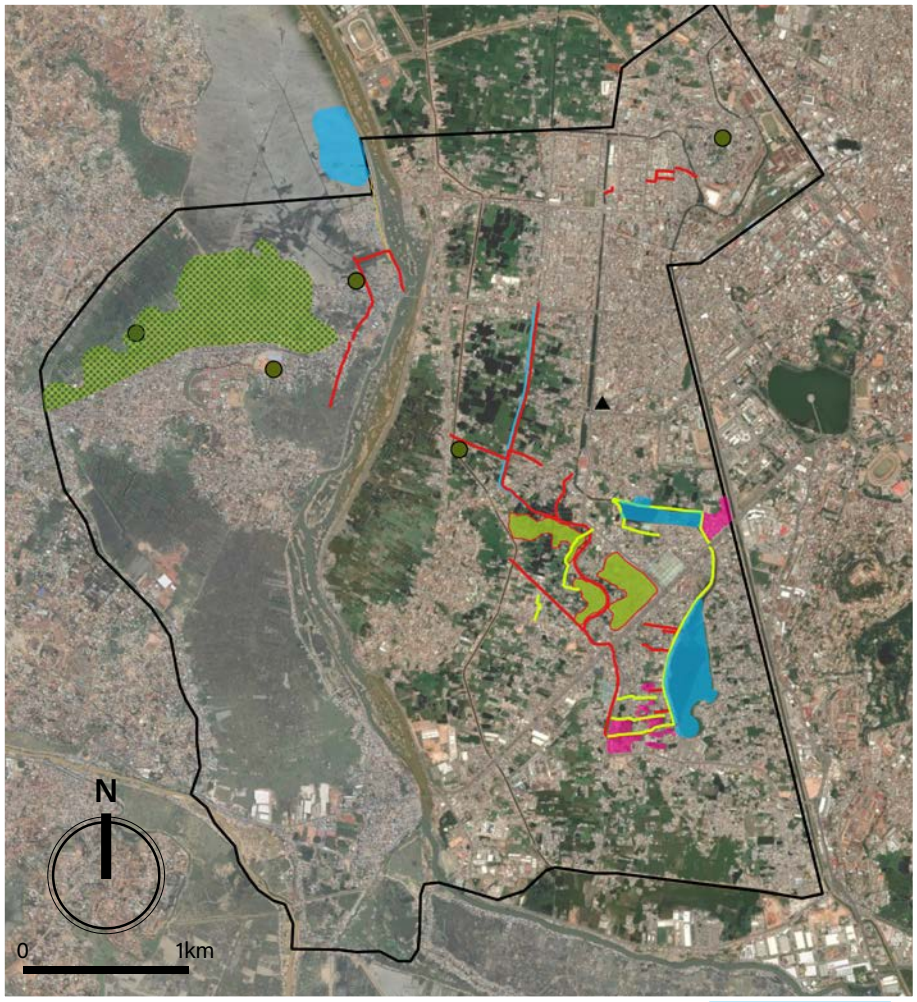
- Linear green infrastructure along main routes and water courses
- Preserve existing green areas (nature)
- Create new buffer basins to store rainwater.
- Equipe the city with disaster refuges, garbage disposal points and public toilets at different locations



Nature-based Solutions (NbS)

NbS suggested by the stakeholders during the **focus groups** were:

- Urban agriculture
- Add green to the landscape
- Rain barrel
- Elevated evacuation routes
- Creation of surface water



Legend

- Urban parks
- Refuge
- Urban agriculture
- Private gardens
- Create surface water
- Buffer basin
- Elevated evacuation routes
- Green routes
- Elevated houses
- Rain barrels

4. Scenario building

- Rationale
- Site selection
- Evacuation plan
    - Phase I - On-site evacuation
    - Phase II - Off-site evacuation
    - Phase III - Off-site evacuation

Rationale

Understand the larger water system, but **manage the water locally** with small-scale interventions based on nature that also provide co-benefits and contribute to address both water-related challenges as well as other challenges present in Antananarivo.

Rationale

Why Nature-based Solutions (NbS)?

- They can be implemented by the community as no-regret measures
- Can be low-tech and have a relatively low implementation cost
- Provide multiple co-benefits
- Improves the situation in the short term and gives time to prepare a more structural solution in the long term

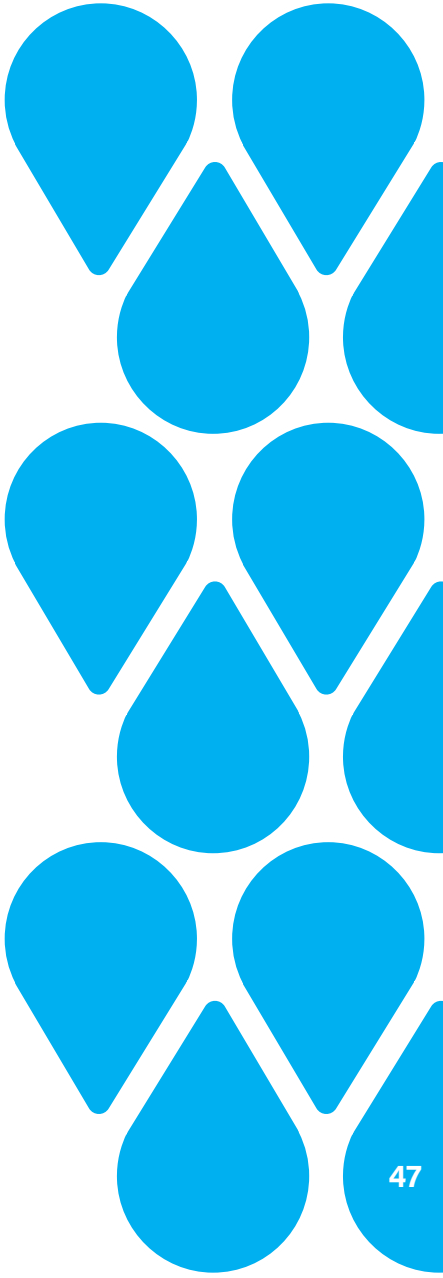
Rationale

We chose several locations to explore and test NbS and other complementary measures. These locations are:

Representative of a larger urban situation, based on the identification of urban typologies.

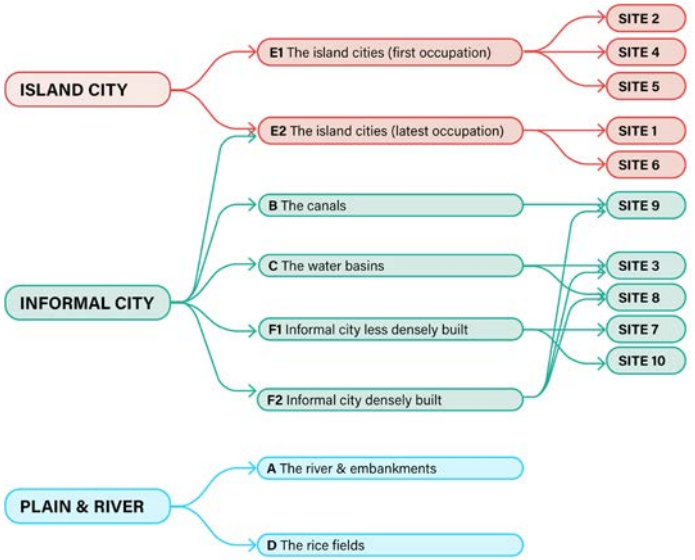
Upscalable. Small-scale interventions could be replicated in other areas of the city with similar characteristics.

Multipurpose, so it is possible to tackle several challenges at the same time, and they can be used during the whole year, not only in times of floods.



Site selection

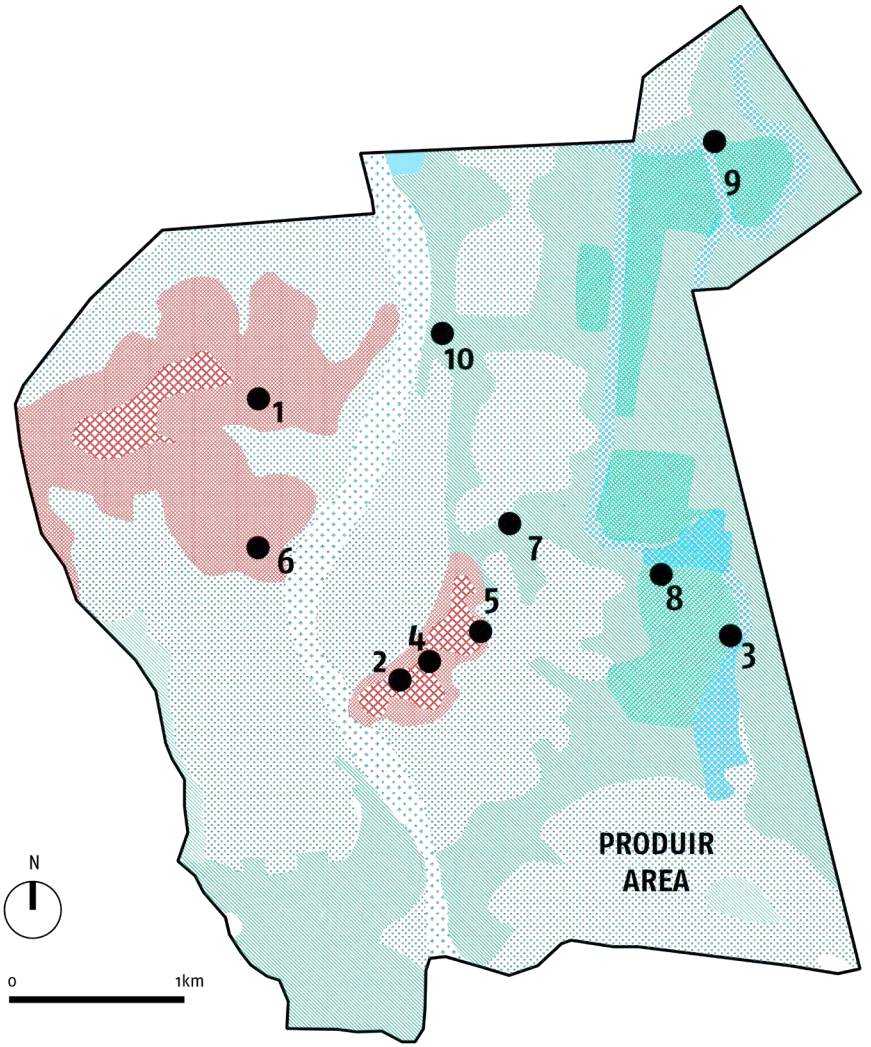
Earlier preselected 10 sites. These sites should be upscalable in other areas of the city that are part of the same urban typology.



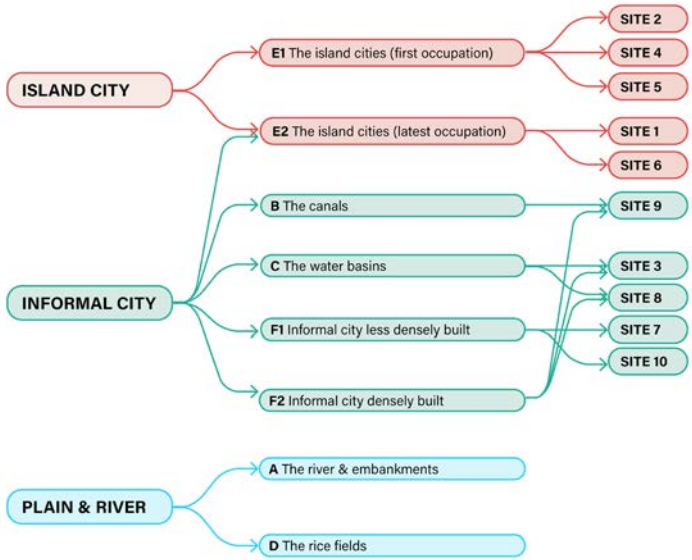
Legend

Urban typologies

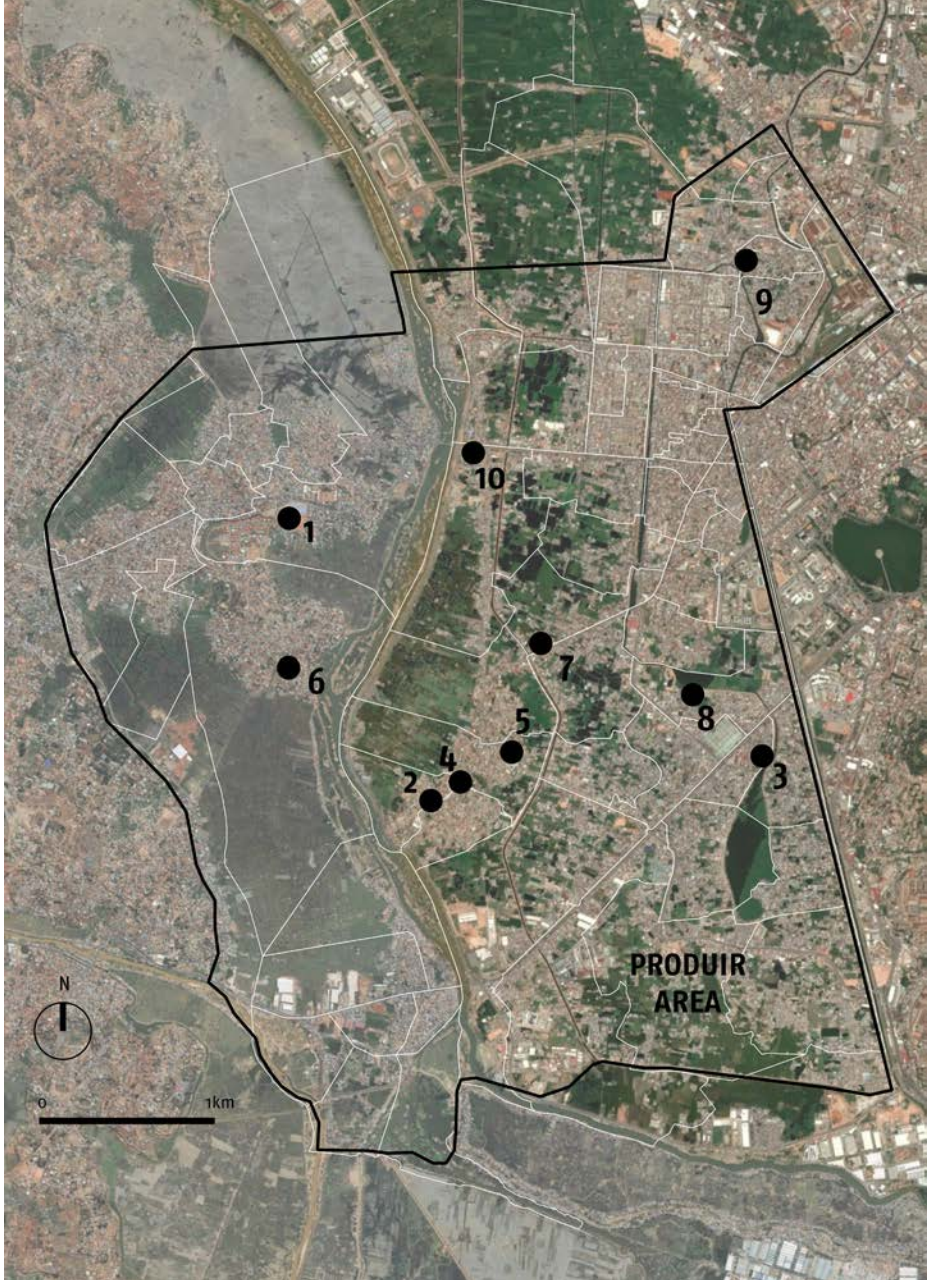
- A - The river & embankments
- B - The canals
- C - The water basins
- D - The rice fields
- E1 - The island cities (1st occupation)
- E2 - The island cities (latest occupation)
- F1 - Informal city less densely built
- F2 - Informal city densely built



Site selection



Legend
Site elevation
Selected sites
Fokontany



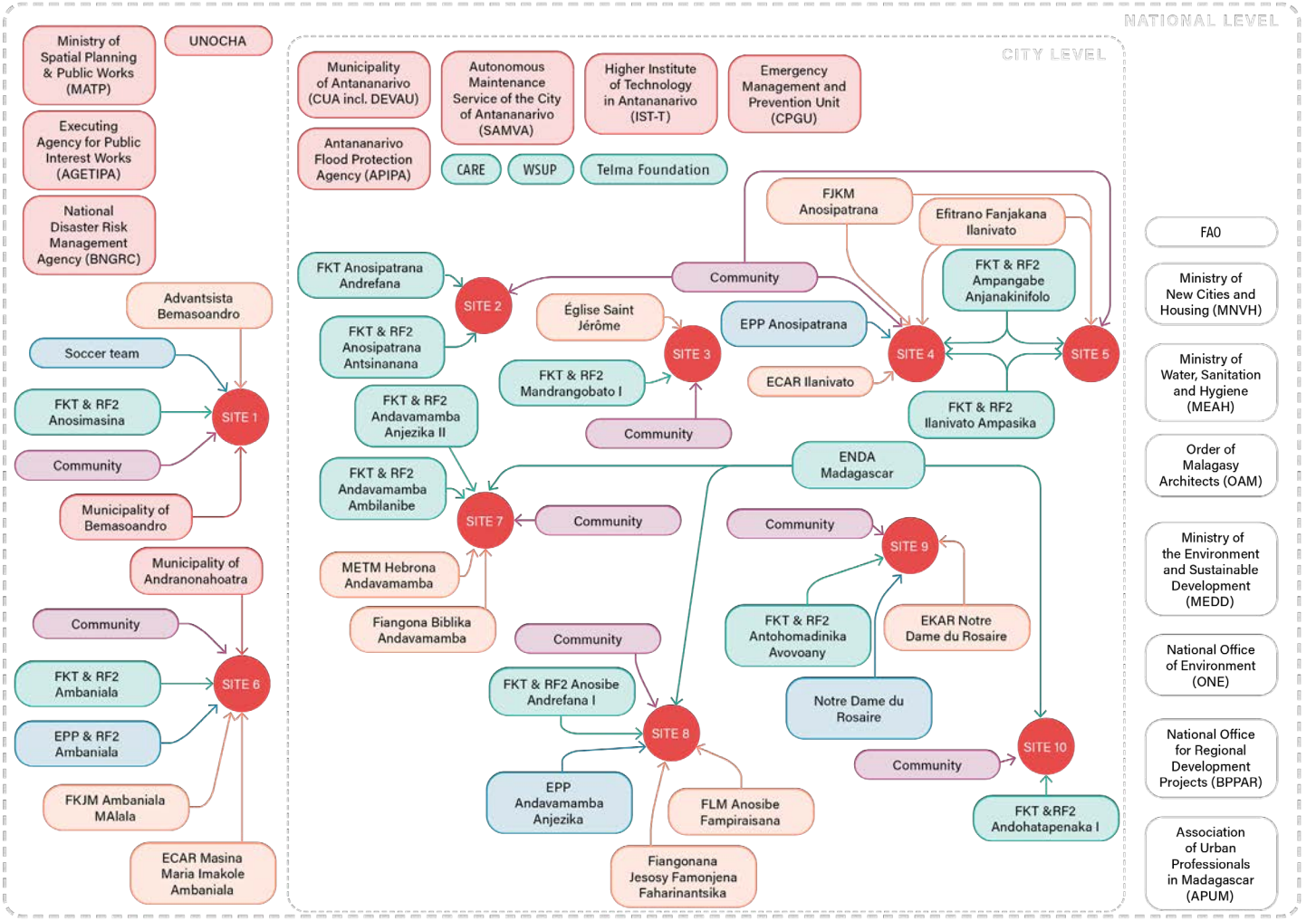
Site selection

Relevant stakeholders

- The current level of engagement and community participation varies per fokontany
- Community, fokontany, RF2 and religious organizations are present in most sites. They could potentially be the main actors in the implementation and maintenance of NbS and complementary measures.
- Schools could also play a role, linking to education and awareness programs about the use of NbS.
- The **mandate of the RF2 could be expanded to cover NbS for water safety and security**. Besides their current activities, they could be responsible for the maintenance of NbS
- On a first stage, this could be implemented on the fokontany where the chosen pilot sites are, to test their feasibility.
- Intensive training, education and awareness activities should be implemented to support this work

Site selection

Relevant stakeholders



Site selection

Population exposed

SITE 1

Population exposed Anosimasina = 4,679 persons

Site capacity = 10,667 persons (228%)

SITE 2

Population exposed Anosipatrana Andrefana + Anosipatrana Antsinanana = 5,954 persons

Site capacity = 1,067 persons (18%)

SITE 3

Population exposed Mandrangobato I = 9,261 persons

Site capacity = 6,167 persons (67%)

SITE 4

Population exposed Ampangabe Anjanakinifolo + Anosipatrana Andrefana + Anosipatrana Antsinanana = 9,976 persons

Site capacity = 1,800 persons (18%)

SITE 5

Population exposed mpangabe Anjanakinifolo + Ilanivato Ampasika = 5,770 persons

Site capacity= 767 persons (13%)

SITE 6

Population exposed Ambaniala = 2,408 persons

Site capacity = 1,800 persons (75%)

SITE 7

Population exposed Andavamamba Anjezika II + Andavamamba Ambilanibe = 26,860 persons

Site capacity = 3,733 persons (14%)

SITE 8

Population exposed Anosibe Andrefana I = 24,270 persons

Site capacity= 2,500 persons (10%)

SITE 9

Population exposed Antohomadinika Afovoany = 3,030 persons

Site capacity = 2,027 persons (67%)

SITE 10

Population exposed Ambodirano Ampefiloha = 13,572 persons

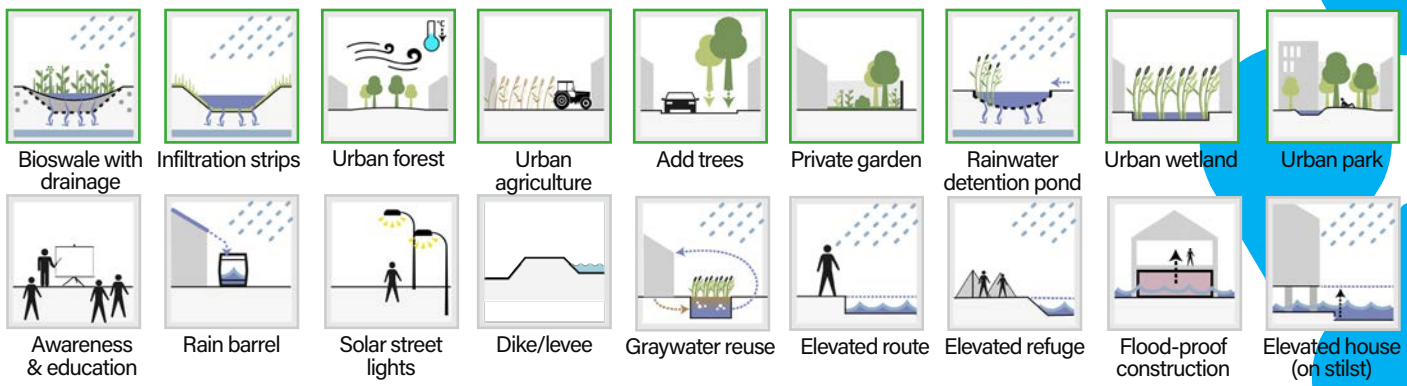
Site capacity= 6,600 persons (37%)

Site selection

Proposed measures

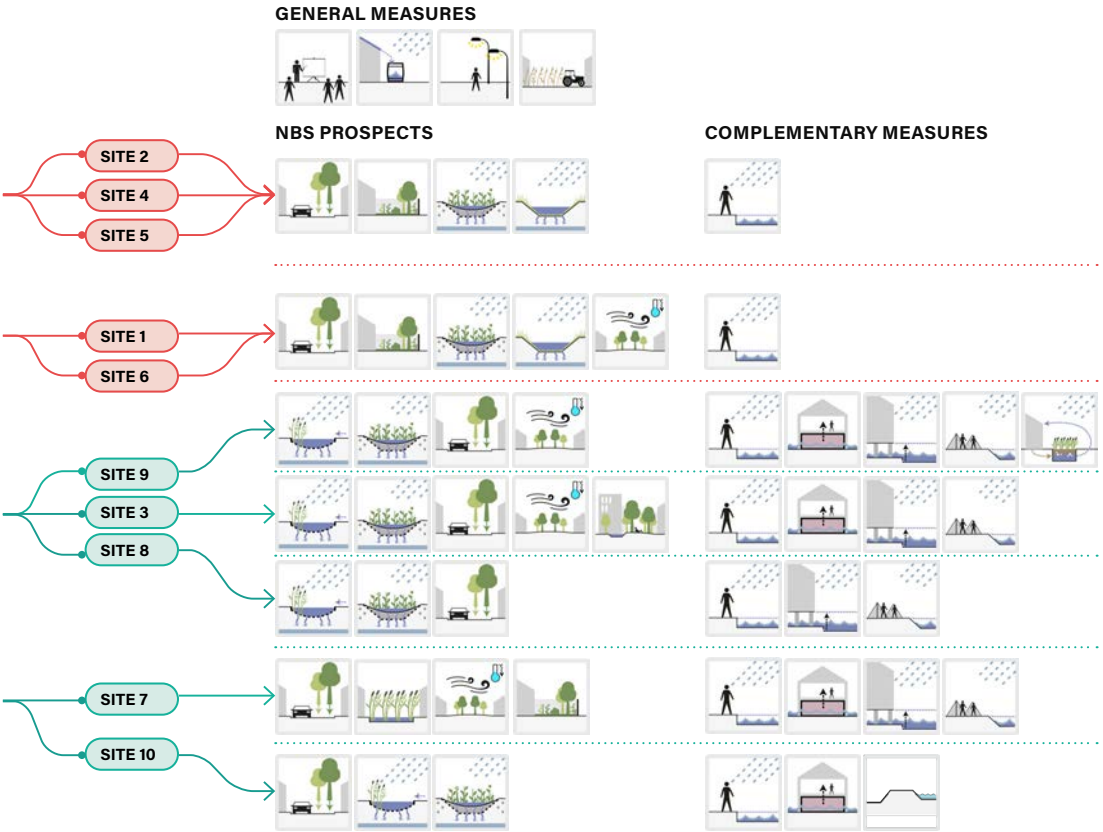
From the longlist of NbS and complementary measures, we chosed a specific **combination of measures for each site** that can contribute to improve disaster evacuation and reduce flood risk, taking into account:

- site characteristics
- challenge that needs to be addressed
- characteristics of measures (technology required, implementation requirements, effectiveness, co-benefits)



Site selection

Proposed measures



Evacuation plan

Scenarios

Two scenarios developed keeping in mind integration, by looking at shared locations (multifunctional land use) and shared costs, and selecting measures that seem promising when combined.

Scenario 1: on-site evacuation

Scenario 2: off-site evacuation

Based on information on flood risk, potential refuges and routes, and potential NbS, each scenario consists of a **multi-evacuation plan** and a range of architecture and landscape design **guidelines** using the pre-selected measures.

Evacuation plan

Approaches for integrating NbS and Evacuation planning

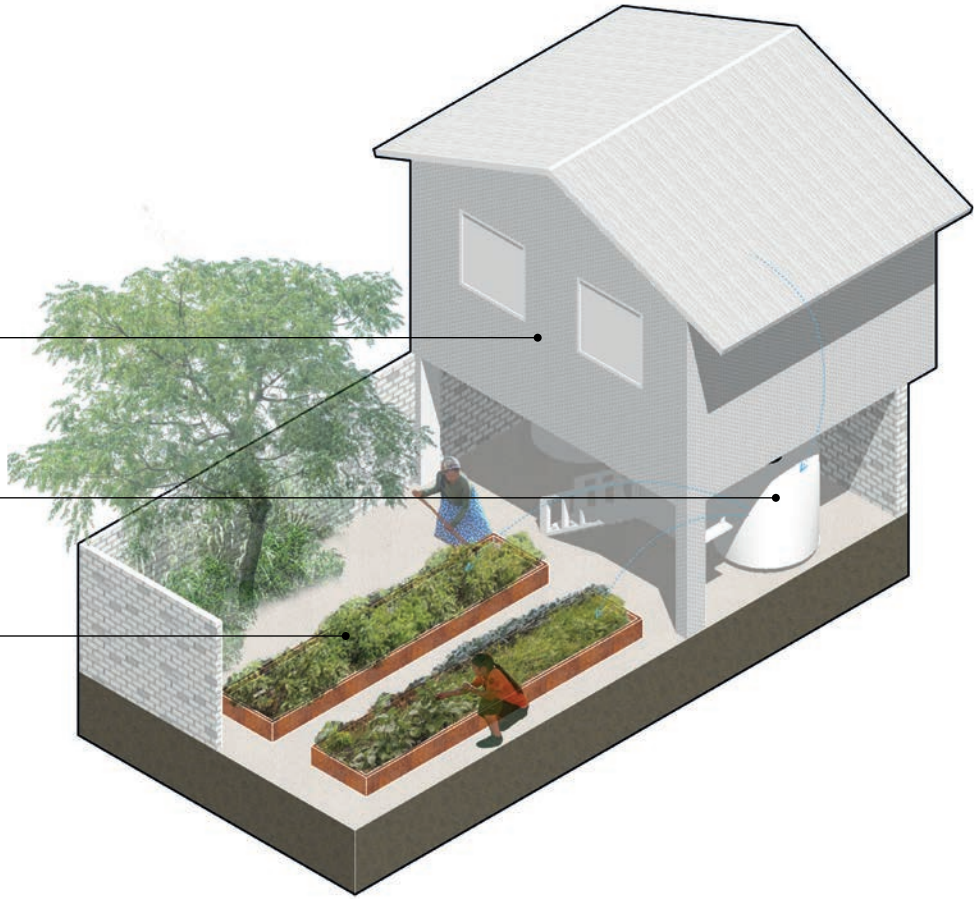
Shared location & shared costs approaches:

- Are not restricted to a single hazard or problem.
- Actively look for opportunities to link up with other hazards and problems.
- Look for win-win solutions.

Evacuation plan

Shared location

It is beneficial if a site can be used for more than one purpose.



Elevated house
Safe refuge

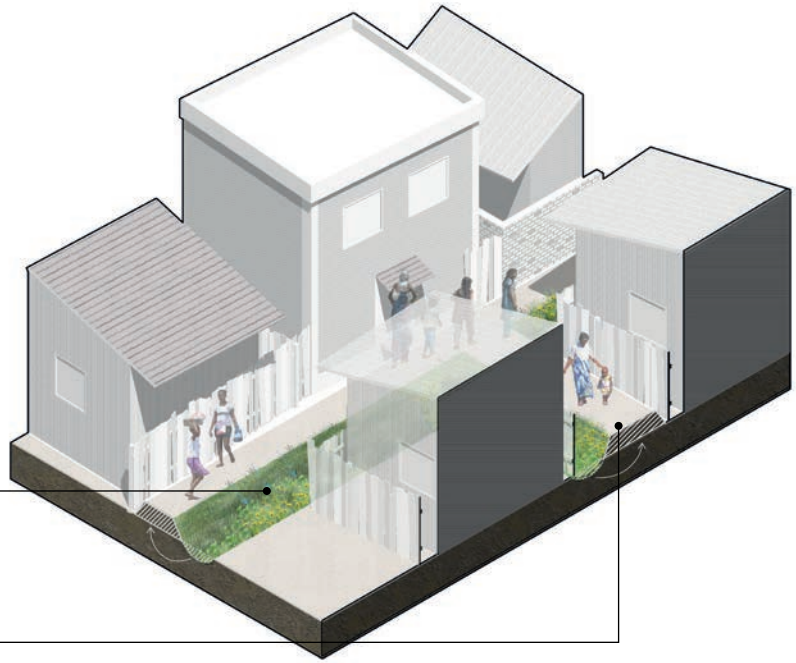
Rain barrel
Rainwater harvest

Private garden
Water retention, food, shade

Evacuation plan

Shared costs

Considering the limited resources to for the implementation of measures, one way of maximizing them is by combining different measures or looking for the right moment for implementation (e.g. when there is another project being implemented)



Bioswale
for water retention
Excavated soil

Use soil to
- improve infrastructure
- create safe and elevated evacuation route

Evacuation plan

We believe that the two scenarios can be complementary phases of one comprehensive evacuation strategy.

Phase I: evacuation and refuge to on-site locations

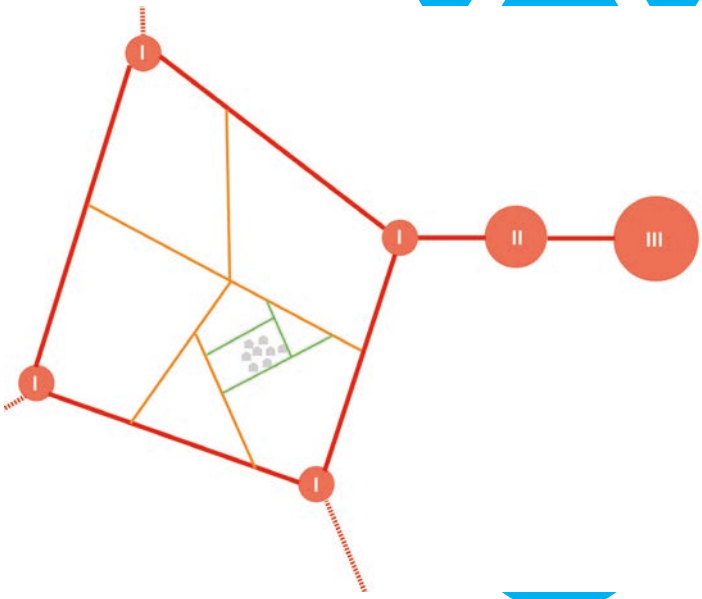
Phase II: evacuation to off-site locations for short term refuge (within the PRODUIR area)

Phase III: evacuation to off-site locations for longer term refuge (outside the PRODUIR area)

Evacuation plan

Evacuation through three types of routes:

- Green route from houses to on-site evacuation routes
- Orange routes to flood refuges
- Red routes between on-site refuges, and between those and off-site refuges

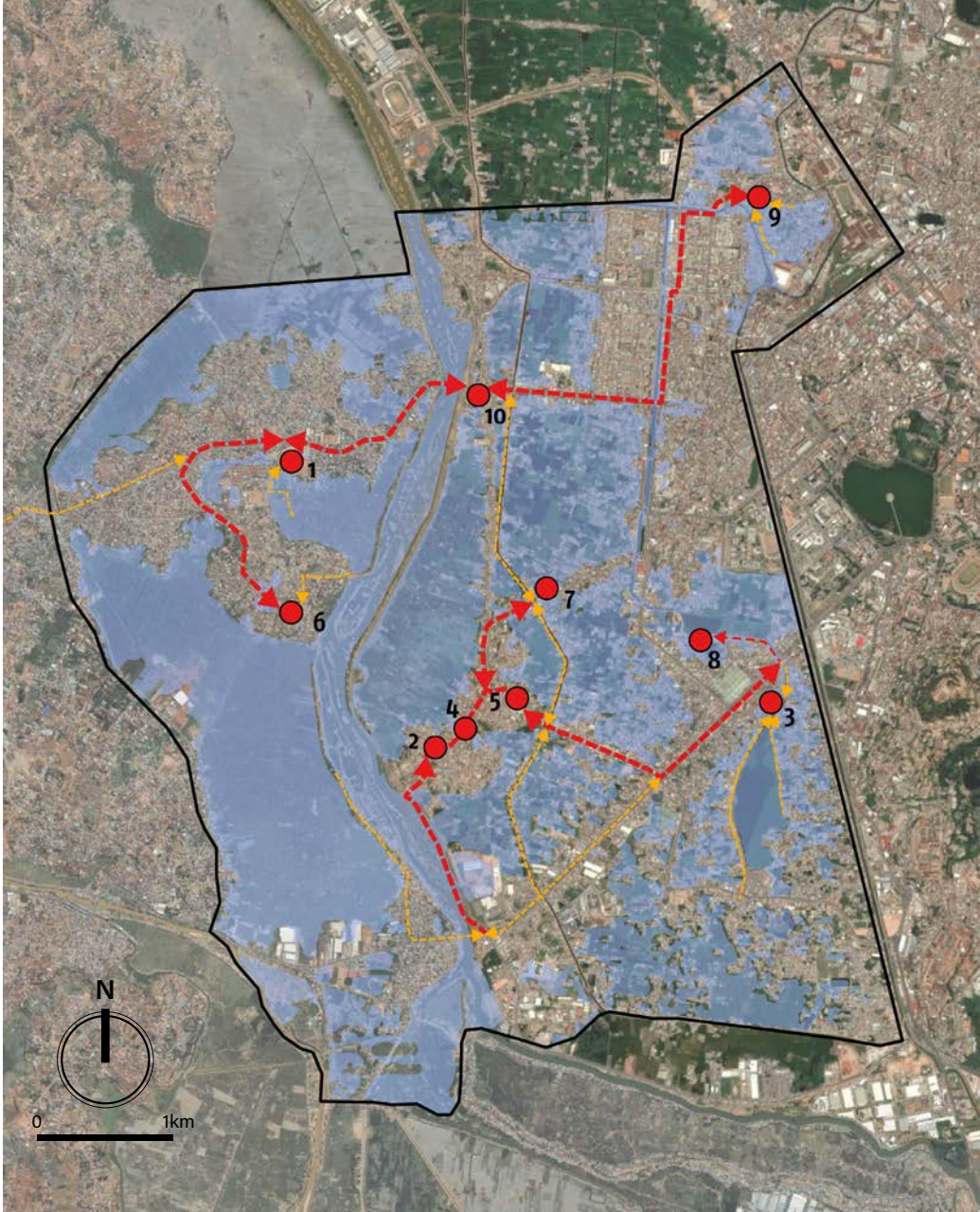


This infrastructure network makes use of existing roads and paths. Several of them need upgrading from their current condition, so when improvements are to be made, NbS (e.g. trees, bioswales) should be integrated.

Evacuation plan

Phase I: evacuation and refuge to on-site locations.

All selected sites can work as on-site refuge.
Evacuation starts with green routes that connect groups of houses to the orange routes. They follow existing paths along canals or main roads, and, preferably, are part of people's daily life.
Depending on the area, they can be elevated paths (soil), or boardwalks (on stilts). In specific locations, boats could be used as well if needed.
The orange routes connect to red routes (main routes). Red routes connect the different refuge sites, and off-site locations.



Legend
- On-site refuges
- Orange routes
- Red routes
- Flood extension (PRODUIR)

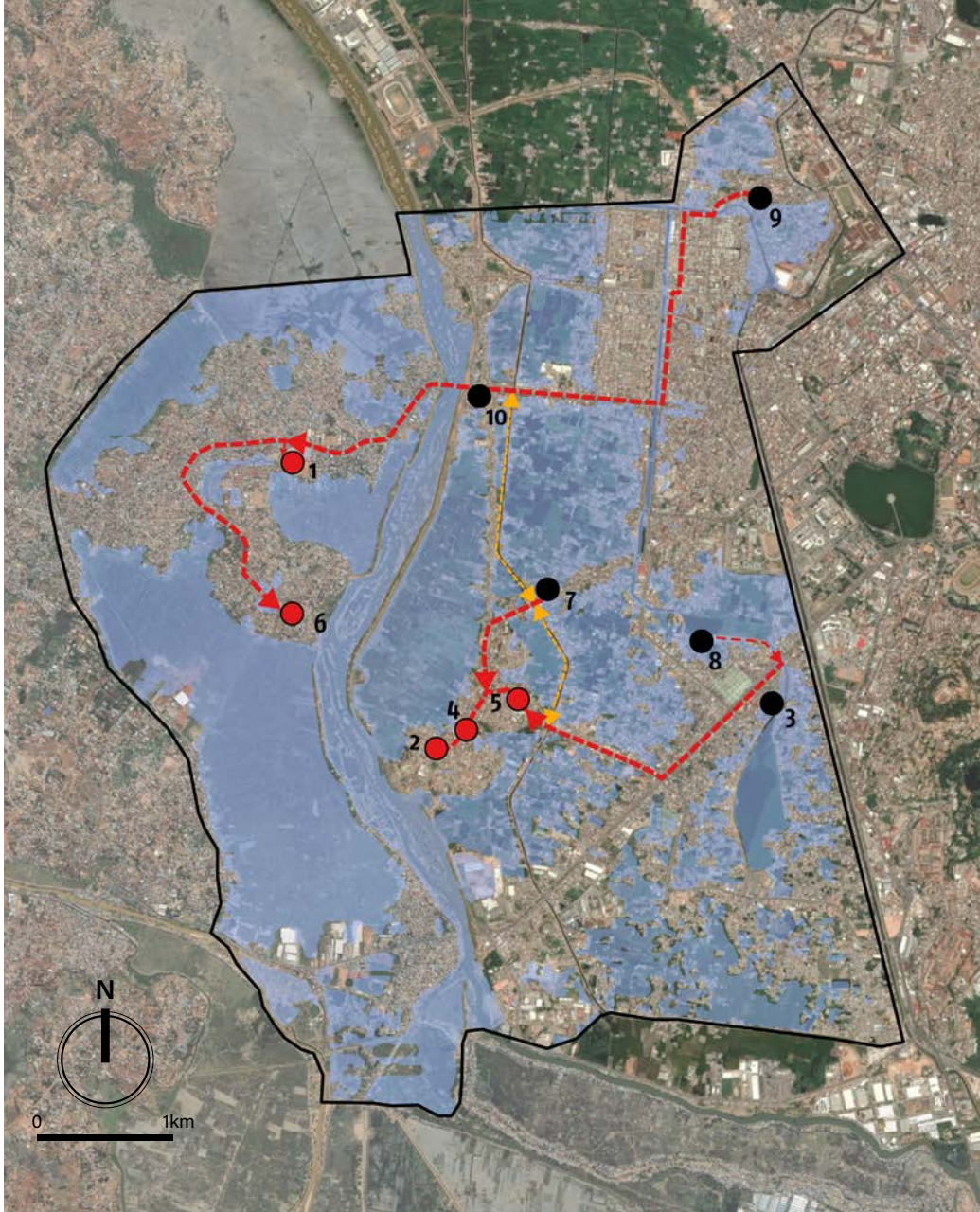
Evacuation plan

Phase II: evacuation to off-site locations for short term refuge (within the PRODUIR area)

Some selected sites double as both on-site refuge and also off-site refuge for citizens of different fokontany.

Evacuation on foot is preferable, since it is low tech and can be more easily implemented. Criteria for route selection:

- **Not flood prone**
- **Shortest route** so that evacuation on foot is possible
- Route that requires the least **height difference**
- **No tunnels**
- Through roads and bridges that have a **bigger capacity** for transit on foot



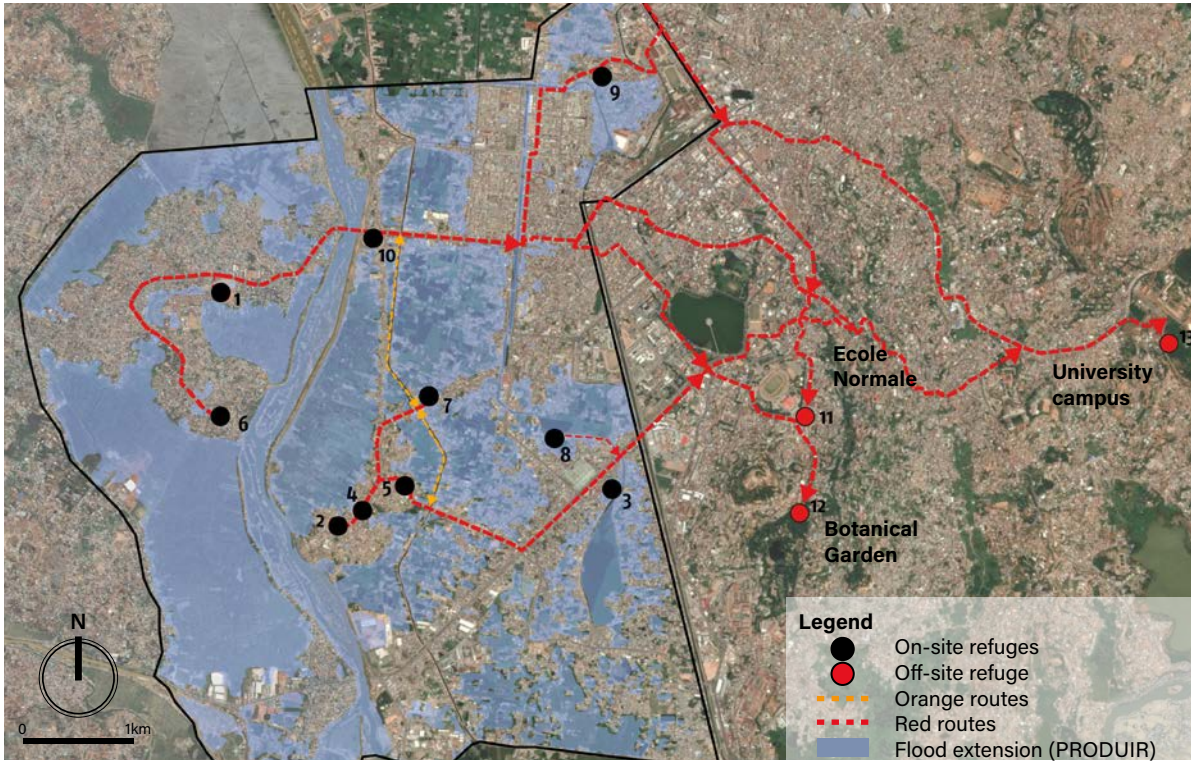
Legend

- On-site refuges
- Off-site refuge
- Orange routes
- Red routes
- Flood extension (PRODUIR)

Evacuation plan

Phase III: evacuation to off-site locations for longer term refuge (outside the PRODUIR area)

Refuge sites should have a higher refuge **capacity**, with l**arger open areas**, **connected** to main evacuation routes and **higher elevation**, so they are less exposed to floods.



Evacuation plan

Overview
1/4

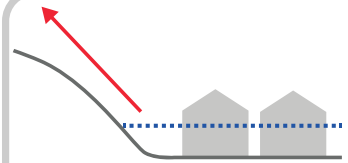
STARTING POINT

WARNING

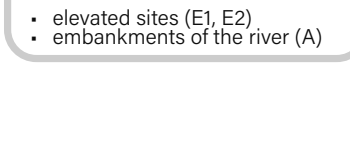
Flood is coming!

PHASE I

WHERE?
Are you close to higher ground or not?



Close to higher ground
- elevated sites (E1, E2)
- embankments of the river (A)

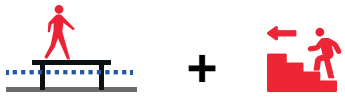


Low laying area
- near canal (B)
- rice fields (D)
- floodplain (F1, F2)
- near the water basin (C)

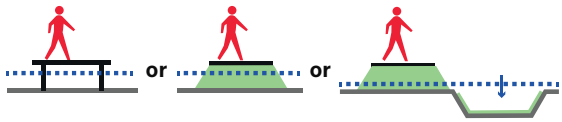
GREEN ROUTE

From homes to evacuation routes

HOW?
How do you evacuate?



To get to higher ground
- board walk made out of plastic to get safely to higher ground
- stairs as evacuation and alternative for disabled people



Low laying area
- boardwalk made out of plastic to get safely to higher ground
- embankment
- embankment + bioswale

Evacuation plan

Overview 2/4

GREEN ROUTE

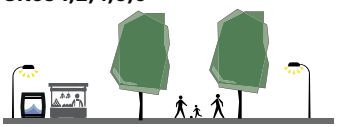
Between on-site refuges

ON-SITE REFUGE

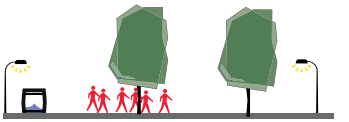
WHERE?

Where is the on-site refuge?

Sites 1,2,4,5,6



Normal situation



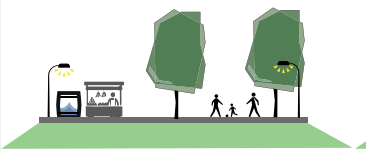
During floods

Public space: market, soccer field, hawker stalls

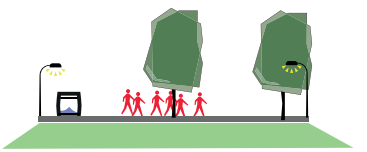
Higher ground

- Trees for improvement of microclimate, water infiltration, soil protection
- Lighting
- Rain barrel for drinking water
- Toilets and first aid
- Security

Sites 3,7,8,9,10



Normal situation

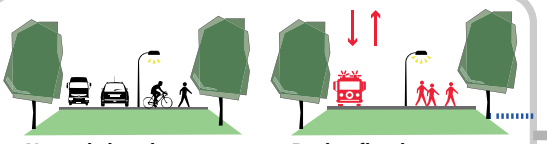


During floods

Public space: market, soccer field, hawker stalls

Low laying area

- elevated safe zone
- trees for improvement microclimate, water infiltration, soil protection
- lighting
- water barrel/ drinking water
- toilets and first aid
- security



Normal situation

During floods

Low laying area

- elevated paved road
- trees as marking and holding soil
- in case of floods change of infrastructure
- street lighting

IS THE FLOOD GETTING WORSE?

Then it is time to move to Phase II

Evacuation plan

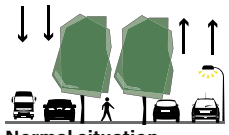
Overview
3/4

RED ROUTE
Between on-site & off-site refuges

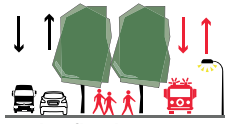
HOW?
How do you evacuate?

OFF-SITE REFUGE - PHASE II
(within PRODUIR area)

WHERE?
Where is the off-site refuge? (phase II)

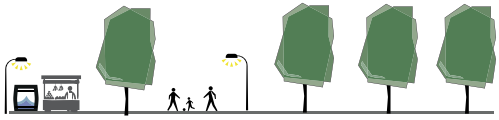


Normal situation

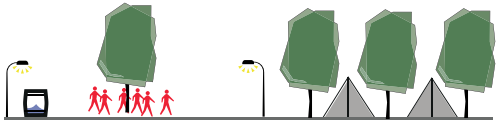


During floods

Higher ground
- trees (indicate route, protect soil)
- in case of floods change of infrastructure
- street lighting
- elevated sites (E1, E2)
- embankments of the river (A)



Normal situation

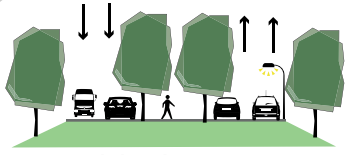


During floods

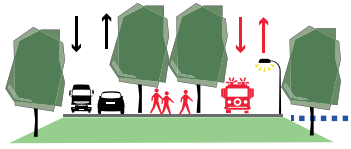
Higher ground
- trees for improvement microclimate, water infiltration, soil protection
- lighting & security
- rain barrel for drinking water
- toilets & first aid
- tent & a place to cook

UPSCALE
Remove people outside flooded area for a longer stay

PHASE II & III

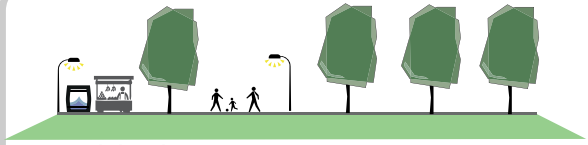


Normal situation

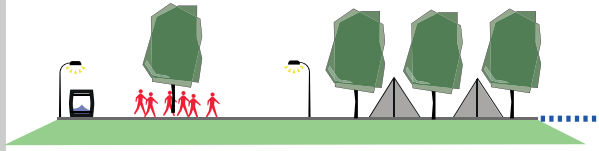


During floods

Low lying area
- elevated paved road
- trees as marking route, improvement microclimate, protecting soil
- in case of floods change of infrastructure
- street lighting



Normal situation



During floods

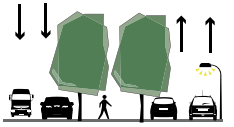
Low lying area
- elevated safe zone
- trees for improvement microclimate, water infiltration, soil protection
- lighting & security
- rain barrel for drinking water
- toilets & first aid
- tent & a place to cook

Evacuation plan

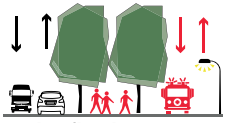
Overview
4/4

RED ROUTE
Between off-site refuges

HOW?
How do you evacuate?



Normal situation

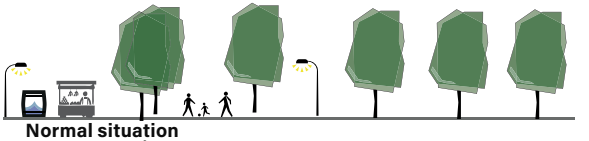


During floods

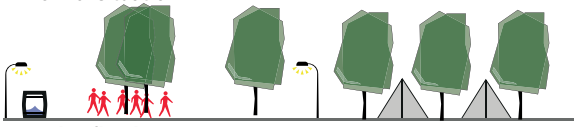
Higher ground
- trees (indicate route, protect soil)
- in case of floods change of infrastructure
- street lighting
- elevated sites (E1, E2)
- embankments of the river (A)

OFF-SITE REFUGE - PHASIE II
(outside PRODUIR area)

WHERE?
Where is the on-site refuge? (phase III)

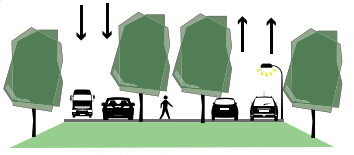


Normal situation

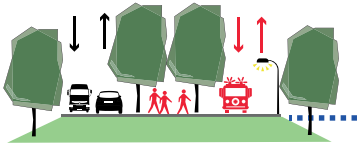


During floods

Higher ground
- trees for improvement microclimate, water infiltration, soil protection
- lighting & security, rain barrel for drinking water
- toilets & first aid
- tent & a place to cook
- playground for children

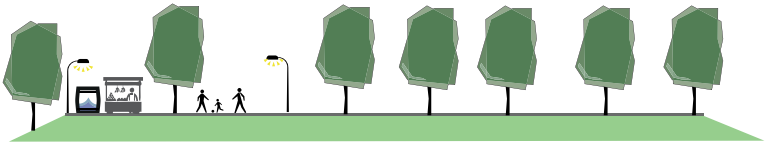


Normal situation

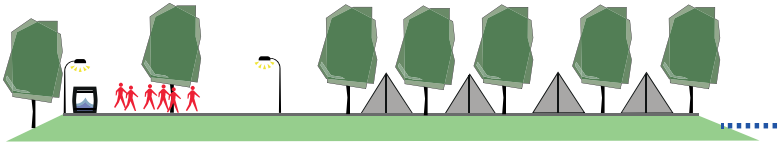


During floods

Low lying area
- elevated paved road
- trees as marking route, improvement microclimate, protecting soil
- in case of floods change of infrastructure
- street lighting



Normal situation

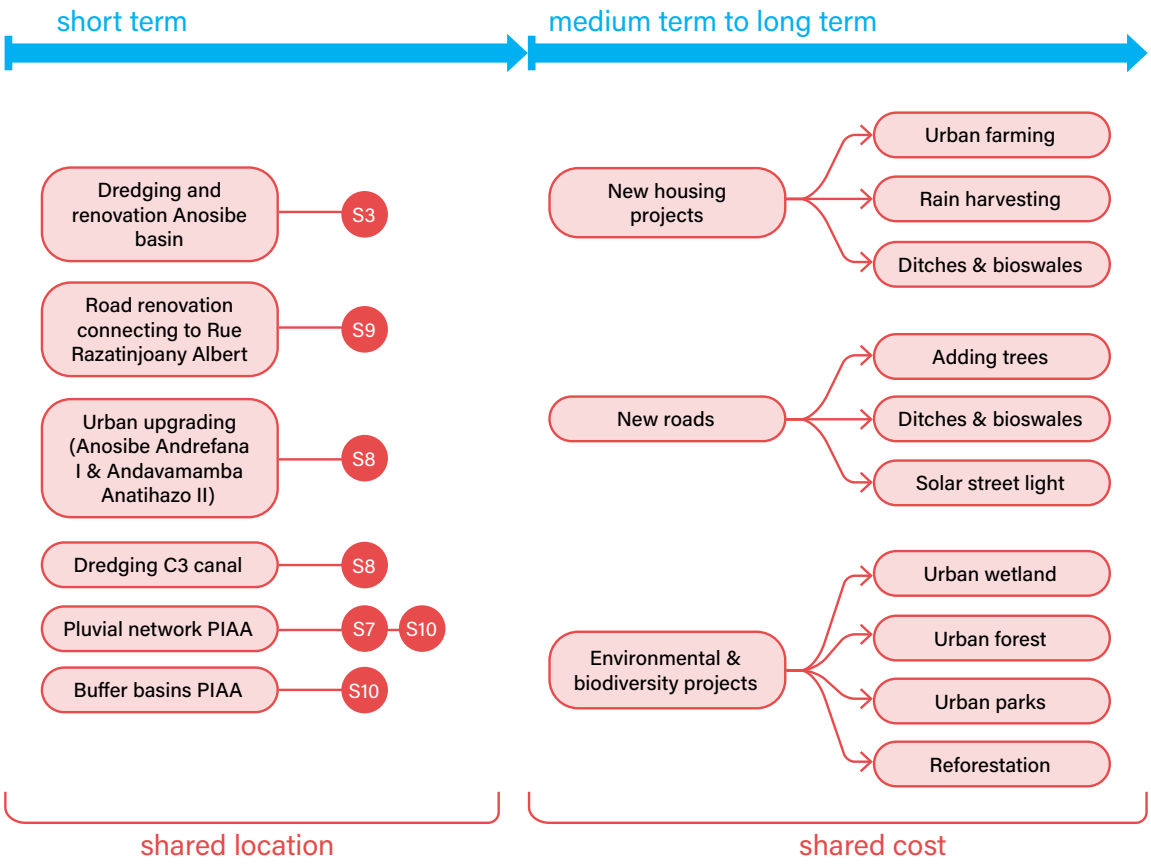


During floods

Low lying area
- elevated safe zone
- trees for improvement microclimate, water infiltration, soil protection
- lighting & security, rain barrel for drinking water
- toilets & first aid
- tent & a place to cook
- playground for children

Synergies

Multiple synergies are possible between the proposed interventions in different sites with existing projects.



Scenario building & synergies findings

The main findings from the scenario building phase are:

- **Scenarios are complementary**. They constitute different phases of the same plan.
- Evacuation routes and refuges conform a network of NbS
- Refuge sites (on-site and off-site) only cover around 10% of the capacity needed to safely evacuate the exposed population
- Considering evacuation by foot, off-site refuge possibilities for phase III are scarce

5. Prefeasibility

- Shortlisted sites
- Effectiveness
    - Routes & refuges
    - Selected NbS
- Plans
- Implementation & maintenance
- Communication

Shortlisted sites

- For 3 sites we made a more detailed plan
- In each shortlisted site we **combined at least 3 NbS and complementary measures**
- For the selection of NbS we also looked at the landscape analysis that was carried out earlier. This way, upscaling of the plans to other parts of the city would be possible

Shortlisted sites

Site 1

- **Urban typology E2** – Island city (latest occupation), recently urbanized The urban typology E2 is very strategic, since it is located between the most flood-exposed low-lying areas and the higher ground (E1).
- **Hazards**. If urbanization continues on that area, people might settle in low-lying areas, and will be more exposed to floods. Besides floods on the areas south of this site, there is a risk of landslides, caused by soil erosion.
- **Soil**. The roofs of houses and compacted soil of roads in the new urbanized areas, are more impermeable than the existing soil. This, in addition to the elevation differences of over 10m in this area, causes that rainfall runs off on the surface and it is not easily infiltrated, triggering erosion.
- **Evacuation opportunities**: identified in the UNOCHA plan and used intuitively by the community for evacuation
- **Governance**: fokontany not very active, but the community is very in initiatives

Shortlisted sites

Site 3

- **Urban typology C** – The water basins and **F2** – Informal city densely built.
- Very **flood-prone area**, so its increasing densification leads to an increase in the population exposed to floods.
- The sense of urgency to implement solutions on this site is high.
- **Soil** is of alluvial deposits
- **Evacuation opportunities**: UNOCHA assembly point
- **Governance**: both fokontany and RF2 are very active and commited
- This site was not initially selected, because it had not been part of the household survey. However, there are a renovation project and a waste sorting initiative with potential synergies.

Shortlisted sites

Site 9

- **Urban typology B** – The canals and **F2** – Informal city densely built. Very urbanized area, well connected by land and water, with some open spaces with the potential to be used for the implementation of NbS, but with increasing densification
- Very **flood prone area**, surrounded by canals
- **High sense of priority** for the implementation of solutions on this site
- **Soil** made of alluvial deposits
- **Evacuation opportunities closeby** (UNOCHA assembly points)

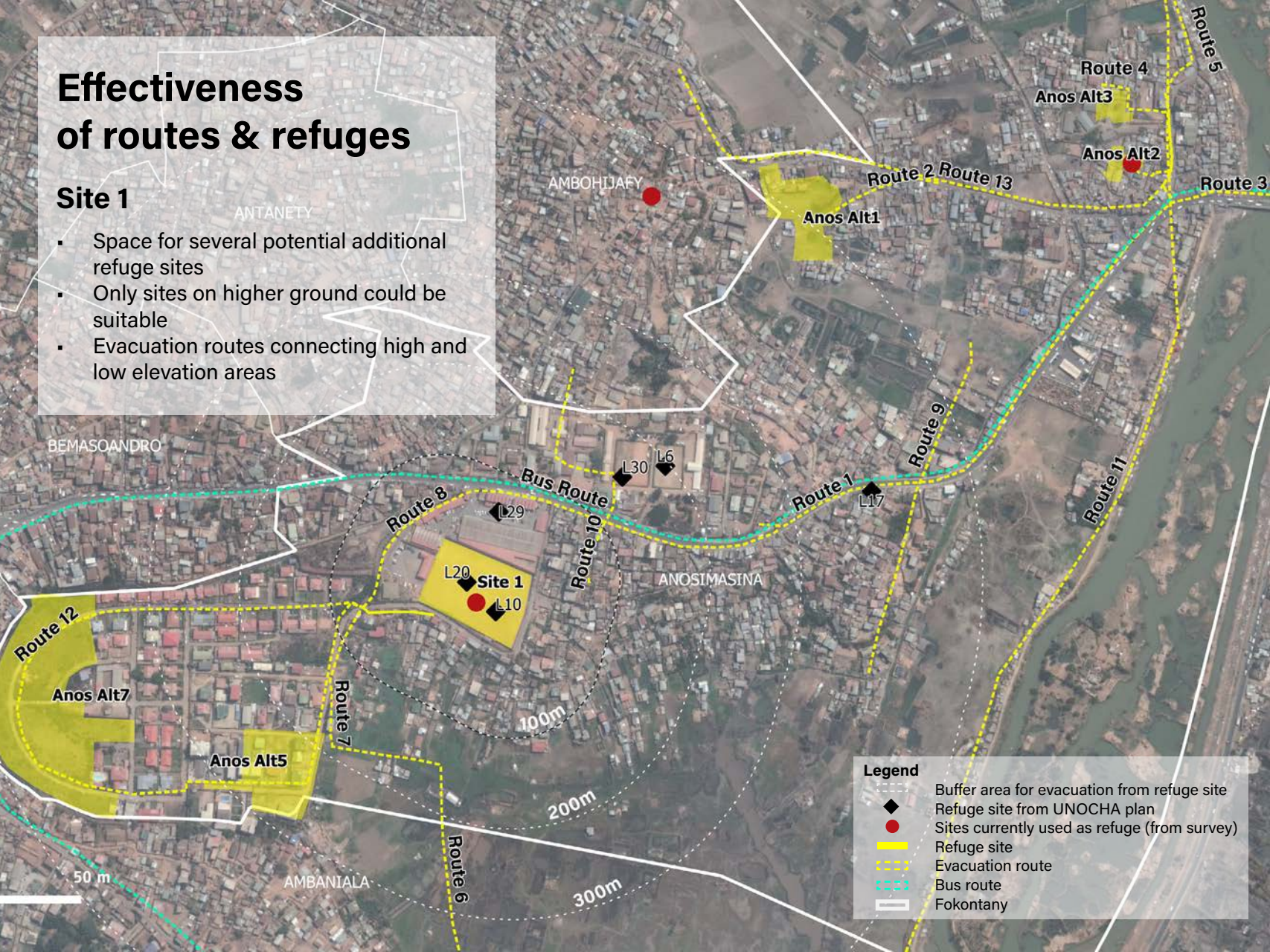
Effectiveness of routes & refuges

- Assessment of the effectiveness of routes and refuges for disaster evacuation, following the steps:
  - **Map** the location of existing evacuation routes connected to the site, including the ones indicated during the household survey
  - **Analyze** the population mobility, including the characteristics of the route (e.g. length, type of pavement, etc.)
  - **Propose alternative refuge sites** and adjust the evacuation routes if needed

Effectiveness of routes & refuges

Site 1

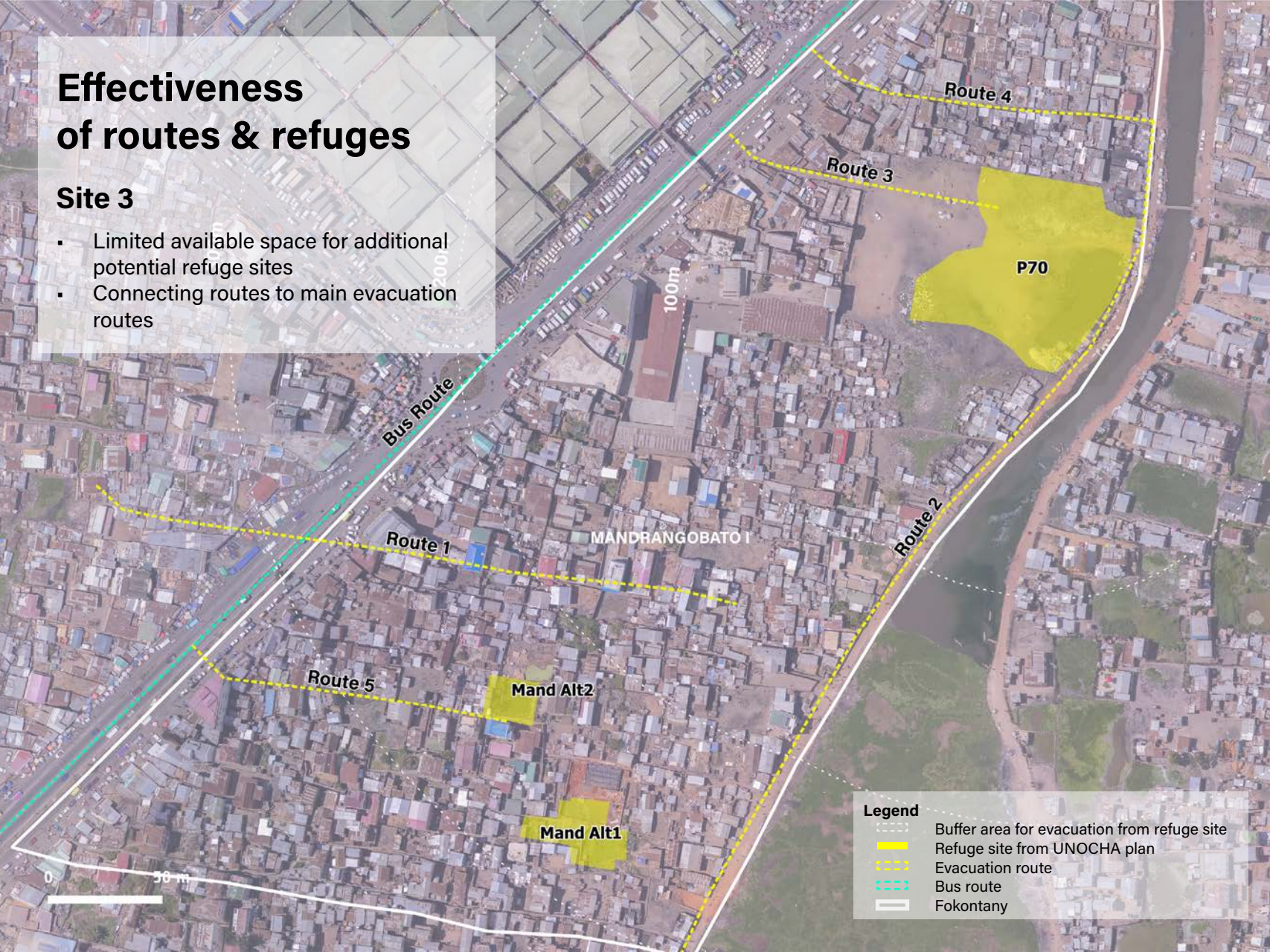
- Space for several potential additional refuge sites
- Only sites on higher ground could be suitable
- Evacuation routes connecting high and low elevation areas



Effectiveness of routes & refuges

Site 3

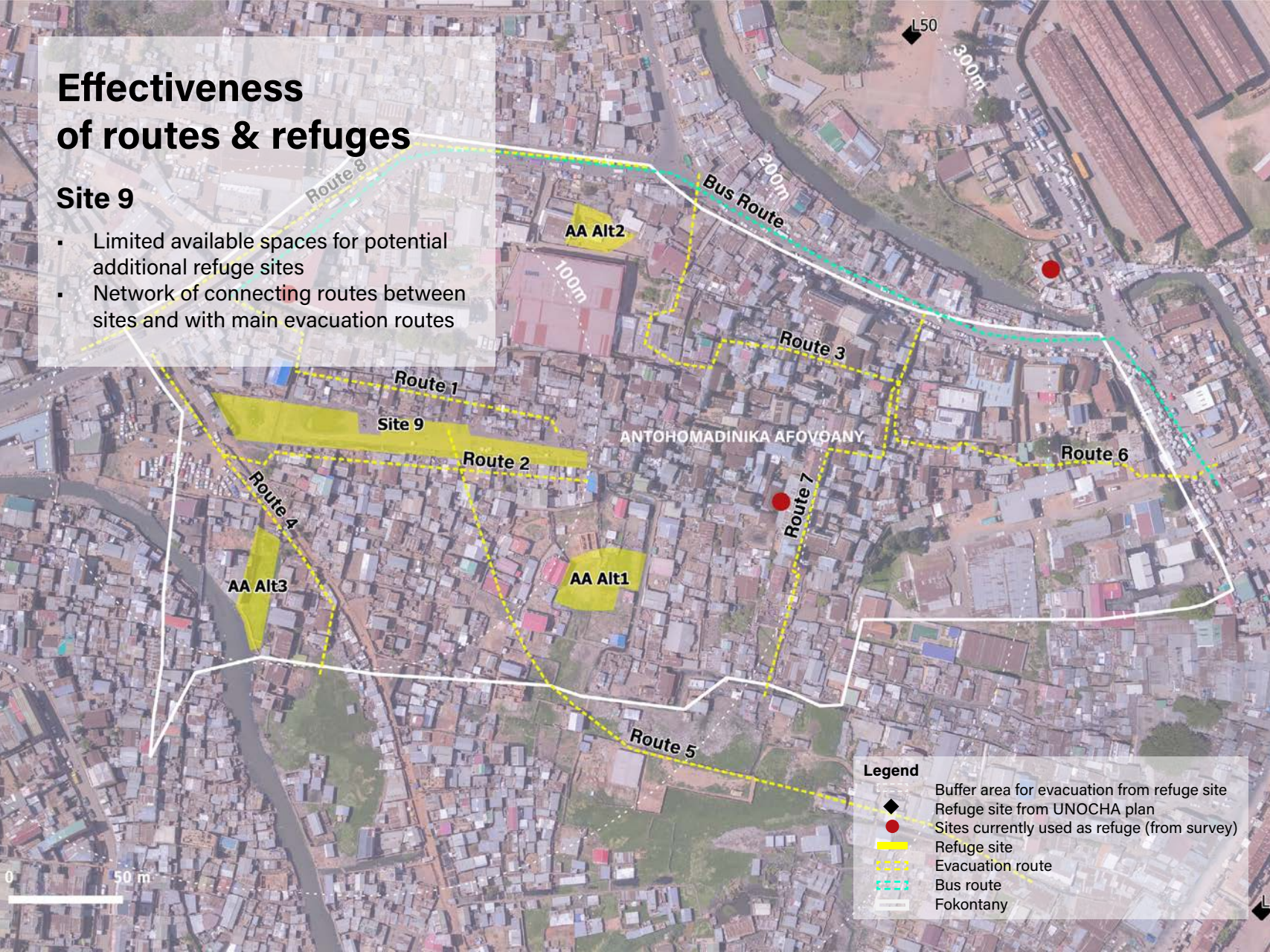
- Limited available space for additional potential refuge sites
- Connecting routes to main evacuation routes



Effectiveness of routes & refuges

Site 9

- Limited available spaces for potential additional refuge sites
- Network of connecting routes between sites and with main evacuation routes



Effectiveness of selected NbS

- We developed a plan for each site, and tested the proposed measures in terms of their **water storage capacity**, contribution to **heat stress reduction**, and contribution to **water quality improvement**.
- The AST (*https://antananarivo.crctool.org/en/*) was used to conduct the assessment, providing an estimation of the impact of each measure
- In addition, we assessed qualitatively the co-benefits produced by the measures that are part of the plan

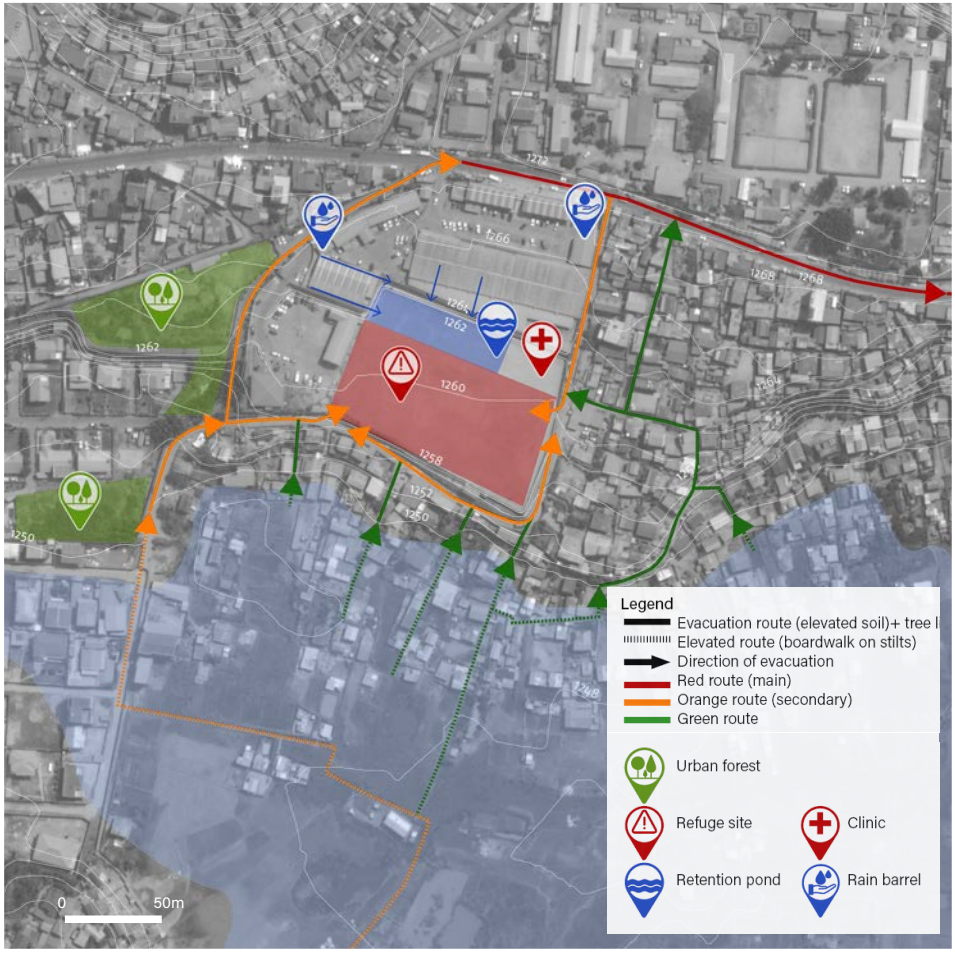
Effectiveness of selected NbS

Site 1

- Not flood-prone, but the surroundings areas on the south are.
- Elevation difference, scarce public greenery, and existence of a public sports facility.

Strategy for this site is based on:

- Manage rainfall locally by (a) **storing rainfall** on site for a later use, (b) **infiltrating rainfall slowly** and as clean as possible, reducing pollution on the subsurface; (c) **draining excess water to swamp**, which has a lower elevation.
- **Decrease erosion** and landslide risks by adding vegetation on the slopes that are unbuilt, especially trees. This also contributes to reduce potential heat stress.
- **Develop a network of safe evacuation routes**, that are elevated and well indicated, from the swampy areas towards safer higher areas.

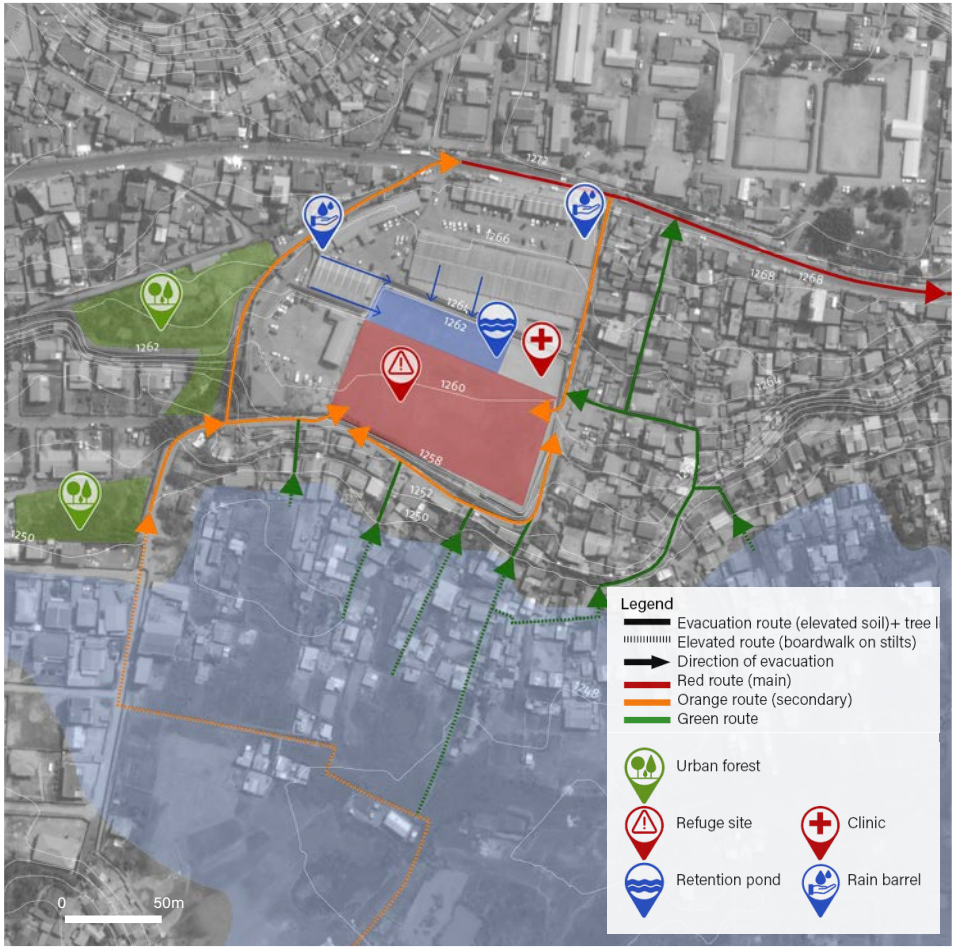


Effectiveness of selected NbS

Site 1

The target set for storage capacity was 6,500m^3, but the measures proposed only reach 3,103m^3.

Measure	Surface (m^2)	Storage capacity (m^3)
Adding green to the streetscape	4,203	841
Retention pond	1,238	495
Urban forest	6,964	1,767
Total		3,103



Effectiveness of selected NbS

Site 3

- Managing rainfall locally by upgrading the drainage system using NbS and **increasing the surface water storage** capacity. At the same time, the design should prevent further densification of this area.
- Increasing the storage capacity of the site by creating **retention ponds** at different locations, that increase surface water storage
- **Storing rainfall** on site for a later use
- **Storm water runoff conveyance** using bioswales along green evacuation routes
- **Infiltrating rainfall** slowly and as clean as possible, reducing pollution on the subsurface
- Decrease heat stress by increasing the surface covered by vegetation and water.
- On empty lots, create elevated refuges that are safe from floods for on-site refuge (phase I of evacuation plan)

Effectiveness of selected NbS

Site 3

The target set for storage capacity was 9,700m^3, but the measures proposed only reach 3,209m^3.

Measure	Surface (m^2)	Storage capacity (m^3)
Adding green to the streetscape	12,134	1,624
Bioswale	1,673	495
Retention pond	52,541	763
Urban forest	1,527	305
Total		3,209

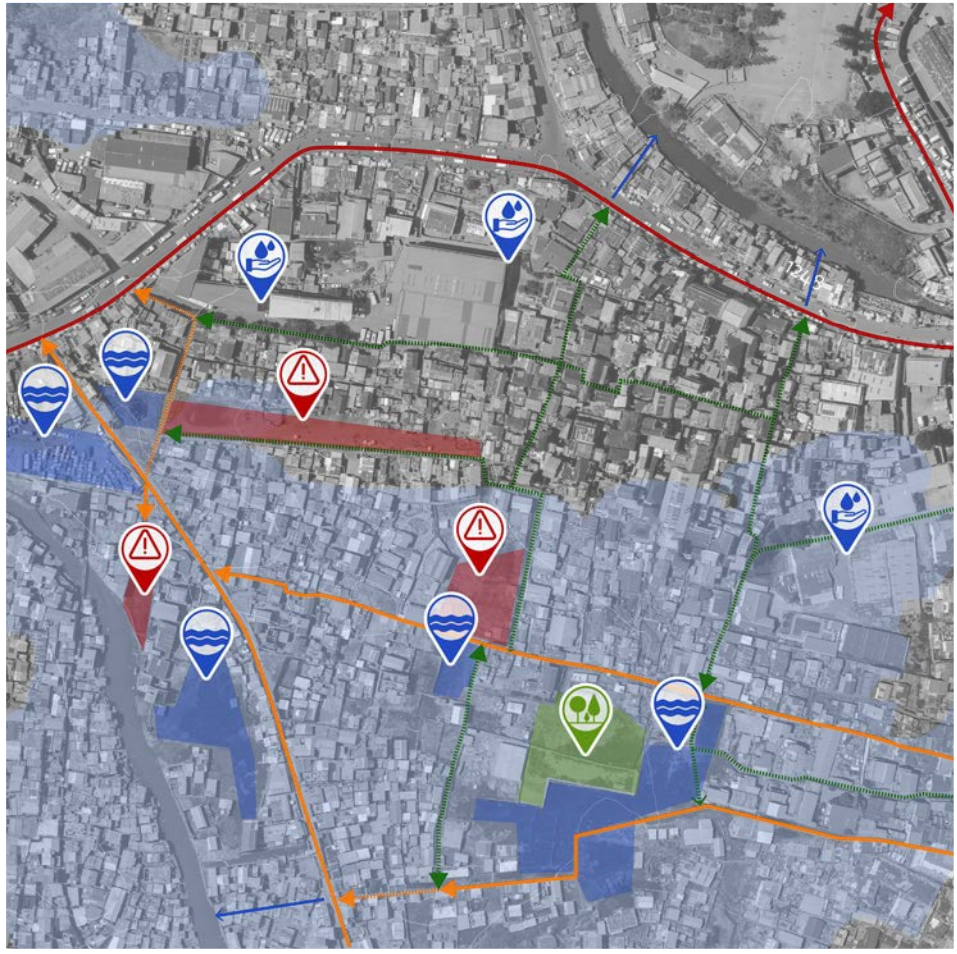
Effectiveness of selected NbS

Site 9

- Limited open spaces, proximity to the C3 canal, and increasing informal settlements

Strategy based on:

- **Increasing the storage capacity** (retention ponds at different locations, that increase surface water storage)
- **Storm water runoff conveyance** using bioswales along green evacuation routes
- **Drain the excess water** to the C3 and Adriantany canals
- **Decrease heat stress** (more vegetation and surface water)
- **Elevated refuges on empty lots** (on-site evacuation, phase I)
- **Network of safe elevated evacuation routes** (highlight with trees)

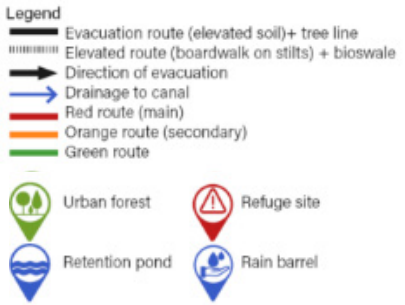


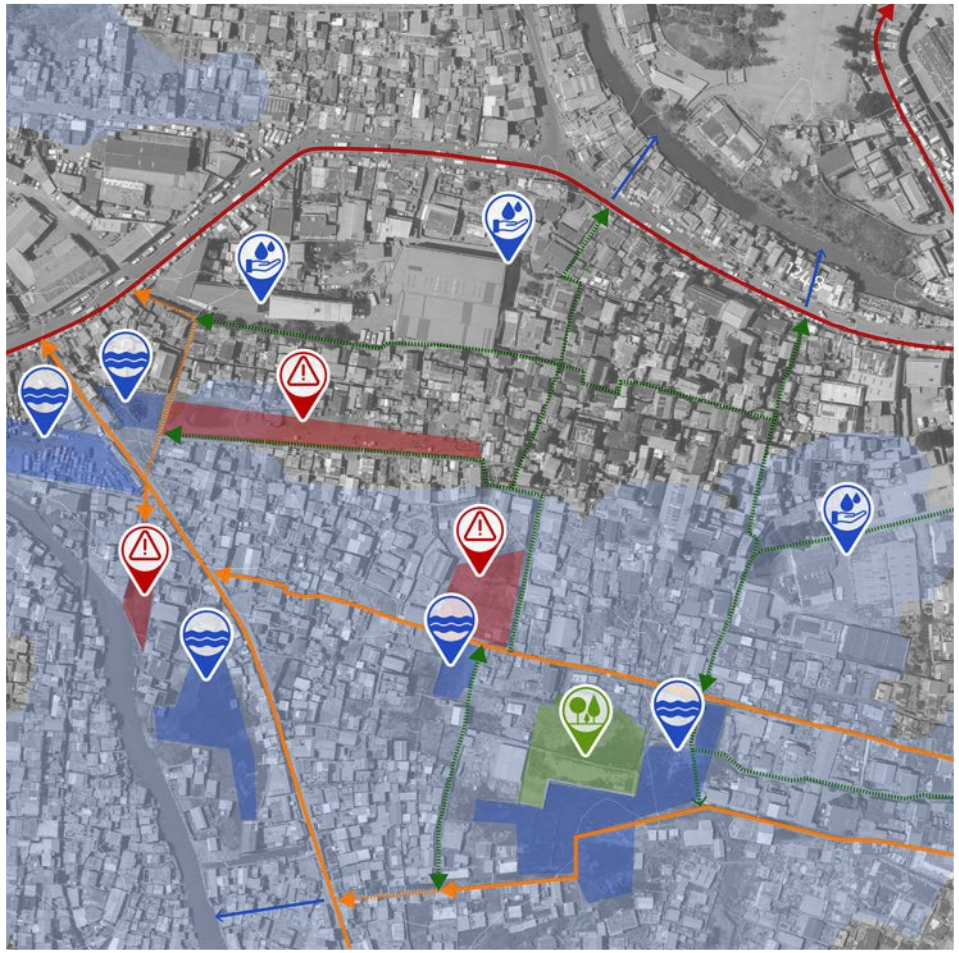
Effectiveness of selected NbS

Site 9

The target set for storage capacity was 9,085m^3, but the measures proposed only reach 4,738m^3

Measure	Surface (m^2)	Storage capacity (m^3)
Adding green to streetscape	13,698	2,130
Bioswale	1,176	412
Retention pond	5,947	1,784
Urban forest	2,058	412
Total		4,738





Effectiveness of selected NbS

Other benefits

- **Improvement of air quality** cannot be quantified, but trees contribute to CO2 sequestration, and therefore to the reduction of pollution. Improvement of air quality has an impact on the health of the community, reducing the medical expenses associated with respiratory diseases.
- **Recreation areas for well-being**. The effectiveness of recreation areas for well-being is estimated based on the added or upgraded green open areas for recreation.
    - Site 1: 11,775m^2
    - Site 3: 8,400m^2
    - Site 9: 4,320m^2
- **Social cohesion**. The creation or upgrading of areas for public use (e.g. for recreation), provides physical spaces that facilitate social cohesion and overall health. Not only the amount of these types of spaces is relevant, but also the quality of the space (de Vries et al., 2013).

Effectiveness of selected NbS

Other benefits

- **Improvement of spatial quality**. Spatial quality is not a priority for the communities, but if a measure improves spatial quality while also improving flood protection, sanitation, waste management and/or mobility, it is expected that it will be valued by the community.
- **Improvement of the local economy**. It is expected that NbS will have a positive impact on the local economy and household economy by:
  - Creating and/or upgrading spaces for trade
  - Creating jobs related to the maintenance of NbS, and the reuse of products that come from it
  - Reducing the cost of water (e.g. rain barrel and graywater reuse reduce the amount of water families need to buy)
  - Promoting neighborhood development

Effectiveness findings

Routes & refuges

- Limited space for the implementation of safe refuges
- Existing open spaces are not always public, so it is unclear if they can be used as refuge
- Further encroachment threatens green and orange evacuation routes

Selected NbS

- Sites 3 and 9 have minimal slope and shallow groundwater level, **reducing opportunities for subsurface water storage**
- Site 1 is not very vulnerable at the moment, but it might be in the future, so interventions could be preventive
- Water storage capacity of the sites is lower than the target set to prevent floods (pluvial), supporting the **ambition to upscale interventions and build a network of NbS** that for flood risk reduction.
- **Trees** are a very low cost measure with **high impact**, that is also very versatile

Plans

Site 1

- Urban forest
- Refuge site
- Green garden/urban farm
- Medical facilities
- Rain barrel
- Retention pond
- Drainage to retention pond
- Trees

Plans

Site 1

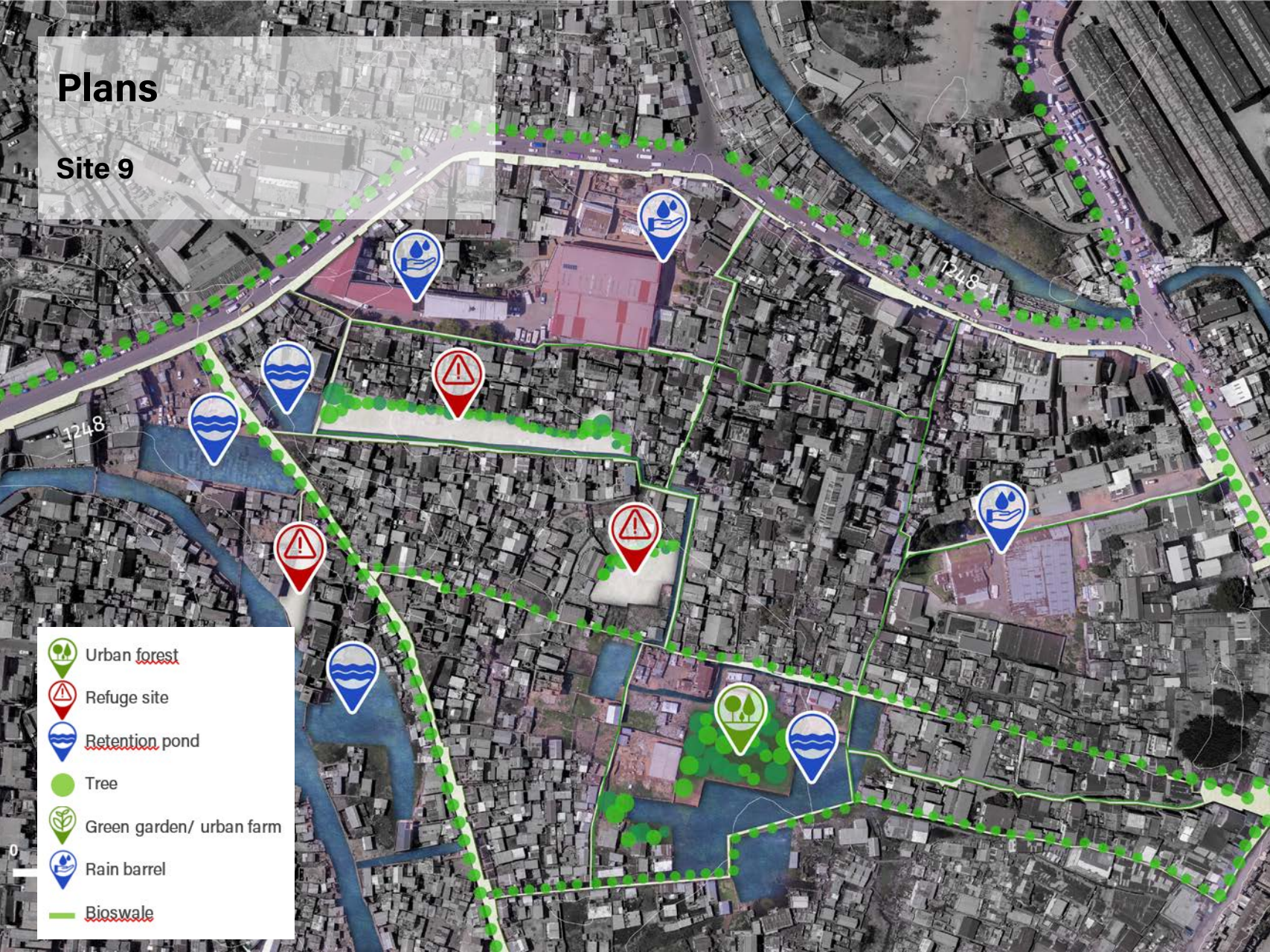
Plans

Site 3

- Urban forest
- Refuge site
- Green garden/urban farm
- Medical facilities
- Rain barrel
- Retention pond
- Bioswale
- Trees

Plans

Site 3


Plans
Site 9
1248
1248
Urban forest
Refuge site
Retention pond
Tree
Green garden/ urban farm
Rain barrel
Bioswale
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Plans

Site 9

Implementation & Maintenance

- **Design with a lifecycle view in mind** (implementation, operation, maintenance)
- Conduct a **collaborative process** with stakeholders from the start
- Think of NbS and design them clearly identifying **what is the measure, what function it provides, and what type of service this offers**.
- Based on the service that a measure provides, identify who is the benneficiary and who willing to pay for the service (e.g. person, organization, government)
- Define who is going to implement the measure and who is going to maintain it. Simple low-tech measures are more likely to be able to be implemented and maintained by the community

Communication

- The communication strategy should be based on **awareness raising and education**.
- This should be an **ongoing activity**, to assure that inhabitants of the city (including new generations and migrants) are educated in the topic.
- This requires a diverse source of funding/financing and a variety of activities that reach the different groups and segments of the population.

Are there risks? What are the risks? Raise awareness about risks and opportunities as part of NGO campaigns door to door, in preschools and schools, in sports and civil organizations.

How do we prevent the risks? What do we do if we are exposed to hazards? Education about disaster risks, NbS and evacuation should be included as part of training programs to relevant stakeholders. It could also be part of high schools and higher education (university).

Prefeasibility findings

- The combination of measures in both public and private areas promotes **different ways for the community to engage**.
- **Simple low-tech measures** require minimum resources for their implementation, and the local capacities for that should be easy to build.
- **Strong governance** is necessary to ensure a transparent, accountable, equitable and inclusive process of building resilience.
- A **community-based implementation** and maintenance approach with a lifecycle, operation and maintenance in mind ensures that the resources available are wisely invested in measures that can perform as expected over time.
- An **ongoing and inclusive communication** strategy allows for the dissemination of clear and timely information
- **Regular monitoring** and evaluation are necessary to ensure the timely implementation of the disaster evacuation plan and identify potential performance issues in advance.

6. Conclusions

Conclusions

- NbS and measures that focus on providing safe evacuation and refuge can be complementary, but often there are trade-offs, so a **prioritization of measures** it is necessary
- Limitations provided by the physical environment (groundwater level, lack of space) restrict the implementation of NbS for flood risk reduction and call for urgent disaster evacuation and refuge measures
- Integration of two different but complementary type of measures, requires also the integration of the institutional structures that allow for their existence

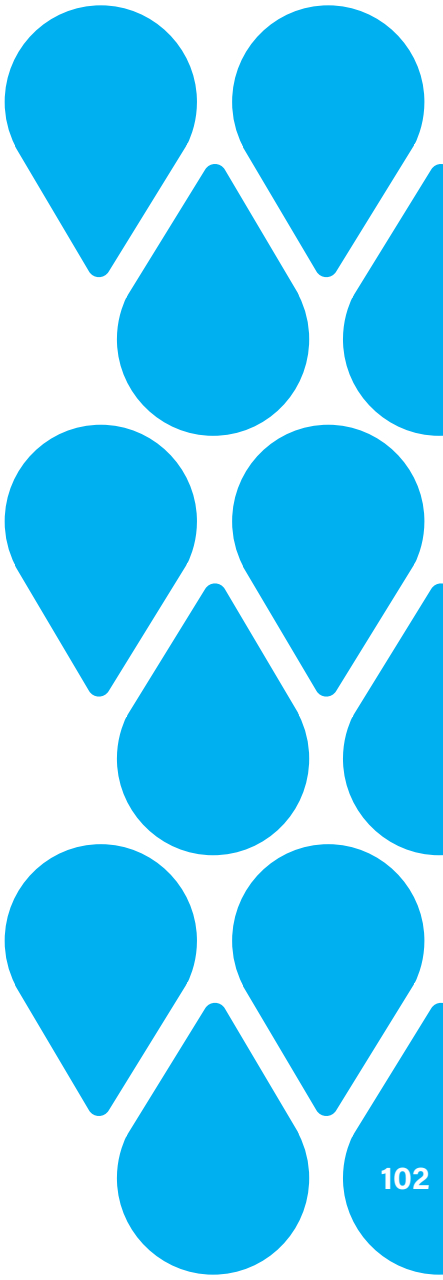
Conclusions

- **The simplest measures can be the most effective and easier to implement**. Implementation of measures can be phased, which could reduce costs and facilitate the implementation process
- Economic impact of NbS can promote the behavioral change of inhabitants who see and understand their direct impact. These requires **adequate and timely communication of the benefits and impact of the measures**
- NbS and complementary measures can contribute to water sanitation and water supply, which is highly appreciated by the community

7. Recommendations

Recommendations

- **Develop an education and awareness program**
- **Communicate the benefits of NbS in terms of the direct impact** they have on people's lives
- **Strengthen the institutional network**. Extend the mandate of the RF2 and assign them as the organization responsible for NbS for water safety and security. By relying on a community-based small-scale organization such as this one, the implementation of small-scale interventions can be more direct.
- **XS measures, XL strategy.** Start small, thinking big. Follow a city-wide strategy for the integration of NbS and disaster evacuation for flood risk reduction, and their implementation.



Recommendations

- **Define stages for the implementation of measures**. You can start small, with community-driven NbS. If successful, the measures implemented could be replicated in other locations in the same neighborhood, growing along the education and awareness capacity of the community.
- **Transfer of skills and knowledge** is necessary so that the lessons learned in one case, can be used by others.
- **Multifunctional and resilient spaces** should be considered when designing any intervention. The challenges and lifestyle from today are not necessarily the ones of tomorrow. Climate change and migration are only some of the variables that will shape the future. It is important that interventions take this into account, and provide spaces that are multifunctional, allowing for different uses, as well as resilient, so they can withstand disasters.

Recommendations

How to select the measures?

We developed a matrix with different measures. According to this matrix, the user can choose which measure or combination of measures are more suitable for a specific location.

We suggest the following steps:

1. **Identify** in which urban typology your site is located
2. **Check** which measures are suitable for that site and compile a list of potential measures
3. **Analyze** the specific characteristics of your location to develop a concept design using some or all of those measures
4. **Test** your concept design using the AST (*https://antananarivo.crctool.org/en/*) to get a first idea of the potential impact of the measures
5. **Prioritize** the implementation of measures according to the urgency to take action and your available resources

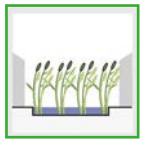
Recommendations

MEASURE	URBAN TYPOLOGY	WHY?
Solar street lights  Awareness & education 	A – The river and embankments B – The canals C – The water basins D – The rice fields E1 – Island city (first occupation) E2 – Island city (latest occupation) F1 – Informal city less densely built F2 – Informal city densely built	**Solar street lights** can be installed everywhere where an evacuation route or refuge exists. **Awareness and education** are important for all the population of Antananarivo, especially the ones located in flood prone areas (e.g. F1, F2). It is also useful to educate the population and prevent them from settling in unsuited areas (e.g. A, B, C and D).
Rain barrels 	B – The canals C – The water basins E1 – Island city (first occupation) E2 – Island city (latest occupation) F1 – Informal city less densely built F2 – Informal city densely built	**Rain barrels** can be implemented everywhere where there are houses, regardless of the size of the roof. Larger roofs can harvest more rainfall. The can provide an additional water supply.

Recommendations

MEASURE	URBAN TYPOLOGY	WHY?
Urban agriculture Private green gardens  	E1 – Island city (first occupation) E2 – Island city (latest occupation) F1 – Informal city less densely built F2 – Informal city densely built	**Small-scale urban agriculture** (vegetable gardens) and **private green gardens** can be implemented in areas where there are houses and barren land, to improve the vegetation cover of the soil.
Urban forest 	E1 – Island city (first occupation) E2 – Island city (latest occupation) F1 – Informal city less densely built F2 – Informal city densely built	On E1 and E2, **urban forests** could decrease landslide risks. On in F1 and F2 they could contribute to limit further densification of informal settlements. In both cases they contribute to infiltrate rainfall and reduce heat stress.
Elevated routes 	B – The canals C – The water basins D – The rice fields F1 – Informal city less densely built F2 – Informal city densely built	On swampy areas, e**levated boardwalks** on stilts allow for the mobility and safe evacuation of pedestrians while allowing the free flow of water

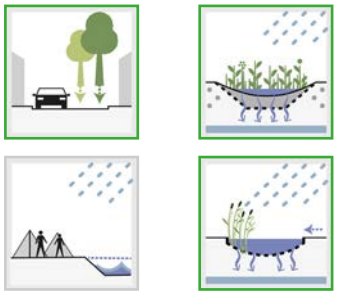
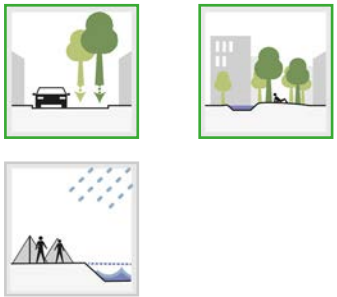
Recommendations

MEASURE	URBAN TYPOLOGY	WHY?
Urban wetland 	D – The rice fields F1 – Informal city less densely built	**Urban wetlands c**ould be implement-ed in swampy areas with more open spac-es available. They can store water on the surface, contribute to biodiversity and improve water quality.
Bioswale + Elevated route  	B – The canals C – The water basins F1 – Informal city less densely built F2 – Informal city densely built	**Bioswales along elevated routes** could be used in mostly flat flood-prone lo-cations, to allow for storm water runoff conveyance while allow-ing for safe evacuation. This could be either through embankments or boardwalks on stilts. The latter is preferred for locations where floods are most likely to occur. This way, the structure of the boardwalk will not interfere with the water flow.

Recommendations

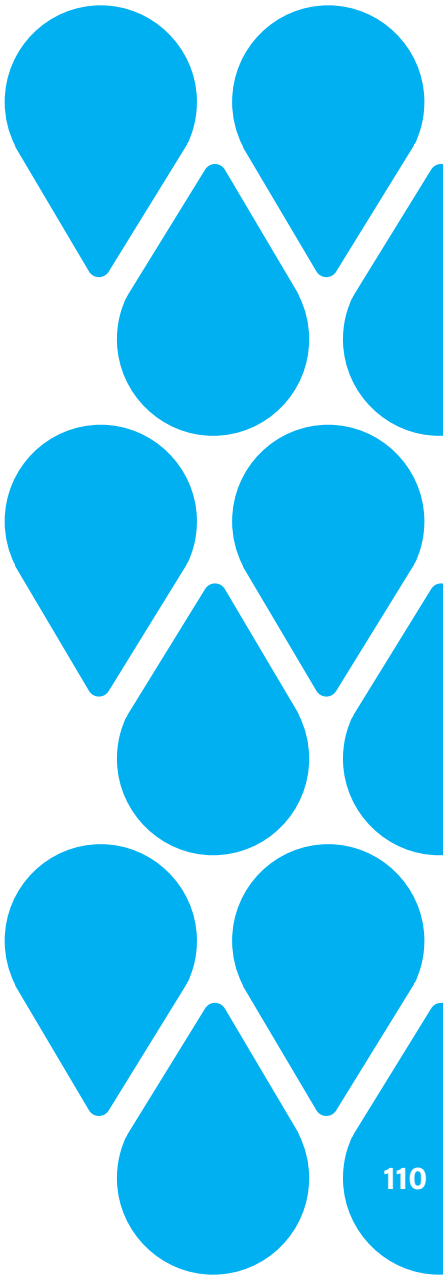
MEASURE	URBAN TYPOLOGY	WHY?
Tree lines 	B – The canals C – The water basins E1 – Island city (first occupation) E2 – Island city (latest occupation) F1 – Informal city less densely built F2 – Informal city densely built	**Trees** can be added in different locations, to mark the edge of a water bodies (B, C), or to mark evacuation routes and the edge of refuges (E1, E2, F1, F2)
Tree lines + Elevated route  	E2 – Island city (latest occupation) F1 – Informal city less densely built F2 – Informal city densely built	**Tree lines along elevated evacuation routes** constitute the main type of evacuation route. They are implemented along main routes (red and orange in the maps we developed) to make them more visible. They are suitable for urban typologies F1 and F2, where flood-prone urbanized areas are located, as well as E2. Even though E2 is elevated, it is located between the floodplains and the higher ground, so the population living in the floodplains, will need to evacuation to E2.

Recommendations

MEASURE	URBAN TYPOLOGY	WHY?
Tree lines + Bioswale + Elevated route + Retention pond 	F1 – Informal city less densely built F2 – Informal city densely built	A network of **tree lines**, bioswales and retention ponds connected by the elevated evacuation routes is suitable for mostly flat flood-prone areas. In this type of location, it is very im-portant to make evacuation routes visible (trees) while also providing enough room for storm water storage and conveyance.
Elevated refuge + Park + Tree line 	F1 – Informal city less densely built F2 – Informal city densely built	**Elevated park-like refuges** surrounded by trees are suitable for mostly flat, flood-prone, and densely populated areas. There, several activities take place at the same time in public spaces but increasing densification with informal settlements constantly reduce the availability of open areas for this purpose.

8. Next steps

(out of the scope of this project)



Next steps

- **Conduct detail studies** in one or more of the selected sites (sites 1,3 or 9). E.g. exact groundwater level, detailed elevation data, soil composition, level of commitment of relevant stakeholders.
- **Refinement**. Based on the results of these studies, refine the plan for the site
- **Testing**. Implement and test the measures that are part of the conceptual design
- **Upscaling**. Based on the results from the testing, upscale to other locations with similar characteristics.

The process of refining/implementing/testing interventions could build towards an approach for the complete PRODUIR area.

Bonus: inspiration images

Plastic garbage

Circular use of resources

3D printer

Boats

Houses (for people in refuge)

Planks for elevated boardwalks

Rain barrel

Inspiration

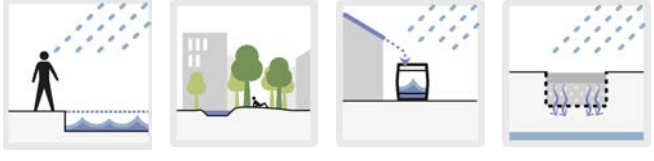
Collection and recycling of plastic will reduce pollution. Espcially if the recycling is done within the PRODUIR area, it will also provide income.

The products that are made of the recycled material can be used in the area, for instance as planks to make board walks, or as water barrels to collect rainwater.

Inspiration

Before

Inspiration



After

Inspiration

After

Inspiration

Before

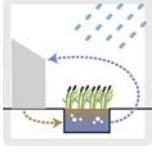
Inspiration

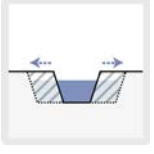
After

Inspiration

Before

Inspiration





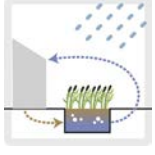
extra water surface to increase water storage

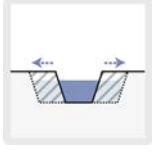
Before

Inspiration

Before

Inspiration





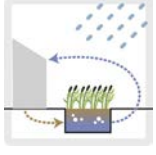
extra water surface to increase water storage

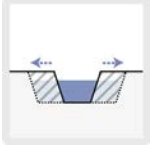
After

Inspiration

Before

Inspiration





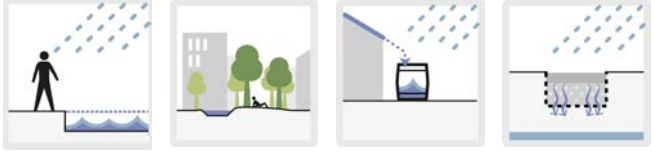
extra water surface to increase water storage

After

Inspiration

Before

Inspiration



After

Inspiration

Before

Inspiration

After