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Prefeasibility report

Study of green infrastructure solutions and disaster evacuation planning and design to mitigate flood risk and strengthen resilience

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Study of green infrastructure solutions and disaster evacuation planning and design to mitigate flood risk and strengthen resilience

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Prefeasibility report

Study of green infrastructure solutions and disaster evacuation planning and design to mitigate flood risk and strengthen resilience

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Executive Summary

The inhabitants of Antananarivo, in Madagascar, are currently struggling with diverse water-related issues, like pluvial floods and water pollution, which are particularly damaging for vulnerable communities within the city. The Government of Madagascar acknowledges these issues and has signed a Country Partnership Framework with the World Bank, to address them. As part of this agreement, the PRODUIR (Integrated Urban Development and Resilience Project) is being implemented between 2018 and 2023.

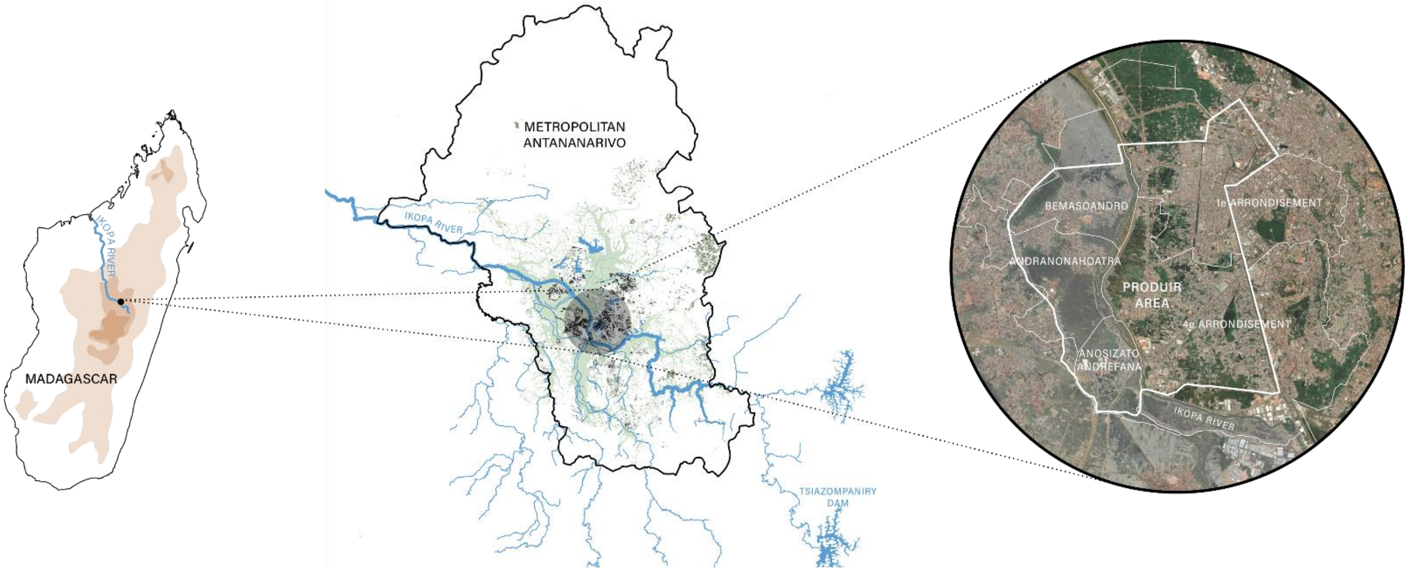


Figure 1. Project location: (left to right) in the context of the highlands of Madagascar, the Metropolitan area of Antananarivo and the city scale.

The project development objective of PRODUIR is to enhance urban living conditions and flood resilience in selected low-income neighborhoods of Antananarivo, located predominantly along the floodplains of the Ikopa river. This study contributes to this objective by focusing on the design and assessment of Nature-based solutions (NbS) for disaster evacuation and flood risk reduction.

The process

The study was organized into four tasks – inception, diagnostic, scenario building and synergies and prefeasibility – which resulted in a city strategy, plans for three pilot sites and recommendations for the implementation and upscaling of those pilots. The study also included continuous stakeholder and community engagement, to ensure the robustness of the study.

During the **inception**, we defined the methodology, approach, and activities of the technical assignment, as well as the community engagement activities, where we discussed with stakeholders to reach a shared understanding of the problem. Besides, we conducted the first field visit, to get insight into the project area.

Then, we conducted the **diagnostic**, where we aimed to understand the current situation, identify challenges and opportunities, and foresee potential solutions. The diagnostic covered: the analysis of the water system in relation to pluvial and fluvial flooding; the exploration of the challenges the city is coping with; plans in other countries to reduce flood risk and improve disaster evacuation, including best practices; and potential interventions for Antananarivo. From the diagnostic, we concluded that to reduce flood risk in the floodplains of Antananarivo, we need to produce a **strategic, versatile, multiscale and upscalable intervention**, able to increase the storage and discharge capacity of the area. This should include **local capacity building and raising awareness** in the community. Following the diagnostic, we worked with **scenarios and synergies**, to explore how different measures and sites could be part of a disaster evacuation plan

After, we worked on **scenario building and synergies**, exploring how the potential measures and locations identified during the diagnostic could best address the challenges in the area as part of a disaster evacuation plan. We focused on on-site and off-site refuges, connected by a network of evacuation routes, where NbS and other complementary measures could be implemented. The main findings from that process were that: a) scenario **are complementary** and can be considered as different phases of one overarching plan, and b) **refuges and evacuation routes form a network of NbS** that can start on a small scale but can extend to cover the entire project area.

Finally, we conducted the **prefeasibility** assessment, aiming at understanding how and where the measures previously studied could be implemented, and what would be needed for it. This, to **develop a project-wide approach, to guide stakeholders at different scales in the implementation and upscaling of NbS and complementary measures for flood risk reduction and disaster evacuation**. We studied preselected sites, leading to the selection of three pilot sites (**Figure 2**). We analyzed the three sites in-depth and assessed the effectiveness of various measures, both NbS and others, which we used to develop a plan for each one of the sites. We also developed design guidelines for the upscaling of these pilots, as well as general strategies for the implementation, maintenance, communication and monitoring of the measures. The main conclusion from this prefeasibility assessment is that **complex challenges should be addressed by simple solutions that are community-based, easy to implement and to replicate**. Moreover, **education and a suitable governance structure** are essential for the design, implementation and maintenance of the successful low-tech intervention for flood risk reduction and disaster evacuation.

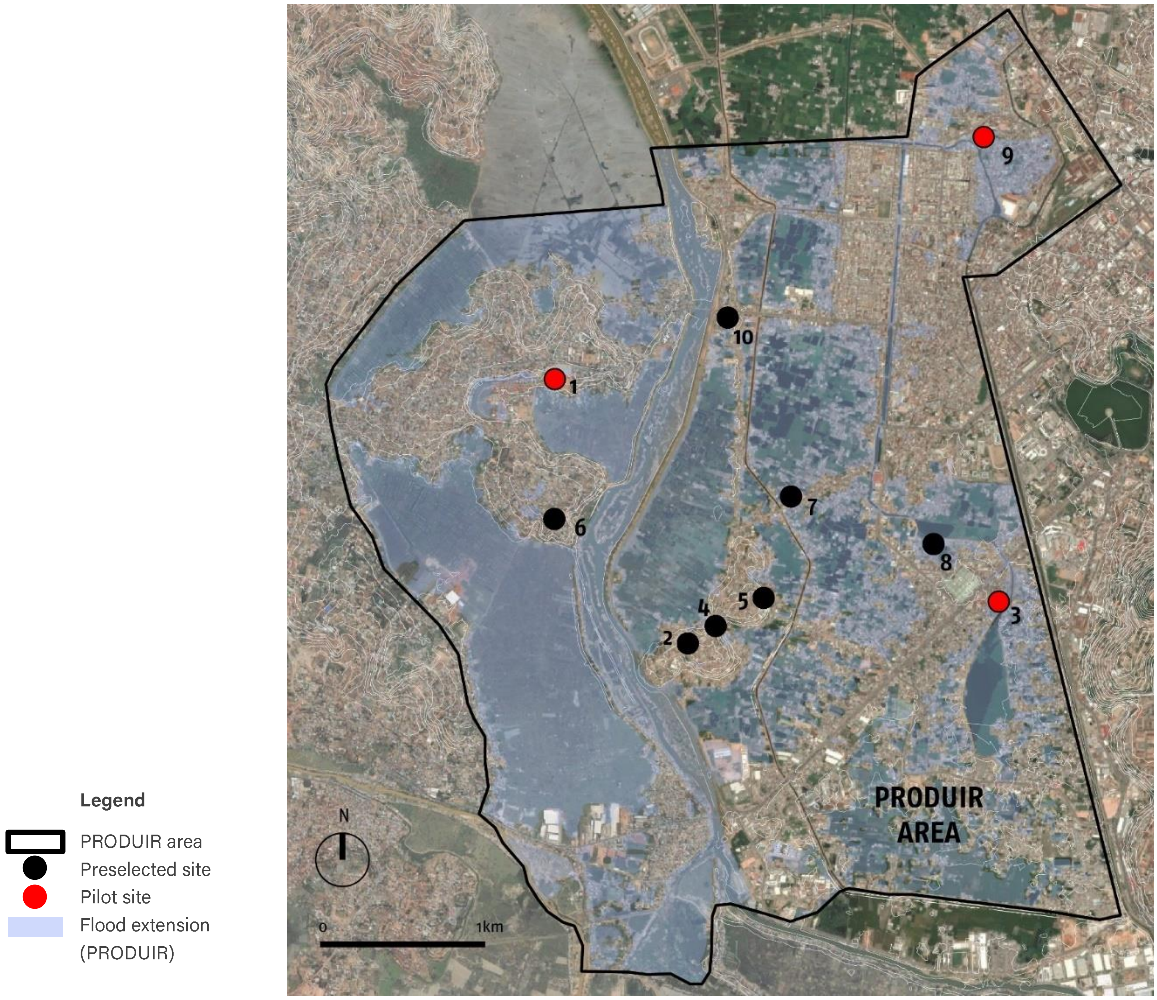


Figure 2. Map of the ten preselected sites in relation to the flood extent from PRODUIR.

The results

Evacuation and refuge strategy

Based on the findings from previous phases of this study, we developed a comprehensive and integrated evacuation and refuge strategy, which served as the framework for the pilot plans. The evacuation and refuge strategy includes the on-site and off-site refuges, a network of evacuation routes, and potential off-site refuges outside the PRODUIR area. The plan has three distinctive phases that respond to the severity of the flood.

Phase I of the plan focuses on evacuation to on-site locations. During this phase, all ten selected sites can work as an on-site refuge. Evacuation starts with green routes that connect groups of houses to the orange routes. As much as possible, 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 (embankments), or boardwalks on stilts. The orange routes connect to red routes (main routes). Red routes connect the different refuge sites and off-site locations. **Phase II** of the plan focuses on evacuation to off-site locations within the PRODUIR area. Some selected sites double as both on-site and also off-site refuge for citizens of different fokontany. Finally **phase III** covers the evacuation to off-site locations outside the PRODUIR area. This phase is only necessary if the flood is so severe, that it is expected that people will have to be relocated for several weeks. Off-site locations for phase III are outside the study area, however, we suggest potential sites based on their capacity to harbor people in a large open area, connectivity and elevation. Potential locations for off-site refuge during phase III are the Ecole Normale (Site 11), the botanical garden (Site 12) and the University of Antananarivo (Site 13).

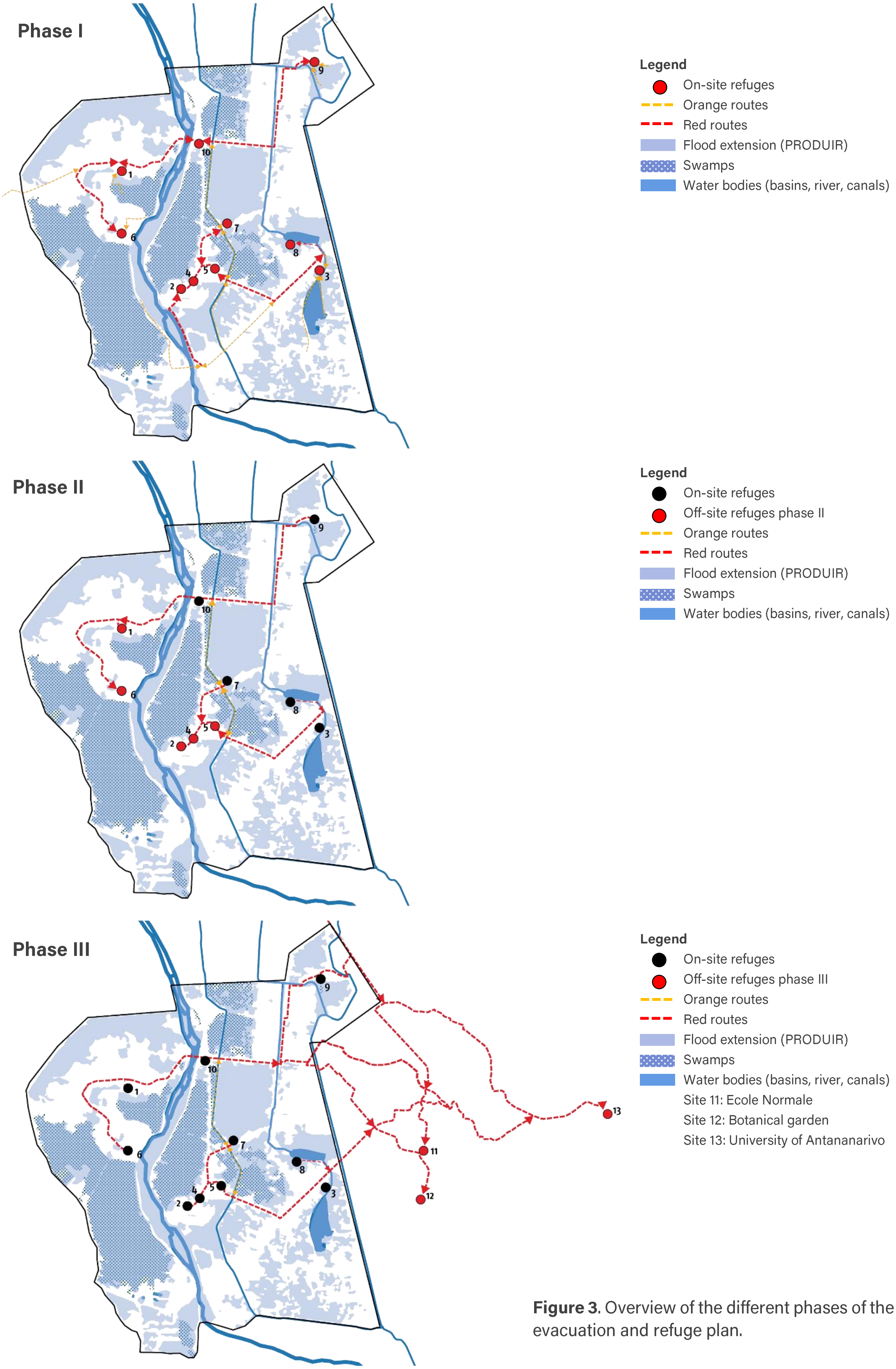


Figure 3. Overview of the different phases of the evacuation and refuge plan.

Pilot sites

Following the design of the evacuation and refuge plan, we focused on three pilot sites. These are sites 1, 3 and 9, which we consider are representative of a larger situation. There are particular challenges and specific characteristics for each site, which define the type of solutions that we envision. We developed a plan for each site, combining a series of NbS and other complementary measures that aim at improving disaster evacuation and reducing flood risks.

Site 1

Analysis

Site 1 is a refuge site indicated in the UNOCHA plan which is also commonly used by the community, making it a robust refuge option. Even though it is not in a flood-prone area, it is located next to one, so it can have a great impact on evacuation and refuge for the surrounding areas. In addition, it is in a part of the city that is not fully urbanized yet, so there is still great potential for the implementation of NbS. If unplanned urbanization continues, it could make this area more impermeable, preventing adequate infiltration and increasing runoff. In turn, this increases flood risk, especially in areas with lower elevation. Instead, if NbS are implemented, they can stir the process in a direction that decreases risks while maximizing opportunities.

According to these characteristics, we consider that the sense of urgency to implement solutions on this site is low. However, if we take into account the implementation times of NbS and the fact that if nothing is done, future urbanizations will reduce current opportunities for implementation, this is a good time to begin planning for flood resilient interventions in the area. We foresee a good integration of the proposed interventions with the existing evacuation plan from UNOCHA. Moreover, several potential alternative locations in the vicinity could be complementary.

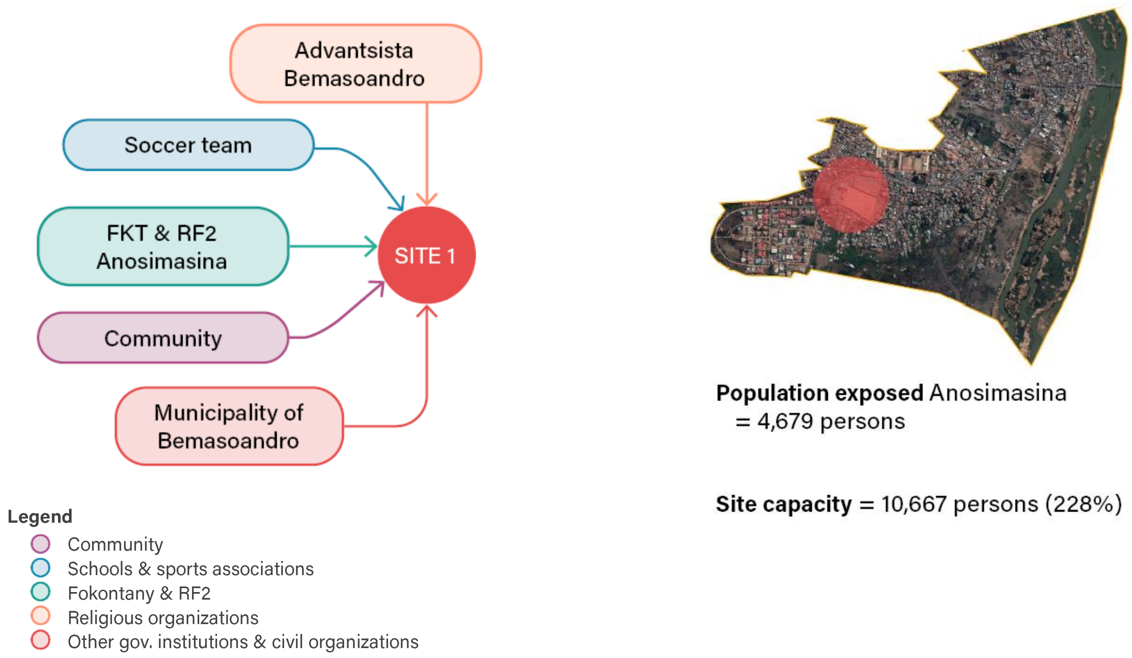
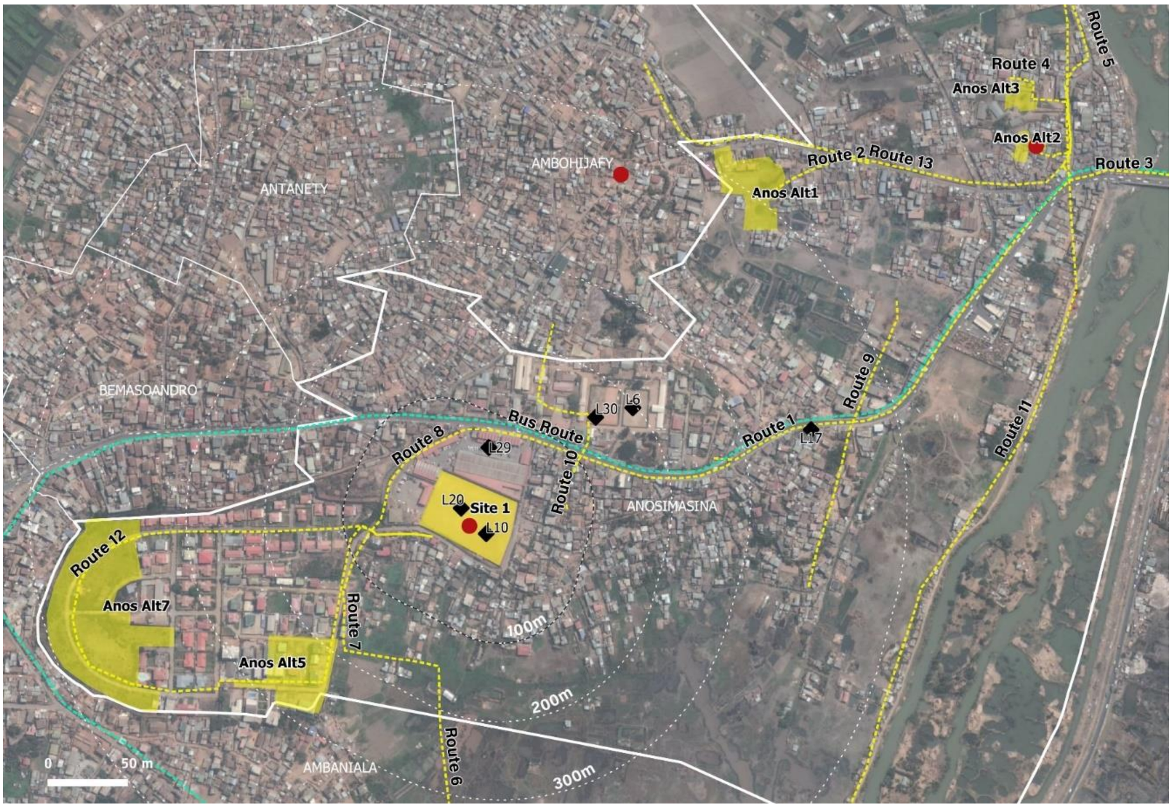


Figure 4. (left) Relevant stakeholders for site 1 on a city scale; (right) population exposed v/s refuge capacity of site 1

In terms of governance, there is a strong involvement of the community in organizing and implementing activities related to neighborhood improvement, even though the fokontany itself it is not very active. This shows the degree of community engagement, which is fundamental for the implementation and maintenance of measures at this location.

According to the household survey results, there is an early warning system in place, focused mainly on flooding. This gives people enough time to evacuate, so we consider an evacuation distance of no more than 500m to a refuge site. Besides the refuge in site 1, it is possible to recommend several other locations for on-site evacuation, although their suitability needs to be further study. During phase II of the evacuation plan, when this site is used for off-site refuge, these additional locations could accommodate the remaining people that exceed the capacity of site 1.



Legend
- Buffer area for evacuation from refuge site
- Refuge site from UNOCHA plan
- Site currently used as refuge (from survey)
- Refuge site
- Evacuation route
- Bus route
- Fokontany

Figure 5. Overview of refuge site 1, evacuation routes, and alternative refuge sites

Plan

Site 1 is in a location that is not flood-prone, but its surrounding areas are. Considering the site characteristics, which include elevation difference, scarce public greenery, and the existence of a public sports facility, the strategy for this site is based on: managing the rainfall locally to reduce the effects of runoff in the surroundings; decrease erosion and landslide risks; and develop a network of safe evacuation routes. The priority is to store the water on-site for later use. When that is not possible, rainfall can be infiltrated slowly and as clean as possible to reduce the pollution of the subsurface. Finally, if storage and infiltration are not possible or not enough, the excess water can be drain to the swamps.

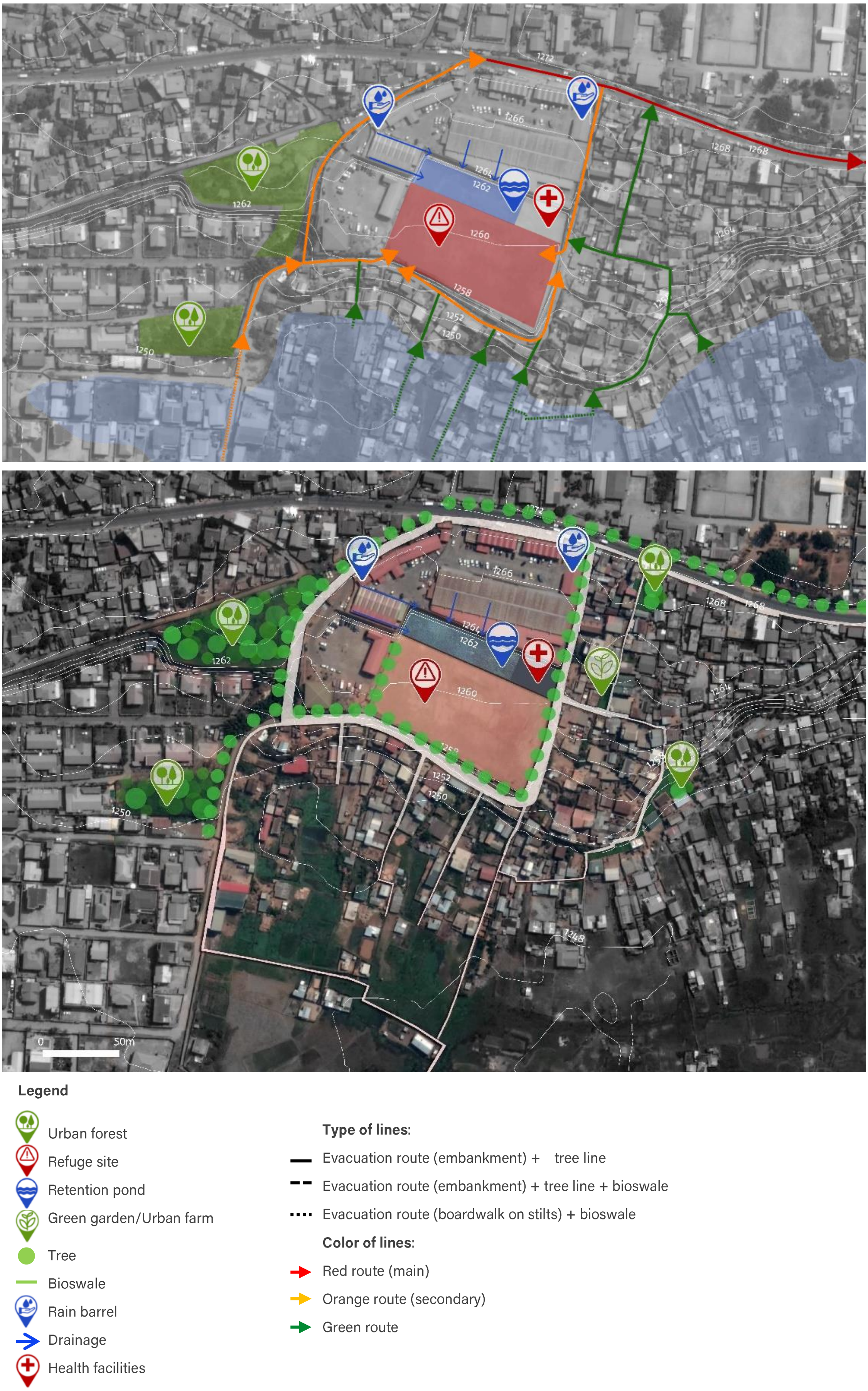


Figure 6. (above) Proposed NbS and complementary measures for flood risk reduction for site 1, including evacuation routes. (below) Plan for site 1

The plan includes the following NbS measures:

Retention pond
Water storage capacity 495m³

Urban forest
Water storage capacity 1,767m³

Trees (lines)
Water storage capacity 841m³

Combined estimated water storage capacity 3,103m³

The plan aims to reduce flood risk by storing and infiltrating water on the site, by means of a retention pond, rain barrels, and increasing the vegetation cover (urban forests and trees). The latter also contributes to reduce landslide risks and reduce heat stress. It also aims to improve disaster evacuation and refuge by developing a network of safe evacuation routes that provide evacuation from the swampy areas towards safer higher areas. The routes are elevated and well indicated with trees. In addition, we make use of popular recreation areas such as the soccer field, to boost awareness initiatives and develop a community-based implementation and maintenance arrangement. For example, the retention pond next to the soccer field could be used to generate awareness in the community about the benefits of rainwater harvest.

Figure 7. Soccer field as refuge site. The soccer field has been constructed as a terrace on the slope, with its surroundings at a lower elevation, except for the buildings and road on the north.

Figure 8. Boardwalk on stilts are suggested on the areas with lower elevation

Site 3

Analysis

Site 3 has several similar characteristics to site 9, but with a distinctive additional opportunity: there is a large empty site with the potential of becoming a refuge site, next to a basin that will be dredged and renovated in the short term. We believe that including this site could be useful to provide recommendations for the renovation project that will take place in the basin. The site is located in a centrally-located, low-lying and very flood-prone urbanized area that suffers from increasing sanitation problems. In spite of its central location, accessibility in some areas within this site is poor. The groundwater level is shallow, so \there is not a lot of space in the subsurface to store water. After heavy rainfall, this causes the water to stagnate in multiple locations. There are some open spaces with the potential to be used for the implementation of NbS, but only one of them is large enough to be used as a refuge site. That site has a temporary use as a marketplace, but it has been urbanized in recent years. Given its strategic and central location, this site could serve several purposes, catering to the needs of a large group of people, both from Mandrangobato I as well as the surrounding fokontany. This site is also categorized as an assembly point in the UNOCHA plan.

According to these characteristics, we consider that the sense of urgency to implement solutions on this site is high. Drainage is not optimal, because of the unorganized disposition of the houses, the presence of solid waste in most existing ditches, and the subsurface characteristics. The increase in population (including migrants) could likely increase the production of solid waste, worsening this problem.

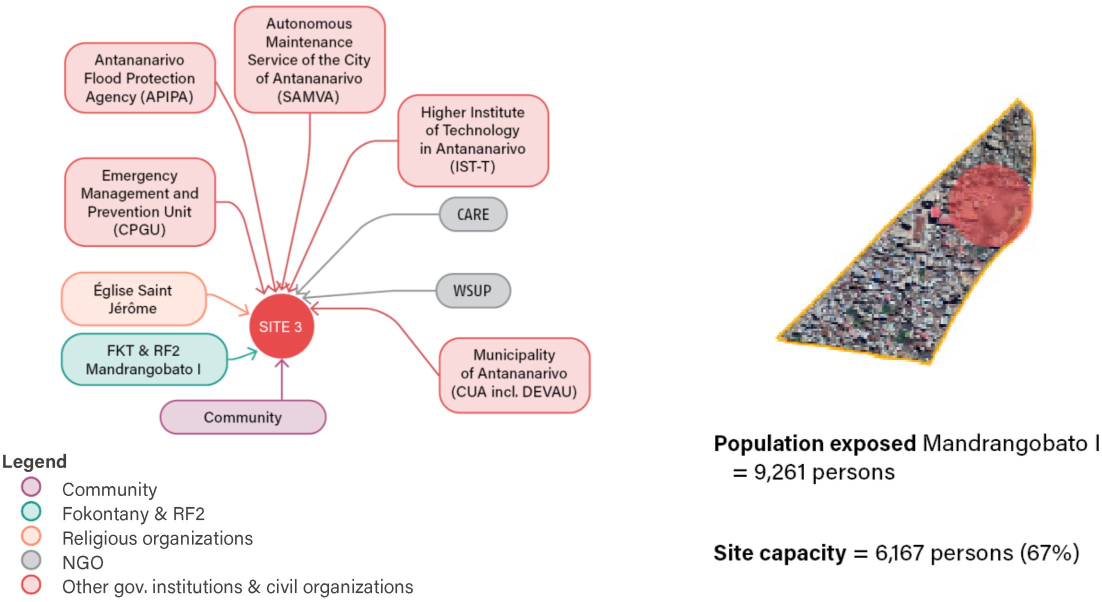
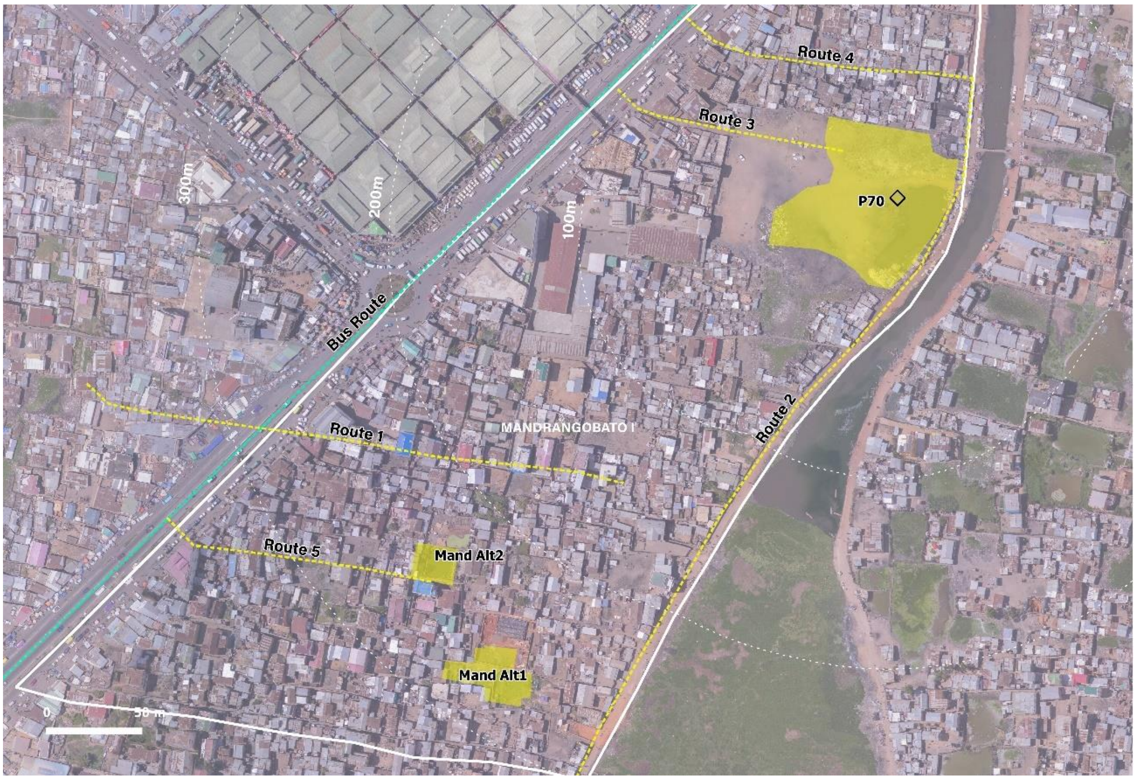


Figure 9. (left) Relevant stakeholders for site 3 on a city scale; (right) population exposed v/s refuge capacity of site 3

In terms of governance, there is a strong engagement of the community and local institutions which is fundamental for the implementation and maintenance of measures at this location. The fokontany of Mandrangobato I is active and committed, as well as the RF2, and the population is aware of the existing risks and interested in improving their current environment.

The household survey did not cover this area. However, based on survey responses from nearby areas together with the two workshops, it is possible to identify other potential evacuation routes and alternative refuges within a radius of 300m that could accommodate part of the exposed population, although their suitability needs to be studied further. The main evacuation route that is also a bus route is located no more than 200m from all the propose refuge sites. During phase I of the evacuation plan, this site can be used for refuge. However, during phase II people would need to evacuate to other safer locations.



Legend

Buffer area for evacuation from refuge site
Refuge site from UNOCHA plan
Refuge site
Evacuation route
Bus route
Fokontany

Figure 10. Overview of refuge site 3, evacuation routes, and alternative refuge sites

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Plan

Site 3 is in a location that is flood-prone, as well as its surroundings. Considering the site characteristics, which include minimal elevation difference, scarce public-use greenery and the existence of a multipurpose open space, the strategy focuses on: managing rainfall locally to mitigate the impact of floods and develop a network of safe evacuation routes. The priority is to increase surface water storage complemented by the upgrading of the drainage system towards the Anosibe basin.

Figure 11. (left Proposed NbS and complementary measures for flood risk reduction for site 3, including evacuation routes. (right) Plan for site 3

The plan includes the following NbS measures:

Retention pond	Urban forest	Bioswale	Trees (lines)
Water storage capacity 763m³	Water storage capacity 305m³	Water storage capacity 495m³	Water storage capacity 1,624m³

Combined estimated water storage capacity 3,209m³

The plan aims to reduce flood risk by increasing the surface water storage capacity of the site using retention ponds at different locations together with bioswales to slowly infiltrate rainfall as clean as possible or alternatively conveying surface runoff towards the Anosibe basin. The overall increase of the surface covered by water and vegetation, using bioswales, lines of trees, urban forests and private gardens also contributes to reduce heat stress. In addition, trees are used to delineate refuge areas, preventing further encroachment. The main evacuation routes (red and orange) and refuges are elevated and delineated by trees, so they are clearly visible and safe during phase I of the evacuation. The secondary routes (green) are elevated on stilts, with a bioswale next to them which allows the free flow of water in case of extreme floods. A robust governance structure should be developed for the implementation and maintenance of NbS at these locations, that combines the local institutions and the community. Interventions on this site make use of a well-connected area, that is popular and easily recognizable by the community, as a refuge site. By implementing multiple and compatible programs that combine basic services (e.g. medical facilities, disaster evacuation) with temporary uses (e.g. hawker stalls, recreation), a robust governance structure should be developed to ensure the implementation and maintenance of the measures at this location.

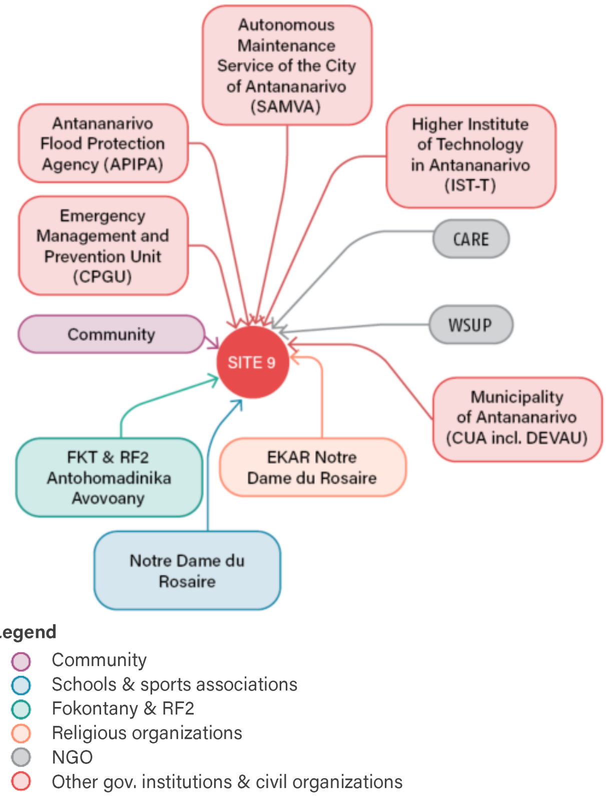
Figure 12. East-West view of site 3, including an elevated route along the basin. This was a preliminary design, and the type of elevated route was later changed to an embankment.

Figure 13. Overview of various improvements to the site for evacuation and refuge for site 3

Site 9

Analysis

Site 9 is located in a flood-prone, well connected and densely urbanized area, that suffers from sanitation problems and where there is an urgent need to provide safe and expedite disaster evacuation, but few opportunities to do so. These opportunities are threatened by the ongoing encroachment and the insufficient infrastructure, such as bridges in poor condition to cross the C3 canal. Drainage is not optimal, because of the unorganized disposition of the houses, the presence of solid waste in most existing ditches, and the subsurface characteristics with shallow groundwater levels. The increase in population could likely increase the production of solid waste, worsening the problem. Strategic measures at this point could have a positive impact on disaster evacuation and flood risk reduction. There some open spaces with the potential to be used for the implementation of



Population exposed Antohomadinika Afovoany
= 3,030 persons
Site capacity = 2,027 persons (67%)

Figure 14. (left) Relevant stakeholders for site 9 on a city scale; (right) population exposed v/s refuge capacity of site 9

NbS, but this constantly changes due to the increasing densification of the area by means of informal settlements, including migrants from other regions of the country. According to these characteristics, we consider that the sense of urgency to implement solutions on this site is high.

In terms of governance, there is no information about the level of engagement and participation of the fokontany and RF2. However, we identified several potentially relevant institutional stakeholders, such as religious and educational organizations.

According to the household survey results, there are several locations currently used as refuge in a radius of 300m. The main refuge together with the alternative refuges have the adequate capacity to accommodate the population exposed in this fokontany during phase I of evacuation. However, during phase II people would need to evacuate to other safer locations.

Figure 15. Overview of refuge site 9, evacuation routes, and alternative refuge sites

Plan

Site 9 is in a location that is flood-prone, as well as its surroundings. Considering the site characteristics, which include minimal elevation difference, scarce open spaces and public greenery, the strategy focuses on: managing rainfall locally to mitigate the impact of floods and develop a network of safe evacuation routes. The priority is to increase surface water storage complemented by the upgrading of the drainage system towards the C3 and the Adriantany canals, and develop a network of safe evacuation routes.

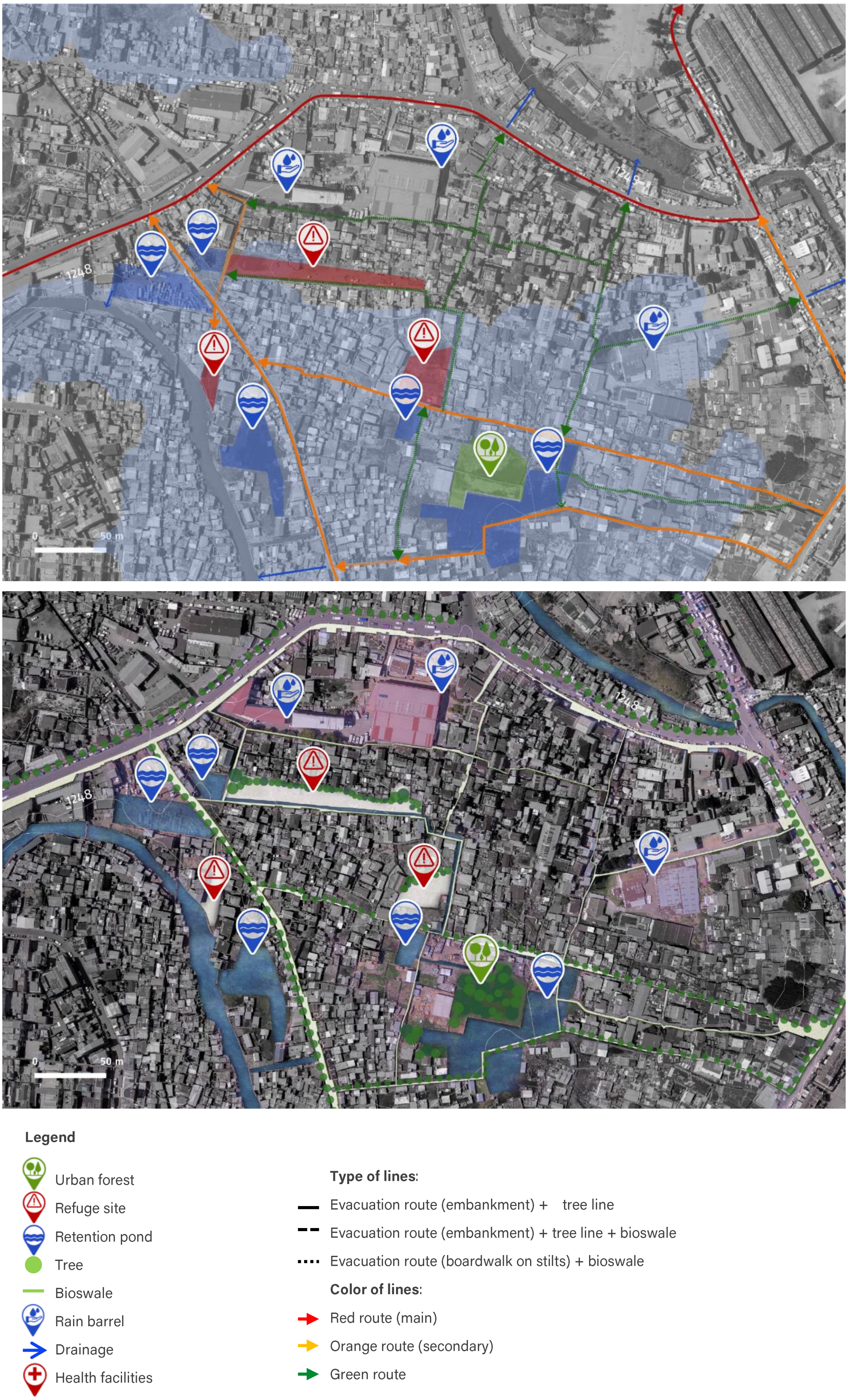


Figure 16. (above) Proposed NbS and complementary measures for flood risk reduction for site 9, including evacuation routes. (below)) Plan for site 9

The plan includes the following NbS measures

Retention pond	Urban forest	Bioswale	Trees (lines)
Water storage capacity 1,784m^3	Water storage capacity 412m^3	Water storage capacity 412m^3	Water storage capacity 2,130m^3

Combined estimated water storage capacity 4,738m^3

The plan aims to reduce flood risk by increasing the surface water storage capacity of the site using retention ponds at different locations together with bioswales to slowly infiltrate rainfall when possible, otherwise conveying surface runoff towards the main canals. The overall increase of the surface covered by water and vegetation, using bioswales, lines of trees and urban forests also contributes to reduce heat stress. In addition, trees are used to delineate refuge areas, preventing further encroachment. The main evacuation routes (red and orange) and refuges are elevated and delineated by trees, so they are clearly visible and safe during phase I of the evacuation. The secondary routes (green) are elevated on stilts, with a bioswale next to them which allows the free flow of water in case of extreme floods. A robust governance structure should be developed for the implementation and maintenance of NbS at these locations, that combines the local institutions and the community.

Figure 17. Elevated houses and boardwalks on stilts, elevated refuge site, and bioswale. Elevated houses and boardwalks are encouraged as a solution for areas with a low elevation that are more exposed to floods.

Figure 18. Elevated houses including a rain harvesting system, a boardwalk on stilts, and a bioswale

Recommendations

We consider the following key aspects for the implementation of NbS and complementary measures:

1. **Develop an education and awareness program**. There is a need for an ongoing educational and awareness program that allows the community and other stakeholders to understand the risks they are facing and how to address them. This is especially relevant for the migrants from other cities, who might not understand the landscape and the risks they are facing.
2. **Communicate the benefits of NbS in terms of the direct impact they have on people's lives**. E.g. Instead of referring to flood reduction, translate that into the reduction of damage costs; instead of urban agriculture to improve rainfall infiltration, refer to the reduction in the expenses per household.
3. **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. Also, the RF2 is more likely to have a better understanding of the community and their needs. As an organization, the RF2 could collaborate with other relevant organizations, strengthening the institutional network with a bottom-up approach.
4. **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, keeping the lifecycle of NbS in mind. Floods do not happen on the household scale, they happen in the landscape. You can manage water locally, but only up to a certain degree. A comprehensive strategy is needed so that all the small-scale interventions create synergies between each other, as opposed to trade-offs.
5. **Define stages for the implementation of measures**. You can start small, with community-driven NbS. If successful, the measures implemented could be replicated at other locations in the same neighborhood, growing along with the education and awareness capacity of the community. This not only results in more robust interventions but also allows you to phase implementation and maintenance costs of the measures.
6. **Transfer skills and knowledge** about NbS, disaster evacuation, and flood risk reduction, so that the lessons learned in one case can be used by others.
7. **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 resilient and multifunctional spaces, so they can withstand disasters.

How to select NbS and complementary measures

We followed an approach that focused on **sites that are representative, upscalable, and multipurpose**. The aim was to develop a project-wide approach, to guide stakeholders at different scales in the implementation and upscaling of NbS and complementary measures for flood risk reduction and disaster evacuation. More specifically, we recognize that certain combinations of measures are more suitable for certain locations, so we analyzed the characteristics of the area, and identified eight urban typologies. The ten selected sites (**Figure 2**) are representative of the different typologies, so we developed a disaster evacuation plan, using the ten sites as refuges, supported by a network of evacuation routes (**Figure 3**). We envision three different phases of the disaster evacuation plan, according to the severity of the flood.

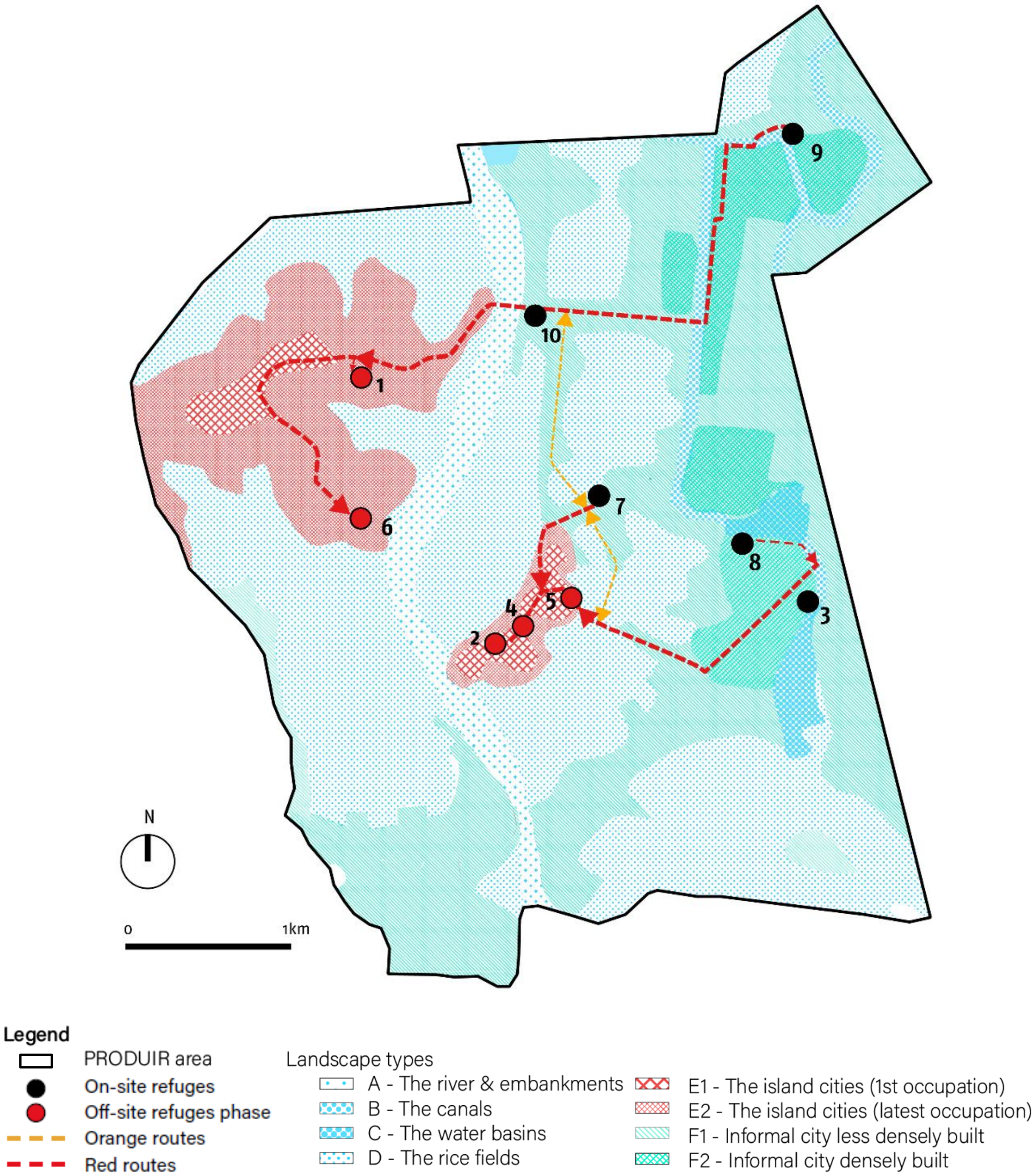


Figure 19. Pilot sites, urban typologies, and evacuation routes during phase II of the evacuation plan.

Each site, according to its characteristics, can serve a specific function as part of the plan, whether is an on-site refuge, or an off-site. Likewise, certain measures are more suitable for certain sites (**Figure Figure 20**), depending on their specific characteristics. Since the ten sites are representative of the different urban typologies, based on the findings from this process, we developed a matrix (**Table 1**) summarizing the recommended types of measures per typology. We understand that within a certain urban typology, there are many different areas, with specific characteristics. However, the matrix serves as a first guide or filter for the selection of measures.

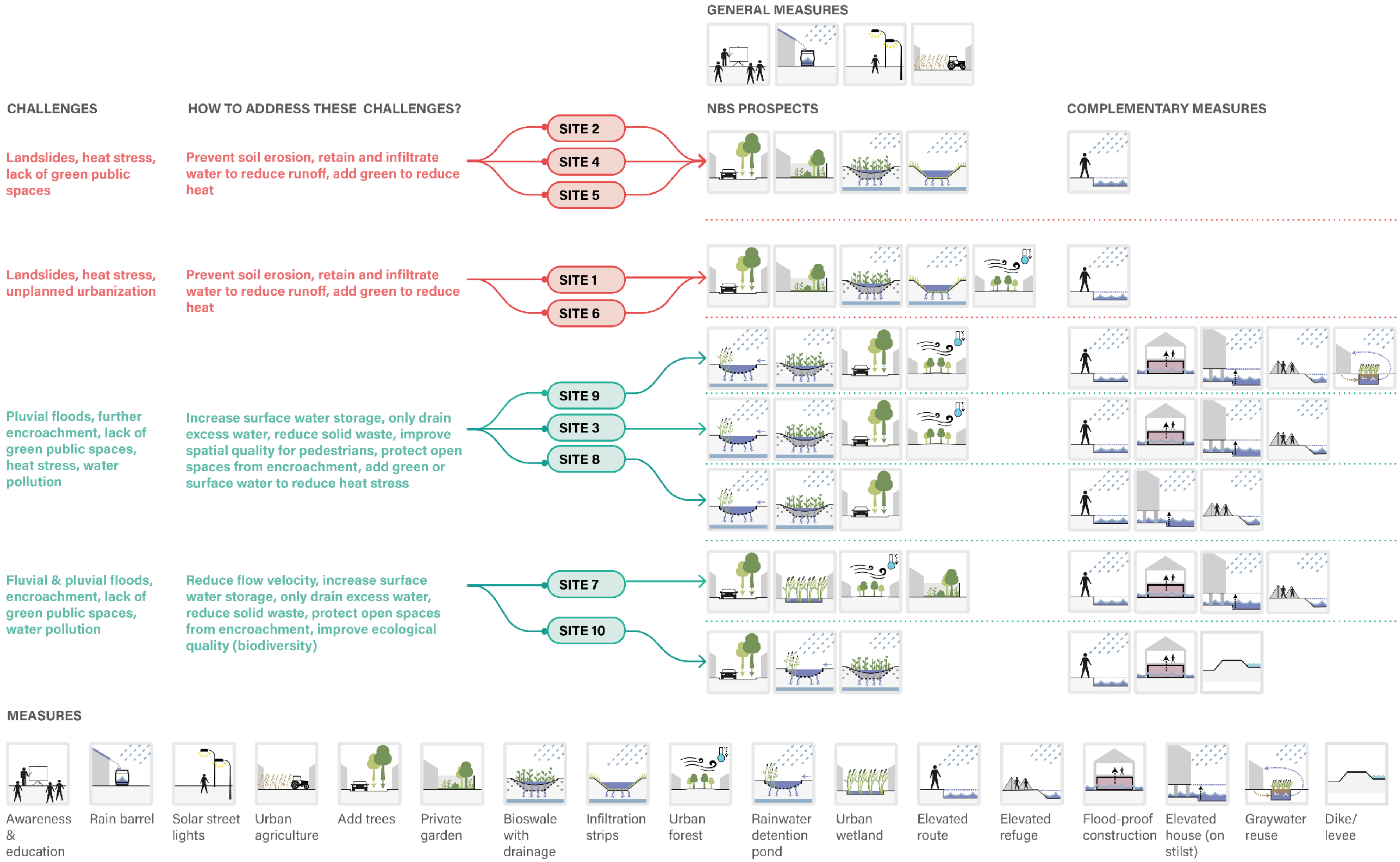
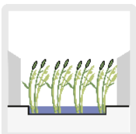
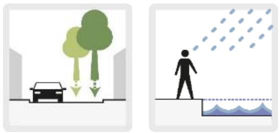
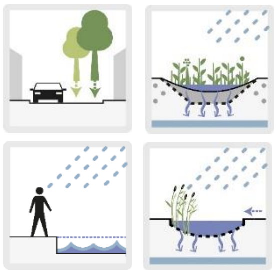


Figure 20. Overview of sites, the challenges they face and the measures that could address them.

Table 1. Matrix with types of measures and urban typologies where they are most suitable

Measure	Urban typology	Why?
Solar street light, Awareness and 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. They can provide an additional water supply.
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. 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, **elevated boardwalks on stilts** allow for the mobility and safe evacuation of pedestrians while allowing the free flow of water
Urban wetland 	**D – The rice fields** F1 – Informal city less densely built	**Urban wetlands** could be implemented in swampy areas with more open spaces 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 locations, to allow for storm water runoff conveyance while allowing 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.
Adding trees 	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 body (B, C), or to mark evacuation routes and the edge of refuges (E1, E2, F1, F2)

Measure	Urban typology	Why?
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 evacuate to E2.
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 most flat flood-prone areas. In this type of location, it is very important to make evacuation routes visible (trees) while also providing enough room for stormwater 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 most 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 reduces the availability of open areas for this purpose.

After this study, we suggest conducting further detailed and site-specific studies, such as the exact groundwater level, detailed elevation data, soil composition and level of commitment of relevant stakeholders for a specific site. According to the results of those studies, the measures could be refined, and tested, and finally upscaled, building towards an approach for the improvement of disaster evacuation and the reduction of flood risks for the PRODUIR area.

Abbreviations and acronyms

AGETIPA	L'Agence d'Exécution des Travaux d'Intérêt Public
APIPA	Autorité pour la Protection contre les Inondations de la Plaine d'Antananarivo
APUM	Association of Urban Professionals in Madagascar
AST	Adaptation Support Tool
BNGRC	National Disaster Risk Management Agency
BPPAR	National Office for Regional Development Projects
CBO	Community-based organization
CPGU	Emergency Management and Prevention Unit
CUA	Municipality of Antananarivo
IST-T	Higher Institute of Technology in Antananarivo
MATP	Ministry of Spatial Planning and Public Works
MEAH	Ministry of Water, Sanitation and Hygiene
MEDD	Ministry of the Environment and Sustainable Development
MNVH	Ministry of New Cities and Housing
NBS	Nature-based solutions
OAM	Order of Malagasy Architects
ONE	National Office of Environment
PIAA	Antananarivo Integrated Sanitation Program
PUDi	Urban Master Plan
PMU	Project management unit
PRODUIR	Projet de Développement Urbain Intégré et de Résilience du Grand Antananarivo
PUDI	Plan d'Urbanisme Directeur
RF2	Water, Sanitation and Hygiene Community Groups (*Rafitra Fikojàna ny Rano sy Fidiovana*)
SAMVA	Autonomous Maintenance Service of the City of Antananarivo
WB	World Bank

Contents

Deltares

Introduction

Antananarivo, the capital of Madagascar and its most populated city, faces several urban challenges. Water-related challenges, such as urban floods and water pollution, are especially relevant since they are interconnected and have a high social, economic and ecological impact. Moreover, they commonly affect some of the most vulnerable communities in the city, namely the inhabitants of informal settlements. Not only they are often the most exposed to hazards because they settle in the floodplains, but they also have limited resources to cope when a disaster hits.

Nature-based Solution (NbS) present an opportunity to address these challenges in a resilient and inclusive way. They are versatile, can be implemented in different scales and contexts, with limited resources, and bring a series of co-benefits that can be appealing for vulnerable populations. Furthermore, during a disaster, they can potentially contribute to an efficient and safe evacuation and refuge for affected communities.

The combination of NbS and certain components of disaster evacuation and refuge have been used in several contexts worldwide. However, best practices that explicitly and purposely combine the two of them are rather scarce.

This report refers to the prefeasibility phase of the project. Chapter 1 of the report provides a summary of the previous phase of this project, that focused on the scenario building and synergies, defining on-site and off-site refuges, and evacuation routes. Chapter 2 provides a detailed review of the site selection process, in terms of landscape, urban characteristics, potential measures, stakeholders and beneficiaries, and synergies with other ongoing projects. This chapter ends with the selection of three sites to perform the prefeasibility assessment. Chapter 3 focuses on assessing the effectiveness of the selected measures per site, in relation to their flood mitigation, environmental and socio-economic impacts. Chapter 4 provides a conceptual design for each of the three sites and presents a set of design guidelines, useful for both the detailed design and the upscaling of measures. This chapter also provides implementation, maintenance, communication and monitoring strategies for the proposed interventions. Finally, chapter 5 presents the main findings, conclusions and recommendations for the general reader, decision-makers and the proponents of NbS for flood protection and disaster evacuation.

1 Summary of the previous phase: scenario building and synergies

The development of scenarios in the previous phase of this project, resulted in one overarching plan, with different phases, according to the severity of the flood. This section summarizes the main aspects of that phase relevant to the understanding of the prefeasibility assessment.

1.1 Approach

The integration of Nature-based Solutions (NbS) and evacuation planning was achieved by looking at **shared locations** and **shared costs**.

These approaches are not restricted to a single hazard or challenge, on the contrary, they actively look for opportunities that link different hazards and challenges in win-win solutions.

SHARED LOCATION

Shared locations refer to the multifunctional land use, where a refuge site and the routes connecting to it, can be used both during floods as well as during normal times. It is beneficial if an area or object can be used for more than one purpose. This also facilitates the funding/financing of that solution, when compared with a single purpose solution. **Figures 1, 2** and **3** show examples of this approach.

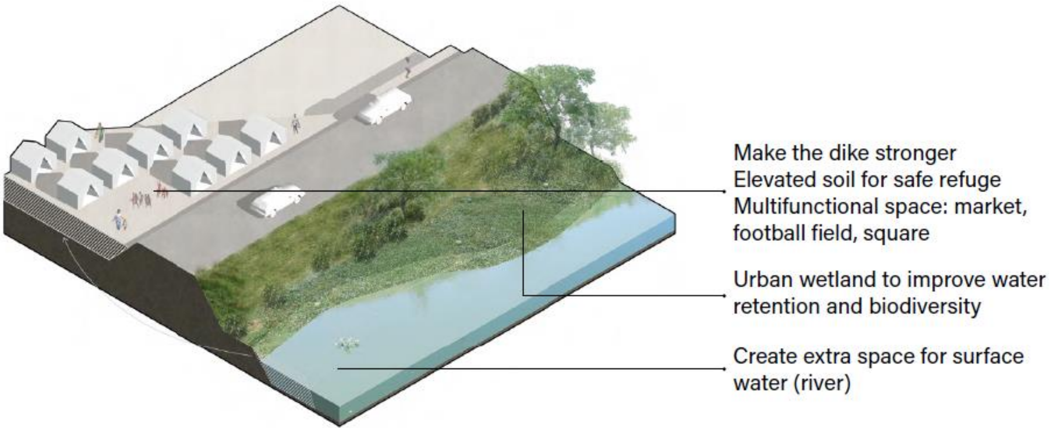


Figure 21. Bird's eye view of examples of NbS on a city scale

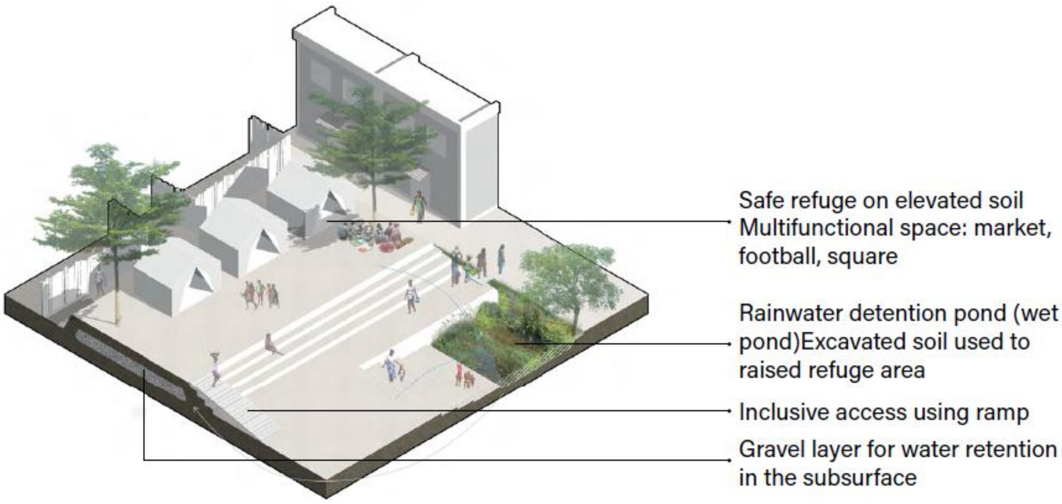


Figure 22. Bird's eye view of examples of NbS on a fokontany scale

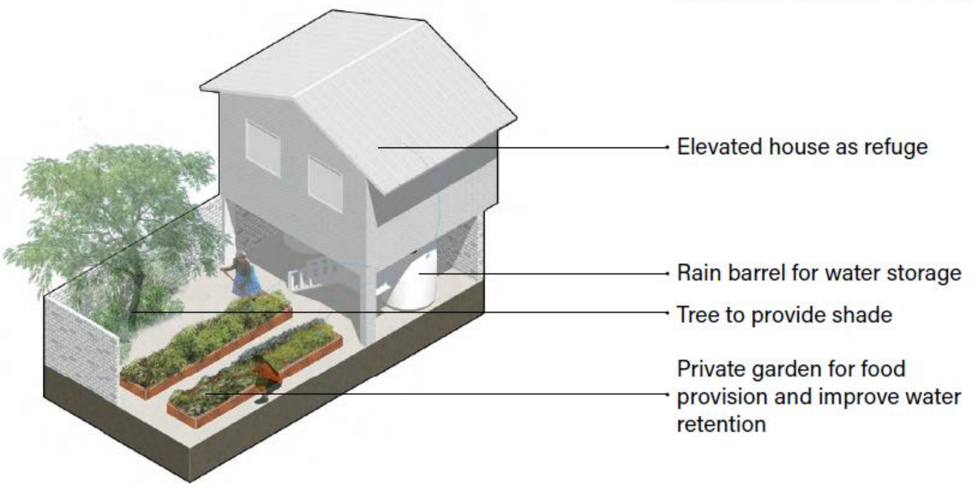


Figure 23. Bird's eye view of examples of NbS on a street scale

SHARED COSTS

The implementation of measures can be expensive. While the main cost of traditional infrastructure solutions might be in the initial implementation phase, most NbS require initial and/or constant maintenance, spreading this cost throughout the lifecycle of the measure. To save costs, it can be more convenient to:

- Combine different measures, like a bioswale that needs to be excavated, with an elevated route or small dike that needs to be filled (**Figure 5**)
- Look for the right moment for implementation, to reduce their cost. For example, the renovation of a bridge can be combined with the implementation of NbS on the river bank for slope stabilization.

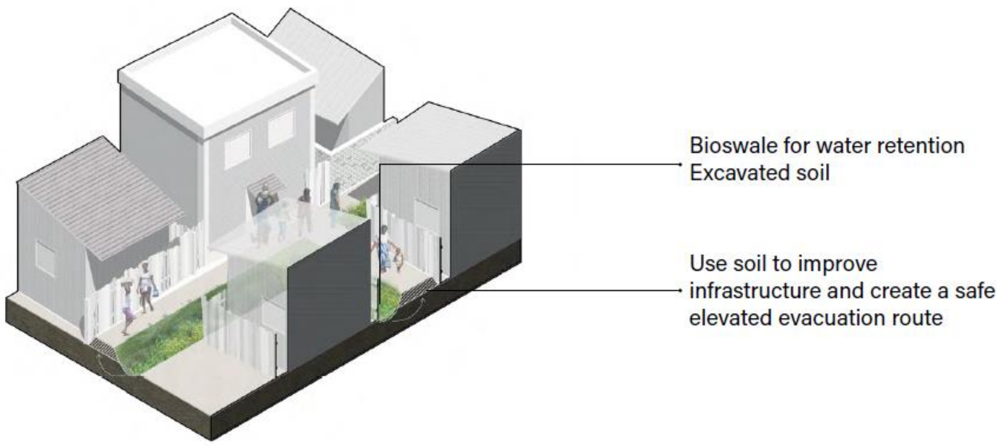


Figure 24. Bird's eye view of examples of NbS on a street scale

1.2 From scenarios to a plan: refuge sites and evacuation routes

During the previous phase of this study, we developed two different scenarios, based on on-site and off-site evacuation. After analyzing and assessing the different selected sites and potential routes for both on-site and off-site evacuation, we concluded that the two scenarios are complementary. On-site evacuation is only feasible as the first and most immediate evacuation. If the flood is not too severe, this would be sufficient, especially in a low-lying area. However, if the flood worsens, the on-site refuges will not have the capacity or characteristics to accommodate the displaced population. In that case, off-site locations would be needed. Off-site refuges would be more elevated and would have a higher capacity to accommodate the displaced population.

SITES

We designated the 10 sites selected during an earlier stage of the project (refer to **section 5.2 of the Diagnostic report** and **section 2** of the present report) as either an on-site or an off-site refuge. The main criteria for this was their location and elevation (refer to **Scenario Building and Synergies presentation**). The elevation is relevant since we prefer sites that have a higher elevation and are more likely not flood-prone.

In general, sites located on the floodplain, and especially the ones located in densely urbanized areas, could only be used as an on-site location. The reason for this is that their refuge capacity is low, with not much space to accommodate people, and they have a very low elevation, so they might not withstand more extreme floods. They could be raised but given their location and the characteristics of the area, this could cause further problems rather than contribute to solving existing ones. Sites 3, 7, 8, 9, and 10 are part of this group, with an elevation between 1250 and 1252m. Sites 2, 4, 5 and 6 have an elevation between 1266 and 1270m, enough to withstand more severe floods, so they could be upgraded to be used as both on-site and off-site refuge. The elevation of site 1 is only 1257m, but considering its location and the space available, this site could also be used as both on-site and off-site refuge.

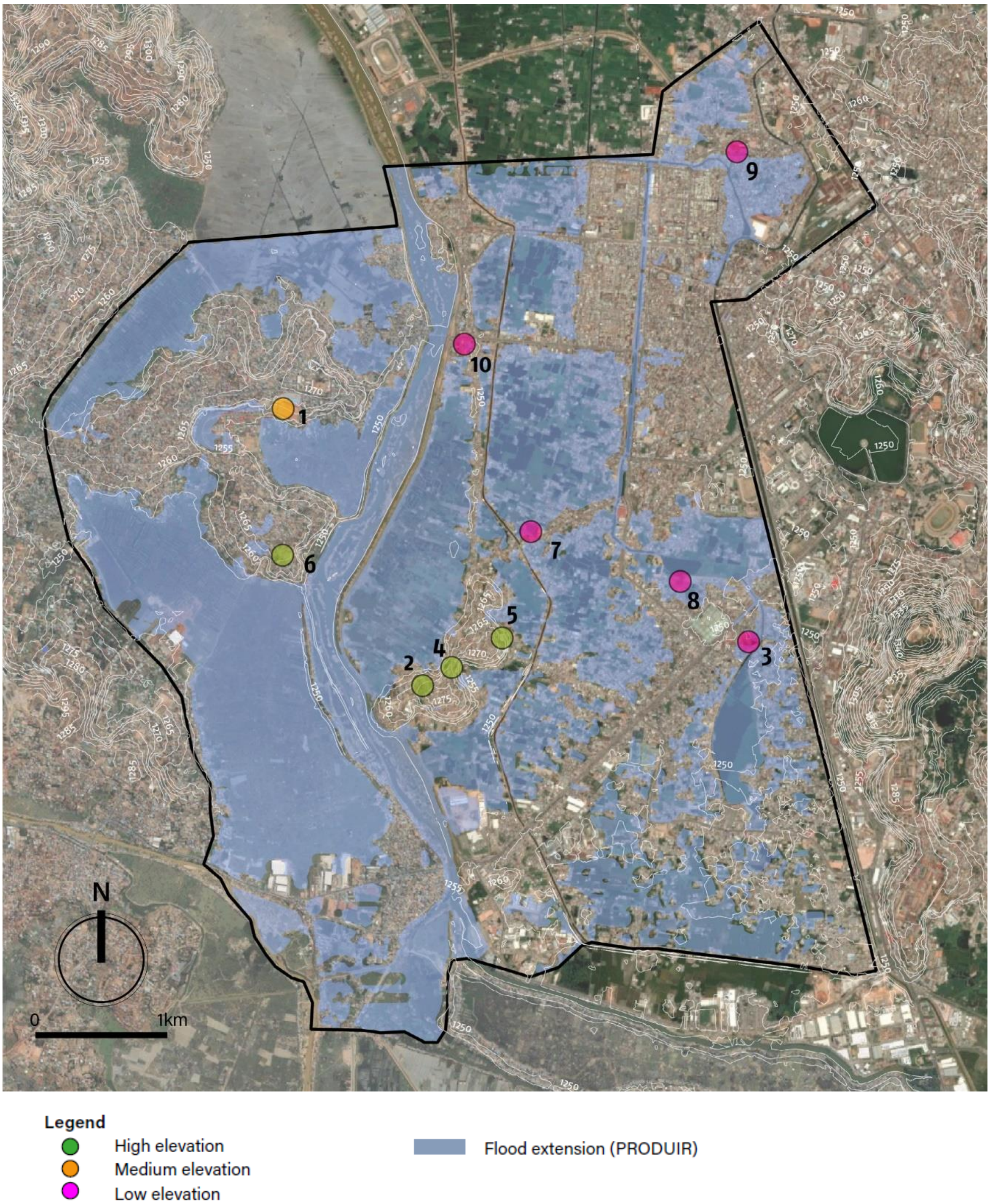


Figure 25. Ten selected sites categorized by their elevation

When floods are even more severe, people will have to be accommodated for a longer period. In such a case, even the off-site refuges will not be enough, and other locations outside of the PRODUIR area should be upgraded for this purpose. This results in a system with three types of refuges:

1) On-site locations that have a limited capacity and can accommodate people for a relatively short period during minor or moderate floods (one or two days)
2) Off-site locations, in the vicinity of the flooded area (within the PRODUIR area), that can accommodate people for a longer time period and also during more extreme flood events (several days)

3) Off-site locations at a greater distance, that can accommodate people for an even longer time period during extreme flood events (weeks)

ROUTES

We defined a network of evacuation routes as follows:

- Green routes connect houses to evacuation routes
- Orange routes connect to on-site refuges
- Red routes connect on-site refuges and on-site to off-site refuges

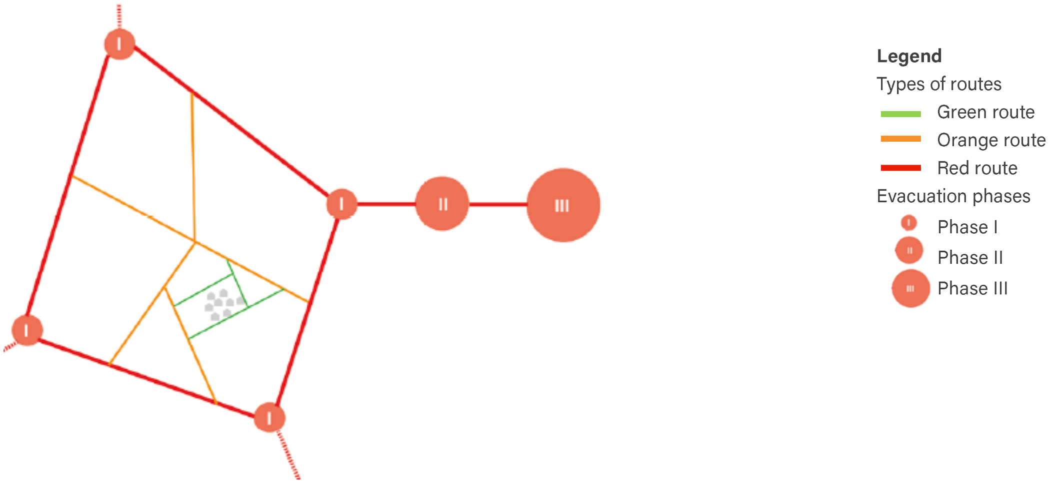


Figure 26. Diagram of the types of evacuation routes in relation to the phases of evacuation.

Evacuation on foot is preferable since it is low tech and can be more easily implemented. The criteria for route selection is: not flood-prone; shortest route so that evacuation on foot is possible; a route that requires the least height difference (e.g. not go up and then down and then up again to reach the refuge); no tunnels, which are bottlenecks within the city; and through roads and bridges that have a bigger capacity for transit on foot.

The routes should provide safe and direct evacuation to pedestrians and connect to main routes where other means of transport could be used for evacuation if needed.

EVACUATION PLAN

We developed a comprehensive plan that includes the on-site and off-site refuges, a network of evacuation routes, and potential off-site refuges outside the PRODUIR area.

Phase I - Evacuation to on-site locations

All selected sites can work as an on-site refuge (**Figure 8**). Evacuation starts with green routes that connect groups of houses to the orange routes. As much as possible, 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). The orange routes connect to red routes (main routes). Red routes connect the different refuge sites and off-site locations.

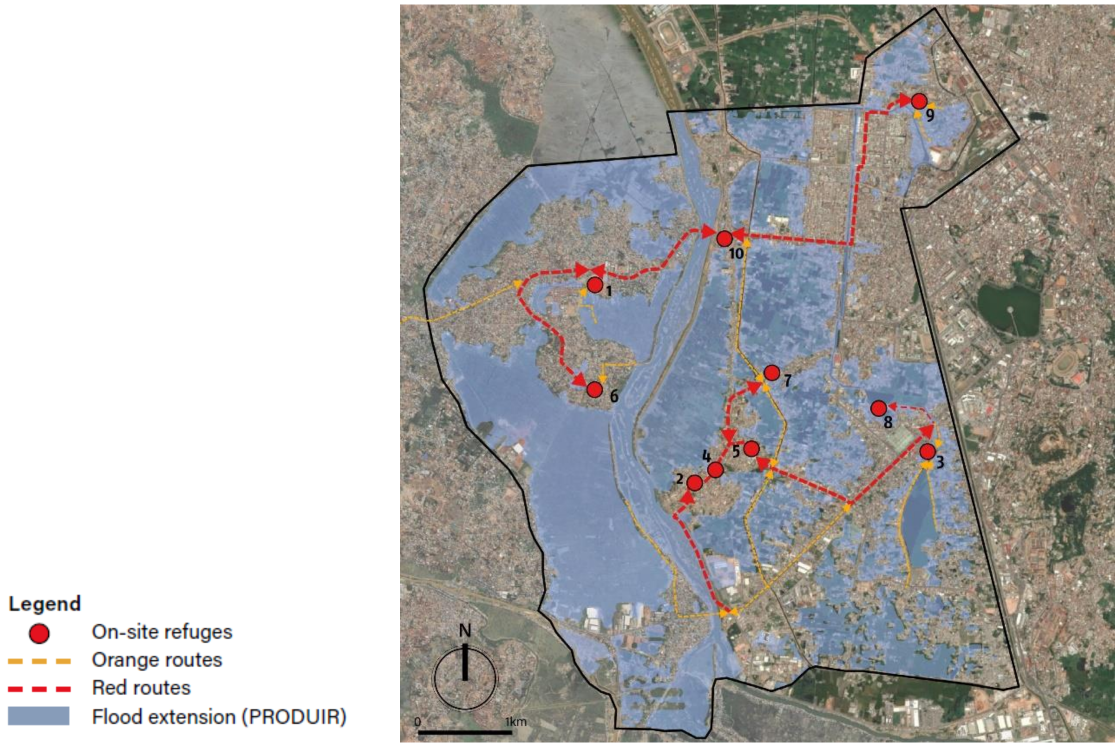


Figure 27. Phase I of the evacuation plan

Phase II - Evacuation to off-site locations (within PRODUIR)

Evacuation to off-site locations for short-term refuge. Some selected sites double as both on-site refuge and also an off-site refuge for citizens of different fokontany (**Figure 9**).

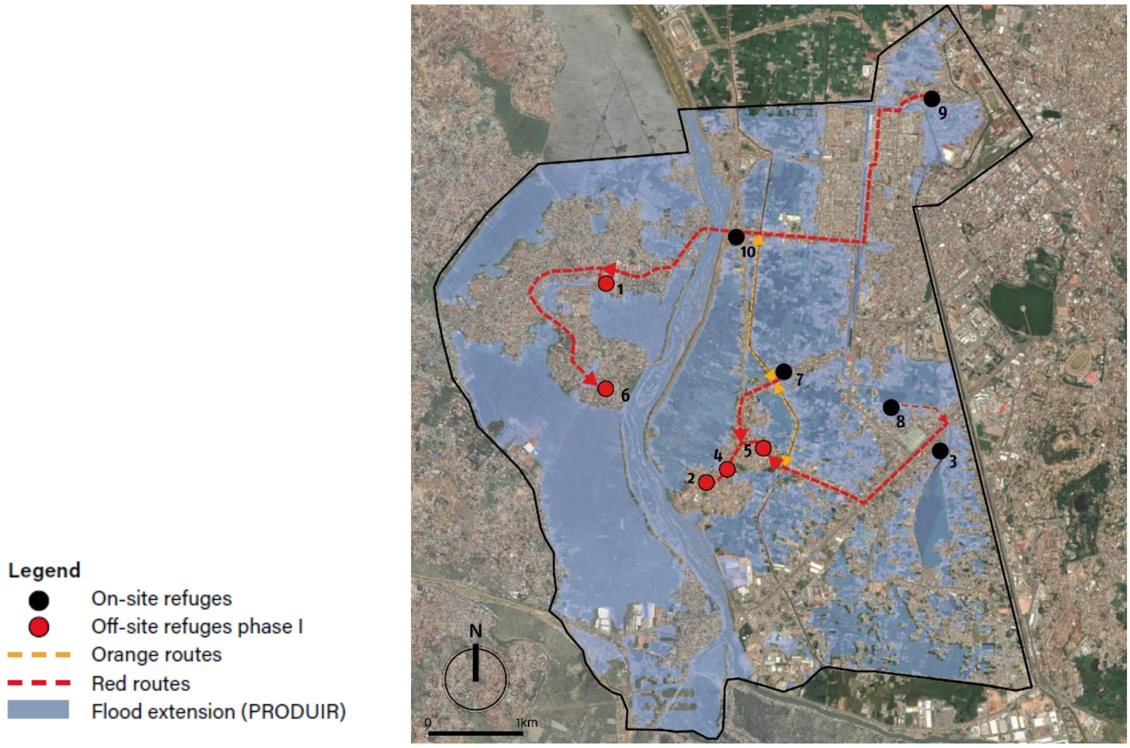


Figure 28. Phase II of the evacuation plan

Phase III - Evacuation to off-site locations (outside PRODUIR)

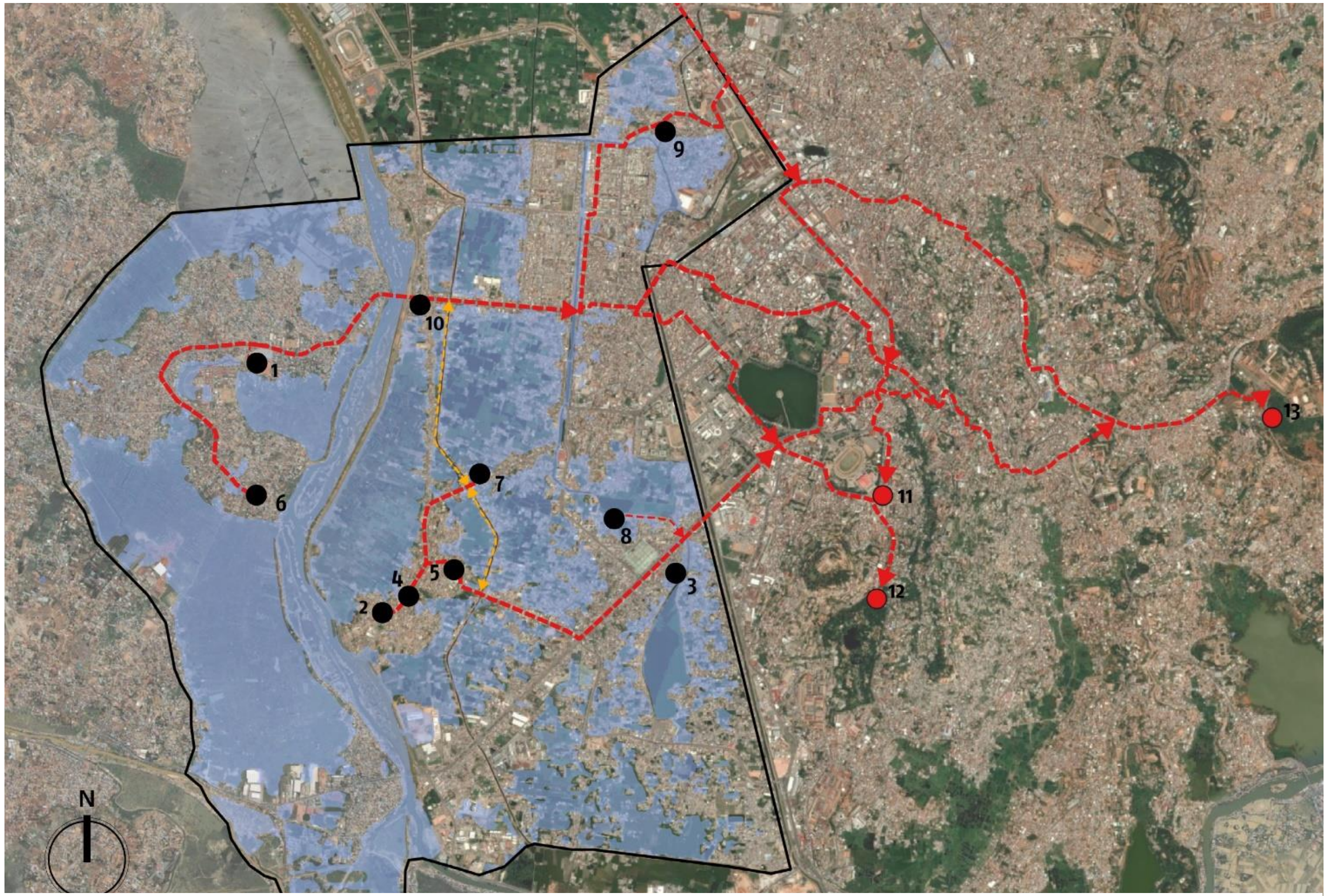


Figure 29. Phase III of the evacuation plan

Off-site locations for phase III are outside the study area (**Figure 10**). However, we suggest potential sites. The criteria for the selection of off-site locations for phase II is:

- **Capacity.** Sites with a bigger refuge capacity to accommodate people
- **Larger open areas** so people can stay for a longer time
- **Connecting routes** should be through main or secondary roads (bigger capacity)
- **Elevation** should be the same or higher as the off-site refuges of phase II (to be used during extreme floods)

Considering these criteria, some possible locations could be the Ecole Normale (11), the botanical garden (12), and the University of Antananarivo (13).

Legend

On-site refuges

Off-site refuges phase I

Orange routes

Red routes

Flood extension (PRODUIR)

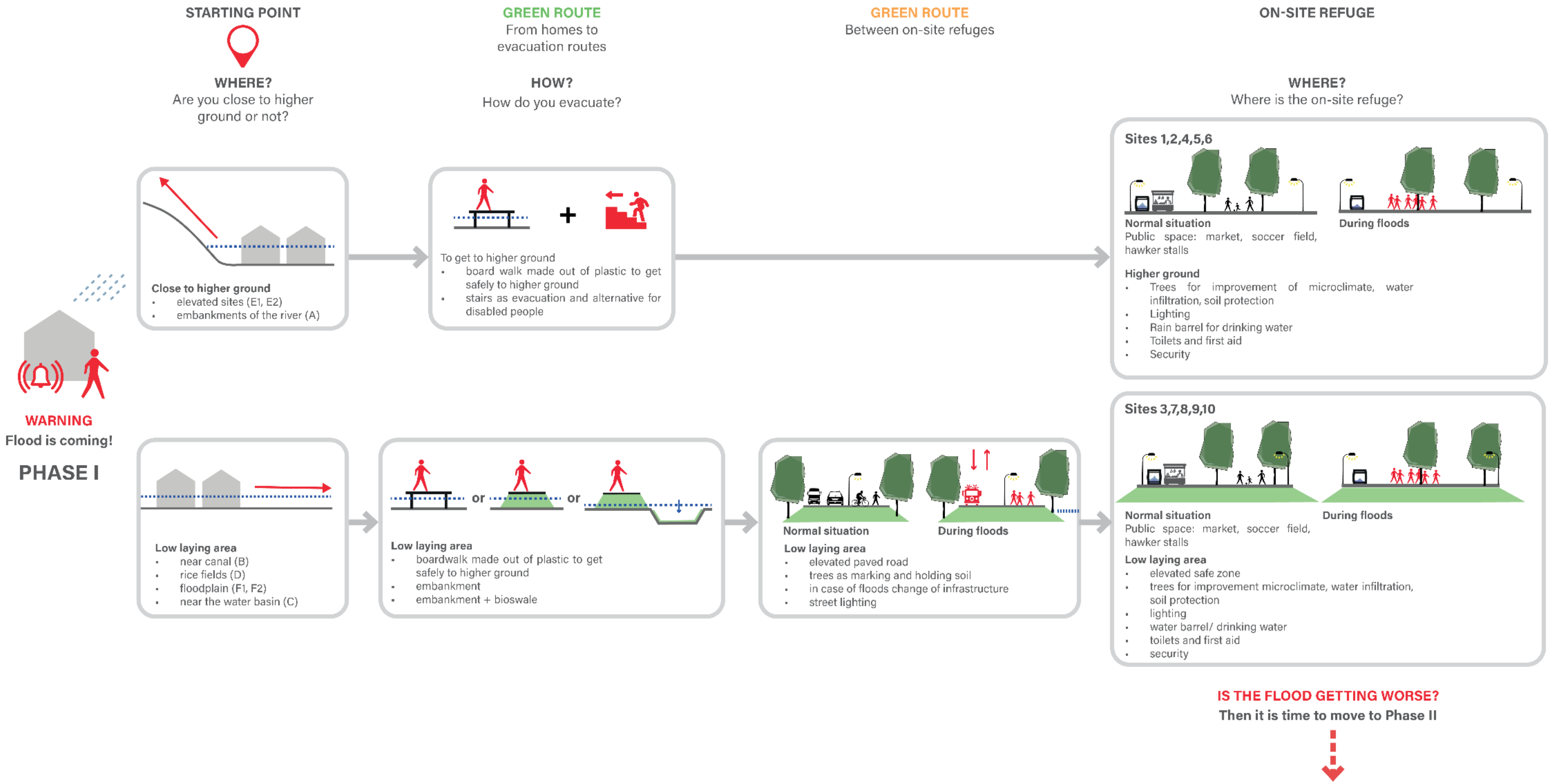


Figure 30. Summary of the steps of Phase I of the disaster evacuation plan

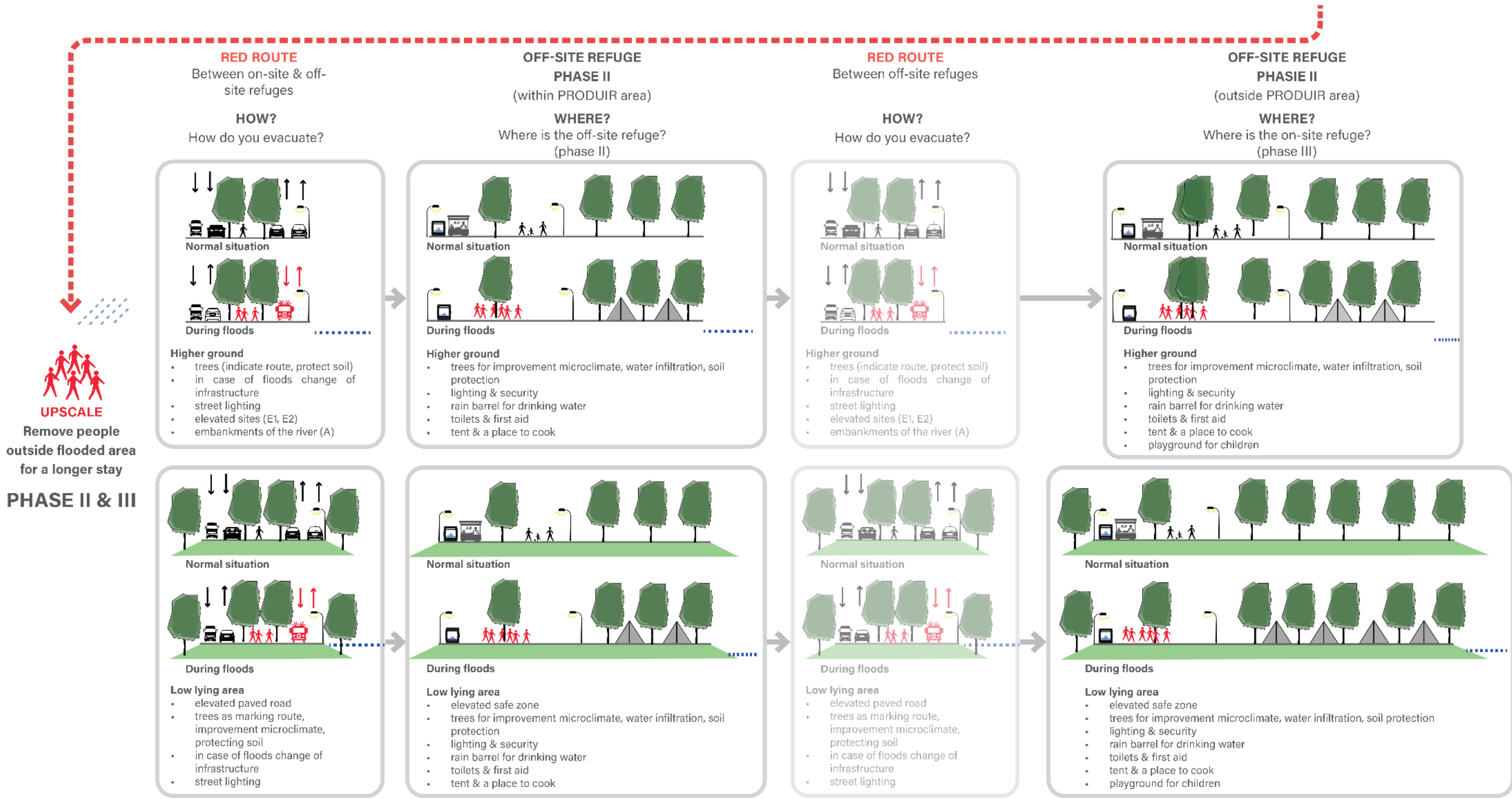


Figure 31. Summary of the steps of Phase II and III of the disaster evacuation plan.

1.3 Validation with stakeholders

This section presents the main findings from the validation process with stakeholders throughout the project in four main activities. The first activity was a **workshop** with stakeholders from institutions, government, and organizations, where we refined the problem understanding and identified potential desirable solutions to general flood-related challenges. After, we conducted a **community survey**, where we gathered insight about evacuation practices and the understanding of NbS. Then we organized several **focus groups** with all relevant stakeholders, where we proposed potential measures. This was discussed, identifying not only what would be suitable for the local context, but also how they could be implemented. Finally, we conducted a **second workshop** to present the scenarios developed, and potential site-specific measures along with guidelines and recommendations for their implementation.

A third workshop was organized as a follow-up to workshop 2, to engage with the stakeholders that could not attend the previous one. In addition, several interviews were conducted with different stakeholders to discuss and get insight into specific topics.

The main findings and recommendations that were provided by the stakeholders are clustered per activity as follows:

Workshop 1

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

Community survey

- Informal refuge sites are corresponding to official refuge sites (according to the UNOCHA plan) in certain locations
- Refuge sites and evacuation routes proposed by the community seem to respond to the necessities of the community and are not necessarily the safest option (e.g. evacuation by swimming)
- The refuge site and evacuation route proposed by the community in Antohomadinika Anfovoany is located close to site 9.

Focus group

NbS suggested by the community were:

- urban agriculture
- add green to the landscape (private green gardens, trees, parks)
- rain barrels, especially in Bemasoandro
- elevated evacuation routes
- creation of surface water (e.g. ponds)

Workshop 2

Fokontany leaders and the community had a precise understanding of the evacuation routes and constraints, while government officials and NGOs had a high-level understanding of the evacuation and urban systems. Stakeholders indicated the following **essential components** for refuge sites:

- **Equipment**: a place to cook, trash bins, lighting, tent, toilettes, playgrounds for children
- **Basic resources**: drinking water (rain barrel)
- **Services**: medical facilities, access to information (radio, tv, etc.)
- **Security**

1.4 Findings and conclusions

The main findings from the scenario building phase are:

- Scenarios are complementary. They constitute different phases of the same plan.
- Evacuation routes and refuges form 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
- NbS and complementary measures suggested at this stage, directly relate to the proposed site and route characteristics

We concluded that the proposed plan is only the starting point for the development of a comprehensive evacuation plan that can be used to safely evacuate the population exposed to floods in Antananarivo. By itself, the proposed sites do not have sufficient refuge capacity, so they should be replicated in other areas of the city that have similar characteristics, following the same strategy.

2 Site Selection

Ten sites were selected for the application of NbS for disaster evacuation and flood risk reduction. These sites are intended as a first stage in the implementation of NbS, to explore the suitability, and relevance of the measures, so they represent a situation that can be found in several locations throughout the city. Then, we select only three sites to conduct a prefeasibility assessment. The understanding of the larger context (PRODUIR area) from the analysis of selected sites, provides the basis for city-wide recommendations.

The rationale behind the selection of the ten sites was based on locations that had the characteristic or potential to be:

Representative + Upscalable + Multipurpose

Representativity. Given the characteristics of this project, it is not possible to explore all the potential locations in the city, so we focus on sites that are representative of a larger urban situation (urban typology). Starting from a system understanding and a landscape analysis, it is possible to zoom in on the most promising specific locations. The selection of these representative locations is the basis for comprehensive recommendations, which will be presented in **section 5.3.**

Upscalability. Interventions that can be replicated in other parts of the city. From previous phases of this project, we discovered the importance of small-scale and community-based interventions, but because of their scale, they are not enough to protect the city from floods. The upscaling of interventions means that instead of having one small-scale intervention, we could have 1000 ones across the city, forming a network of NbS that is capable of reducing floods while improving disaster evacuation.

Multipurpose. The objective of this project is to propose NbS for disaster evacuation and flood risk reduction. Even though floods are frequent, and are considered the main challenge, they mostly happen during the rainy season. The inhabitants of the city, especially the most vulnerable ones, are very affected by them, but they also have other more pressing challenges, such as access to water and sanitation, or the provision of food. These challenges are present in their daily lives throughout the year. By developing multipurpose interventions, it is possible to tackle both disaster evacuation and flood risk reduction, as well as several other challenges at once. This potentially minimizes the cost of the intervention.

Section 5.3 of the Diagnostic report provided the preliminary assessment of the preselected sites in terms of suitability for disaster evacuation and refuge, and the implementation of NbS, resulting in a shortlist of 10 sites (**Figure 13**).

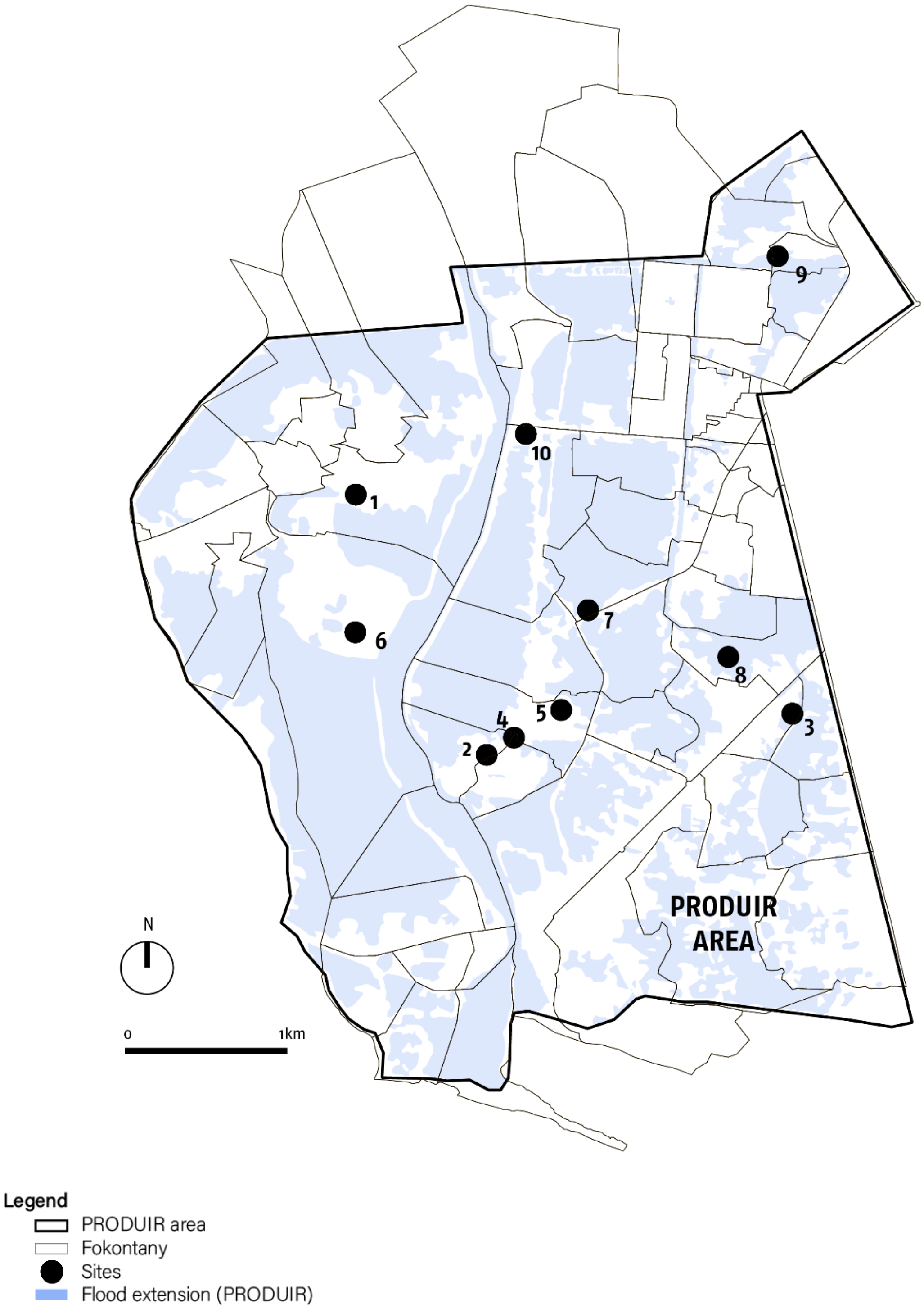


Figure 32. Ten selected sites within the PRODUIR area

In this section, we provide an in-depth review of the specific characteristics of those 10 sites, which will result in the selection of three sites to perform the prefeasibility study. The review starts from the city scale, and it covers the following aspects:

- Landscape types (city scale) identified in previous studies
- Urban typologies identified as part of this study
- NbS prospects
- Relevant stakeholders
- Beneficiaries: estimated population exposed to floods, beneficiaries of the co-benefits
- Quick-wins

By considering the landscape types and urban typologies, we ensure that the sites we choose are representative of the most common urban situation. The review of NbS prospects and beneficiaries, allows us to understand how multipurpose a site can be, and choose the most promising locations in this respect. In addition, the exploration of quick wins and relevant stakeholders provides insight into the potential upscalability of the different sites: are there synergies with other plan projects that can enable a more robust implementation of NbS? Is there a suitable stakeholder network to support the upscaling? At the end of this section, we provide the main findings of the site selection process and an explanation of the three chosen sites.

2.1 Landscape types

The Green Plan of Antananarivo (Plan Vert, 2007), introduced eight landscape types (**Figure 14**) for the city and surroundings. This plan does not include the communes of Bemasoandro, Anosizato Andrefana, and Andranonahoatra, on the West of the Ikopa River, therefore we expanded this analysis to cover that area as well. Three of the landscape types overlap with the PRODUIR area. These landscape types are the island cities, the informal city, and the plain and river.

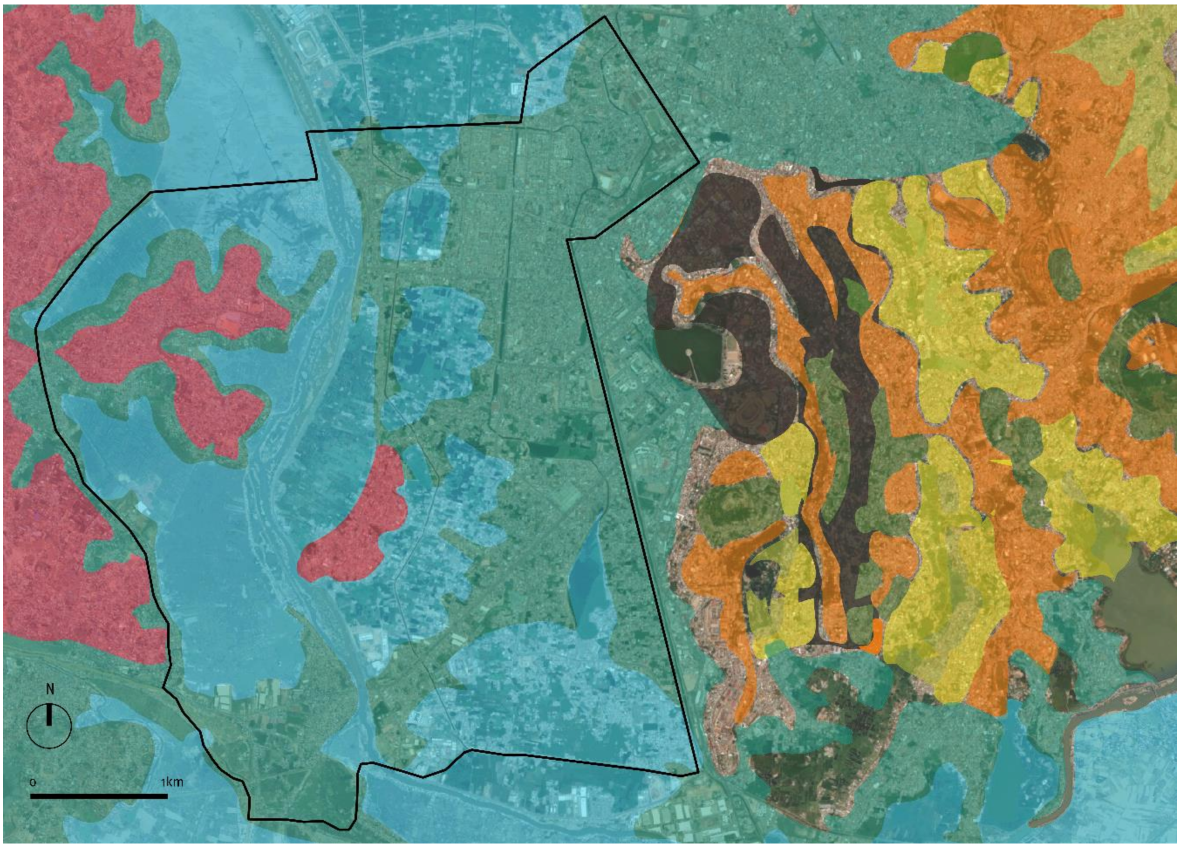


Figure 33. Overview of landscape types and PRODUIR area. Source Green Plan of Antananarivo (Plan Vert, 2007)

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

These three relevant landscape types are analyzed covering the abiotic, biotic and anthropogenic aspects.

ISLAND CITIES

Abiotic. This landscape type is present in the elevated areas of the city (above 1250m), surrounded by areas with lower elevation, which makes them look like islands within the city landscape. According to Andriamamonjisoa and Hubert-Ferrari (2019), the soil composition is predominantly migmatitic granite. The scope of that study only covered the area east of the Ikopa River. However, based on the understanding of the larger natural system and our field observations, we assume that other areas under this category, located to the west of the Ikopa River, have a similar composition. These areas do not usually flood. Because they are elevated, they are not exposed to fluvial floods, and there is runoff downhill, so rainfall does not usually stagnate on the site.

Biotics. Vegetation is scarce, and usually present in private lots as part of private gardens. There is no street greenery, and public-use green areas are almost nonexistent. There are several open spaces in these landscape types, especially in the communes of Bemasoandro and Andranonahoatra, but they are predominantly barren land.

Anthropogenic. They are mostly urbanized, with predominantly residential land use. Urbanization is organized firstly along the main paved roads, and from there it expanded towards the areas with less elevation. There is no comprehensive drainage and sewage infrastructure in these areas, but we observed several constructed small channels and ditches (Image 1), which are used both for the drainage of rainwater and wastewater.

Image 1. Existing ditches in the commune of Bemasoandro

THE INFORMAL CITY

Abiotic. This landscape type covers a large area, mainly on the east of the Ikopa River, in the communes of 1e and 4e Arrondissement, between the rice fields and the old city. Its elevation is low, around 1250m. The soil composition is predominantly alluvial, with a very shallow groundwater level of less than 1m deep (Andriamamonjisoa and Hubert-Ferrari, 2019). Because of its low elevation and minimal slope, the rainwater that falls in the area stays there. Moreover, since the groundwater table is very shallow, even if water can infiltrate, there is not enough space in the subsurface to store it.

Biotics. Vegetation is not abundant, and it is usually present in areas with surface water, such as the basins or flooded lots. Because of that, the predominant type of vegetation is watercress and grasses that can withstand these conditions. There are limited green areas for public use and street greenery, the latter mainly present along parts of the C3 canal (**Image 2**) and in the neighborhoods close to the Anosy lake.

Image 2. Informal settlements in 1er arrondissement.

Anthropogenic. Urbanization in this landscape type grows organically, mainly along main roads, focusing on infrastructure rather than the landscape itself. The use is mixed, and there are several informal settlements that continue to grow organically every day, with no comprehensive drainage and sewage infrastructure in those neighborhoods. However, there are three main canals that cross this landscape type: the GR, C3, and Andriantany canals, which drain excess water from south to north. In addition, we observed small channels and ditches, which are used both for the drainage of rainwater and wastewater in some neighborhoods.

THE PLAIN AND RIVER

Abiotic. This landscape type is located in the floodplains of the Ikopa River, both on the East and West. Its elevation is low, and it does not exceed 1250m. The soil composition is predominantly alluvial, with a very shallow groundwater level of less than 1m deep (Andriamamonjisoa and Hubert-Ferrari, 2019) which results in wet saturated land. Because of its low elevation, minimal slope, shallow groundwater table, and proximity to the river, this landscape type is exposed to both fluvial and pluvial floods.

Biotics. Vegetation is present in several locations, usually in the form of agricultural lots, mainly for rice cultivation. There are also several locations where the water is stagnated, prompting the growth of watercress and other similar species that can withstand these conditions. Formal green areas for public use (i.e. squares and parks) are not very common, but there are several locations where open green areas are informally used for recreation and everyday activities, especially when there are trees (**Image 3**).

Image 3. Green open area in the fokontany of Ambaniala, which is being used for recreation and drying laundry.

Anthropogenic. There is not a clear boundary between the city and nature in this landscape type. There are several informal settlements in both peri-urban and urban areas, as well as several small dikes of different dimensions, and channels and ditches that are usually built for agricultural purposes. Along the Ikopa River, there are also bigger dikes, built to protect the city from potential floods. The main routes present in this landscape type are the roads that go across the Ikopa River (Route d'Itaosy and RN1). Because of the unorganized urban grid, and the presence of high dikes, the river is not always visible, even though it is one of the main features of this landscape (**Image 4**).

Image 4. View from the dike along the Ikopa River in the fokontany of Anosizato Antinanana I

2.2 Urban typologies

Within the landscape types, we identified a series of urban typologies (**section 1.2 of the Diagnostic report**), based on the predominant specific characteristic of certain areas in terms of biotic (vegetation), and anthropogenic aspects (infrastructure network and urbanization). Urban typologies are not fixed, but they reflect the predominant characteristics of an area at this moment in time, so in the future, the classification could be adjusted if there are considerable changes in the characteristics of the city.

In this section, we provide an overview of the main characteristics of each one of the ten selected sites in relation to their typology, as well as the main challenges that need to be addressed in each of them (**Figure 15**).

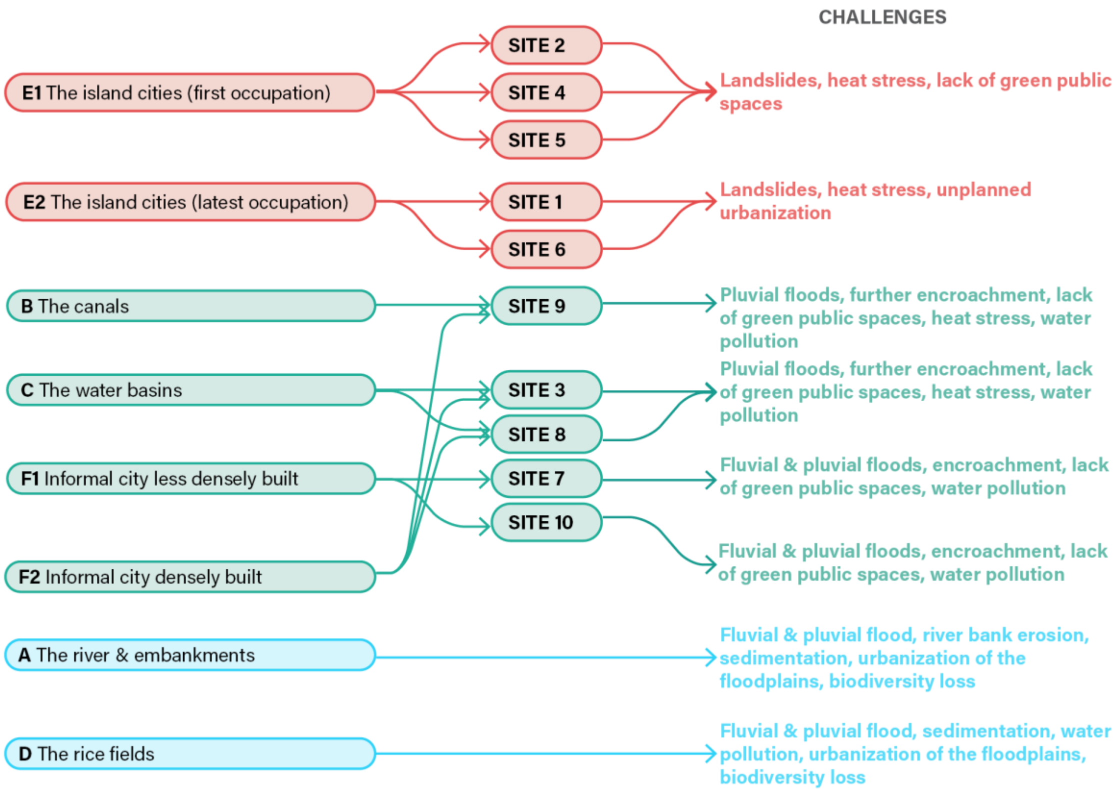
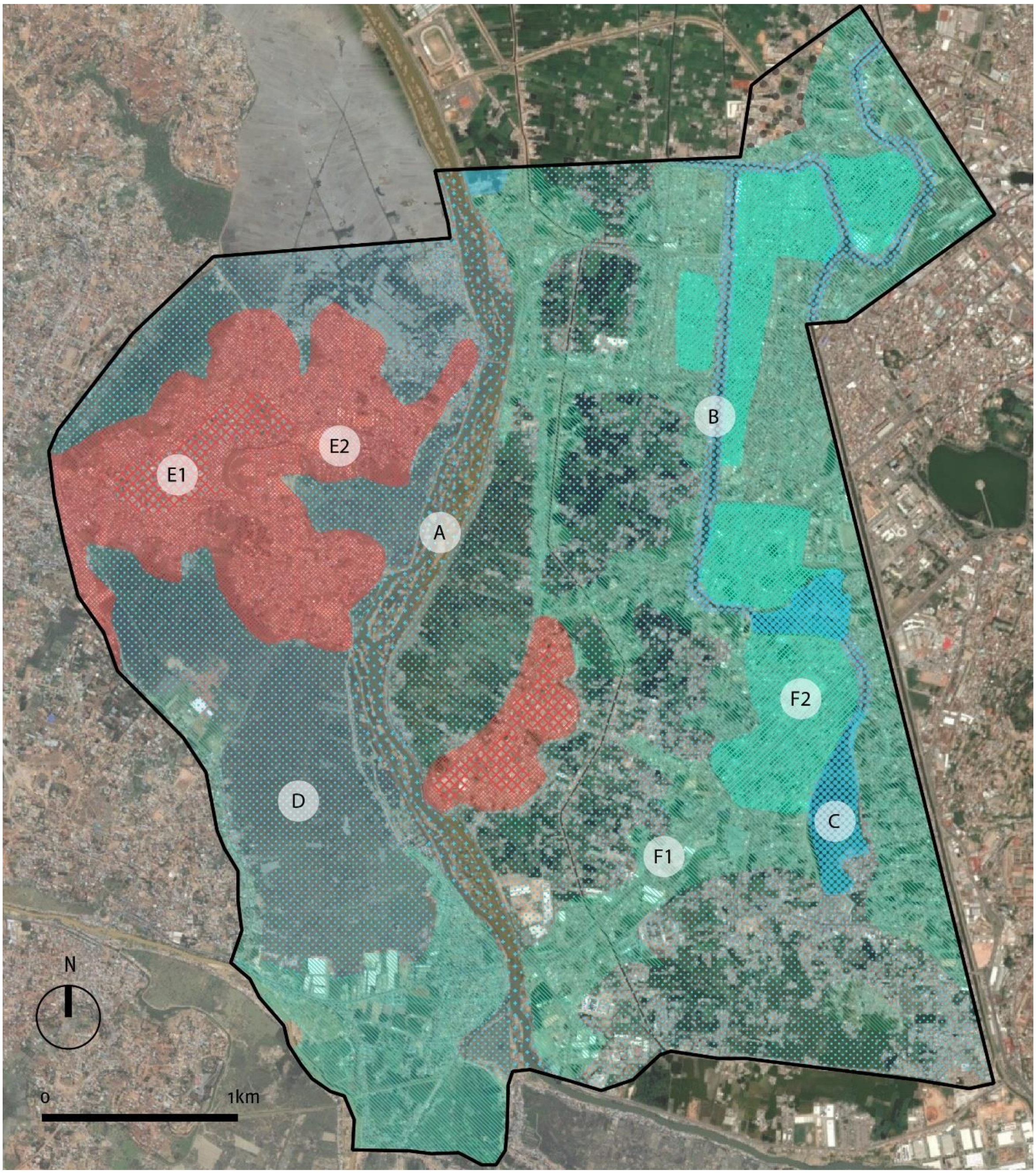


Figure 34. Overview of the ten selected sites in relation to the urban typology and landscape type they belong to, as well as the main challenges that need to be addressed.

Figure 16 shows an overview of the different urban typologies.



Legend

Landscape types

- 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

Figure 35. Urban typologies in Antananarivo. Each typology is not uniform, so the classification is based on the predominant characteristics of a certain area.

By choosing sites that belong to different typologies, we focus on representative pilot sites. Those pilots could be later upscaled on other locations with similar characteristics, contributing to a comprehensive strategy that addresses flood risk reduction and disaster evacuation in the PRODUIR area.

Sites 3[1] and 8 are located on the border between two urban typologies: the water basins (C) and the informal city densely built (F2), while site 9 is on the border of the canals (B) and the informal city densely built (F2). The Plain and River landscape type and its urban typologies (A and D) cover both the Ikopa river and embankments and the rice fields. Because of its land use, it is mostly uninhabited, except for temporary uses predominantly related to work activities (e.g. brick making) and domestic activities (e.g. washing laundry) (**Image 5**).

Image 5. Women washing laundry in the fokontany of Anosizato Antsinanana I

Even though we are not focusing on the urban typologies A and D, below is the overview of their main characteristics.

THE RIVER AND EMBANKMENTS

Biotic – Greenery and open spaces. Within the riverbed weeds and small shrubs can be found. The dike embankment is covered by grass. The upper soil and the grass are often taken to be used in private gardens (**Image 6**), which can lead to erosion, and ultimately compromise the adequate functioning of the dike. The sediments in the floodplain are used to make bricks. Piles of bricks can be found along the elevated ridges in the floodplain. The width of the bed varies strongly (**Image 7**) which has a negative effect on the water flow.

[1] During the diagnostic (refer to section 5.3 of the Diagnostic report) we categorized site 3 as part of the urban typology F2. However, after more detailed analysis, we refined this categorization, and decided that site 3 is both part of the urban typology F2 and C.

Image 6. People removing grass from the dikes

Image 7. Narrower section of the river bed, brick making (left, on the background), and other activities.

Image 8. Houses on the Ikopa river.

Anthropogenic – Infrastructure network and urbanization. East of the Ikopa river, National Route 4 is situated on the dike. The river space is hardly used as a transport route, namely to get from one side to the other. Wooden footpaths and bridges are made to get to the areas where brick-making takes place (**Image 7**). There are some buildings on the riverbed and embankments. These are at great risk of floods (**Image 8**).

THE RICE FIELDS

Biotic – Greenery and open spaces. The land in this urban typology is used mainly for agriculture. Small dikes are used as a separation between different lots and to keep water in for agricultural purposes.

Anthropogenic - Infrastructure network and urbanization. The dikes are used as pedestrian routes, and the most important routes are elevated by tires (**Image 9**), sandbags, and pieces of plastic. There are no roads for vehicles. This urban typology has a very low density of occupation, with only some farmhouses.

Image 9. Existing elevated pedestrian route

Given the predominantly temporary and flexible use of the area, we decide not to select sites on this urban typology and instead focus on other typologies where floods are expected to cause more direct damages to inhabitants and where disaster evacuation is expected to have a higher urgency.

This is not to say that the flood impact in peri-urban or urban areas such as these ones is insignificant. We understand that agricultural activities provide the main income for some families and that it is an activity highly impacted by urban expansion. However, we have decided to focus firstly on inhabited urban and peri-urban areas, and on how to improve the resilience of those areas to protect people's homes and their livelihoods (see **section 1.4 of the Diagnostic report**), provide safe evacuation opportunities, and overall reduce urban floods. Further explanation about the urban typologies can be found in **1.2 of the Diagnostic report**.

SITES 1 AND 6

Urban typology: E2 Island city (latest occupation)

Abiotic – Elevation. Small elevation differences can be found, as this site has an intermediate elevation, above 1250m, between the high and low-lying grounds. Site 1 is approximately at 1257m, and site 6 at 1269m. The elevation for all the sites was retrieved from **https://nl-nl.topographic-map.com/maps/fjqv/Antananarivo/**, and contrasted with the elevation data provided by the MATP (Antananarivo_MNT_grille2m_fev2015UTM38S-WGS84)

Biotic – Greenery and open spaces. Scarce public urban green, except for fruit trees and other species found in private gardens. On site 1, a football field is the biggest recreational facility in the area, surrounded by large paved surfaces and constructions. On site 6, there is no vegetation, but there are some trees and shrubs on neighboring lots, as part of private gardens and in more wet areas with less elevation.

Anthropogenic - Infrastructure network and urbanization. Most roads are unpaved and consist of compacted soil. There are also, unpaved pedestrian paths between houses. In these narrow streets, open sewage runs towards the main roads. The width of these paths is insufficient to evacuate large amounts of people or people with disabilities if they need special aid. On the southeast of the site, urbanization is more disorganized, characterized mainly by small houses, extending to the low-lying areas. On the north and west of the site, there are several bigger houses and other larger buildings, as well as more space between the buildings.

Figure 36. Overlap of contours every 2m and satellite image (Source Bing maps aerial) for site 1

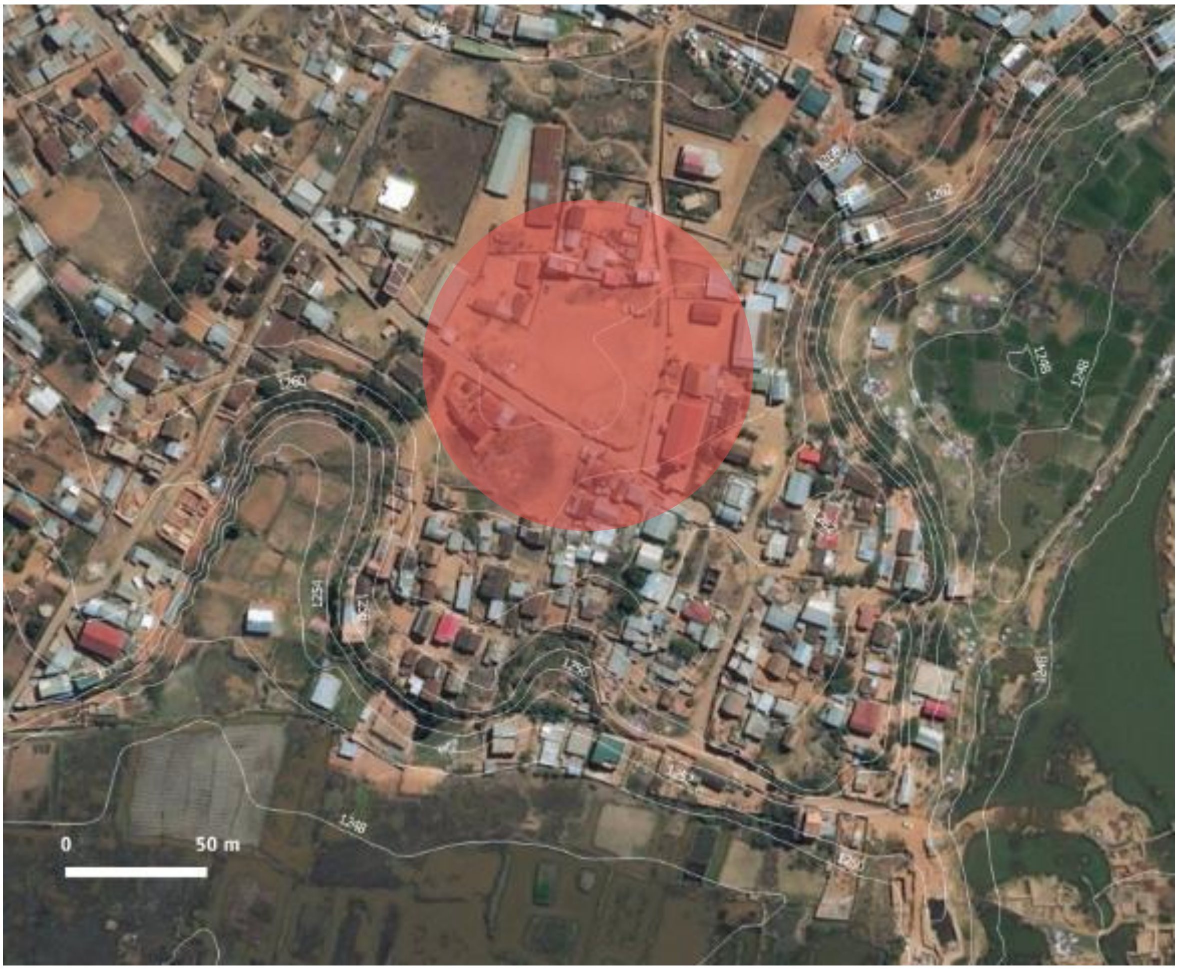


Figure 37. Overlap of contours every 2m and satellite image (Source Bing maps aerial) for site 6

SITE 2, 4 AND 5

Urban typology: E1 Island city (first occupation)

Abiotic – Elevation. The elevation of this site is between 1248m and 1250m, with minimum elevation differences that are too small to be perceived given the coarse data available. Site 2 is approximately at 1270m, site 4 at 1266m, and site 5 at 1262m.

Biotic – Greenery and open spaces. Trees and greenery are found in the private gardens which vary in size. In some cases, trees from the private gardens are close to the main road. There are some open spaces between buildings, which are mostly privately owned. Site 2 has a narrow connection to the main road in between buildings, but extends to the north, maintaining the same elevation. It is mostly barren land, with limited greenery. Site 4 extends to both sides of the main road, including the 2 existing buildings that are used as churches. It is partly covered by shrubs and trees. Site 5 present some greenery, mostly trees in the perimeter of the site, which is privately owned.

Anthropogenic - Infrastructure network and urbanization. The main road that sites 2, 4 and 5 connect to is paved and bidirectional, and it reaches the RN4 on the west and the Ny Avana Ramanatoanina on the northeast as well as other small routes. The main road has a limited capacity, reduced even further by the parking that takes place along it. Pedestrian routes, like in many places in the city, are narrow. The sewage system is mostly not visible or not present, except for some open ditches. Site 5 faces the main road and is only over 200m away from the GR canal, which can provide a direct evacuation route. Several houses in the low-lying areas are less than 200m from the site, easily accessible through the main road or smaller unpaved ones.

Figure 38. Overlap of contours every 2m and satellite image (Source Bing maps aerial) for sites 2 and 4 (above) and site 5 (below)

Deltares

SITE 3 AND 8

Urban typologies: C The water basins and F2 Informal city densely build

Abiotic – Elevation. The elevation of this site is between 1248m and 1250m, with minimum elevation differences that are too small to be perceived given the coarse data available. Site 3 is approximately at 1250m, and site 8 at 1251m.

Biotic – Greenery and open spaces. Scarce public urban green areas. The existing green are the areas that are constantly flooded or the water bodies that are covered by watercress and hyacinths.

Anthropogenic - Infrastructure network and urbanization. We observe mostly small roads made of compacted soil in poor shape, used by all transport forms. On site 3, between houses (mostly informal settlements), there are small pedestrian paths made of elevated wooden boardwalks or elevated paths using sand bags, which form a pedestrian transport network. It is in poor condition, but it is essential to the mobility of most neighbors around site 3. In these narrow streets, open sewage runs towards the main roads and the basin. The connection of site 3 to the main road (RN1) is narrow, in between buildings, which are slightly at a lower elevation than the road. The other existing main route is the unpaved road along the basin, with an edge that is only a few centimeters higher than the level of the basin itself, which is commonly used for several types of everyday activities. This connects to the RN1 as well.

Figure 39. Site 3 and surroundings (Source Bing maps aerial)

Site 8 is located 400m of the RN1, following an unpaved multipurpose road in average condition. Around site 8, between houses, there are pedestrian paths in less than optimal condition. Open sewage runs towards the main roads and the basin at the beginning of the C3 canal. Urbanization is heterogeneous, with some clustered houses, some bigger buildings (e.g. church), and empty lots, some of which are barren land, while others are periodically flooded.

Figure 40. Site 8 and surroundings (Source Bing maps aerial)

SITE 7

Urban typology: F1 Informal city less densely built

Abiotic – Elevation. The elevation of this site is between 1248m and 1250m, with minimum elevation differences that are too small to be perceived given the coarse data available. Site 7 is approximately at 1250m.

Biotic – Greenery and open spaces. Existing green areas mainly consist of small rice fields in between the houses. In some private gardens, there are fruit trees. There are several open spaces, but they are mostly underused.

Image 10. Elevated boardwalks connecting houses

Anthropogenic - Infrastructure network and urbanization. Site 7 is well connected by a main paved road (Ny Avana Ramanatoanina) that connects to Rue Amical Cabral, which reaches the colonial part of the city. This site is also only 100m away from the GR canal. Smaller roads are made of compacted soil. The pedestrian network is made of small alleys and elevated boardwalks on stilts between houses (**Image 10**). In these narrow streets, open sewage runs towards the main roads. Houses are mostly present along the main road, and they are more spread apart the further away of the road they are.

Figure 41. Site 7 and surroundings (Source Bing maps aerial)

SITE 9

Urban typology: C The canals and F2 Informal city densely built

Abiotic – Elevation. The elevation of this site is between 1248m and 1250m, with minimum elevation differences that are too small to be perceived given the coarse data available. Site 9 is approximately at 1251m.

Biotic – Greenery and open spaces. Scarce public urban green areas. The existing green areas are mostly the ones that are constantly flooded.

Anthropogenic - Infrastructure network and urbanization. The main connection is a bidirectional paved road that connects with Lalana Pasteur and other main roads to the east. Other small roads are made of compacted soil in poor shape, used mostly by pedestrians, given their narrow size. Access to houses is often obstructed. Between houses (mostly informal settlements), there are small pedestrian paths, which form a pedestrian transport network. It is in poor condition, but it is essential to the mobility of most neighbors. In these narrow streets, open sewage runs towards the main roads. There are small wooden bridges that connect to the other side of the C3 canal, which are not apt for people with disabilities, and are often in regular condition. Only in some areas, it is possible to walk along the canal.

Figure 42. Site 9 and surroundings (Source Bing maps aerial)

SITE 10

Urban typology: F1 Informal city less densely built

Abiotic – Elevation. The elevation of this site is between 1248m and 1250m, with minimum elevation differences that are too small to be perceived given the coarse data available. Site 10 is approximately at 1252m.

Biotic – Greenery and open spaces. Existing green areas mainly consist of small rice fields in between the houses. In some private gardens, there are fruit trees. There are several open spaces, but they are mostly underused.

Anthropogenic - Infrastructure network and urbanization. Main roads are paved (NR4 and East-West road), while smaller roads are made of compacted soil. A few smaller unpaved routes connect different areas. The pedestrian network is made of small alleys and elevated boardwalks between houses, where open sewage runs towards the main roads. Urbanization is very heterogeneous, with small houses along some secondary roads, some bigger warehouses and similar buildings, and several open unused areas that are periodically flooded.

Figure 43. Site 10 and surroundings (Source Bing maps aerial)

2.3 NbS prospects and complementary measures

The historic approach to deal with floods in Antananarivo has been to drain the excess water away from the city as soon as possible so it does not cause floods within the city. That is why the main canals have been built. This approach, while it can be effective, it requires resources for its initial implementation at scale, it is designed with a fixed lifecycle and deprives the local communities of benefits that are not directly related to flood prevention. The use of Nature-based Solutions (NbS), provides an alternative to this traditional approach, allowing for a paradigm shift **from "draining the city" to "dealing with water locally"**. At the same time, NbS provide diverse co-benefits, with potential environmental, social, and economic impact, such as air and water quality improvement, public green areas for recreation, and improvement of livelihoods.

Following that approach, we identified a series of potential measures to be implemented in the selected sites. Those measures have been previously explained (**see section 5.1 of the Diagnostic report and Scenario Building**) in terms of scale, expected co-benefits, and relevant consideration for its implementation, maintenance, and financing. They were also assessed both quantitively and qualitatively (**section 5.3 of the Diagnostic report**).

We selected the ones that are most suitable for each one of the ten selected sites, as well as a set of measures that are relevant for all sites. This selection has been informed by earlier phases of this project (**Diagnostic report** and **Scenario Building**), which served to understand what are the specific challenges that need to be addressed in each site and how this could be done considering their characteristics (**Figure 24**).

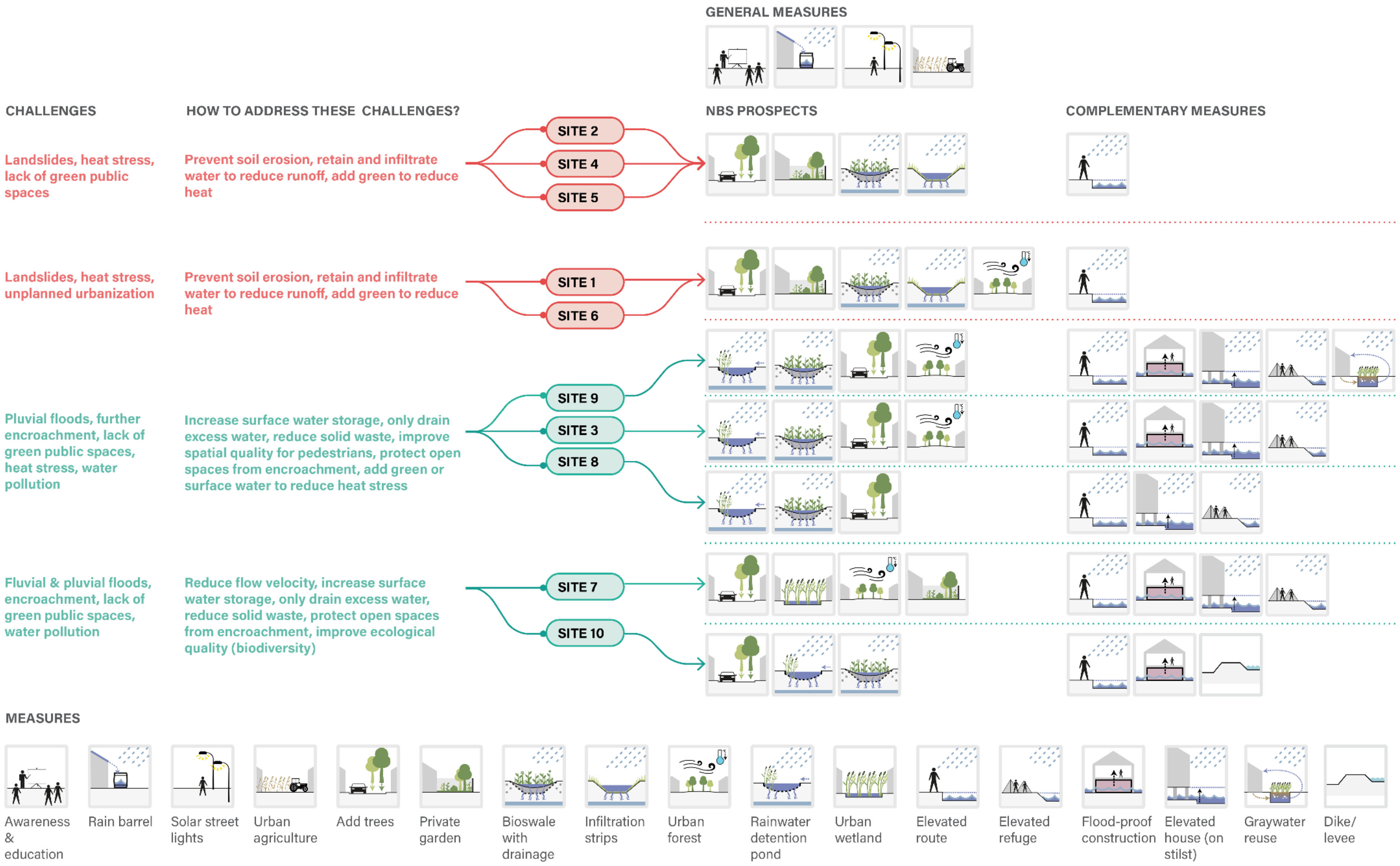
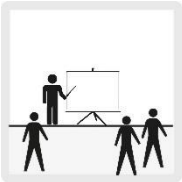


Figure 44. Overview of sites, the challenges they face and the measures that could address them.

GENERAL MEASURES



Awareness and education

Awareness and education programs are important, so the community understands the hazards is exposed to, knows how to prevent them, and is knowledgeable about what to do if they are exposed to them. This should include ongoing and culturally sensitive activities, that ensure to reach the majority of the population.

Awareness: Are there risks? What are the risks?

Education – including training -: How do we prevent the risks? What do we do if we are exposed to hazards?

Both awareness and education contribute to building local capacities, so the community is less vulnerable and more resilient to future challenges. Moreover, the training of both the community and stakeholders about NbS is vital to the upscaling of interventions.

Rain barrel

Rain barrels are a simple but effective way of rain harvesting, which provides a clean water supply. The rainwater that runs off from rooftops, and then via rain gutters, can be directed to and stored in one or several barrels or tanks that are placed next to buildings. The water stored should not be directly used as drinking water, since it has not been treated properly, but instead, it could be used for example to flush toilets, to water gardens, wash clothes, wash cars, and for agriculture. If a filter is added to the rain barrel, the water harvested could be used as drinking water. This would also require periodic maintenance to ensure that the filter works properly.

This system could be implemented in connection to all kinds of buildings, both houses or bigger buildings, to make use of rainwater locally. If the building rooftop is too large, the system will require an overflow so that when the tank is full, the water can be directed someplace else.

The World Health Organization indicates that 50 liters of water per day per person is the recommended amount required to cover health and hygiene needs and for all household uses. When provided by water kiosks, the cost of those 50 liters of water is approximately USD$0.032 a day per person (WaterAid, 2016). For a family of 4, the recommended amount would be 200 liters, which would cost USD$0.128. Commonly used rain barrels can store up to 224 liters, which would be enough to cover the water necessities of a family of 4 for 1 day. During the rainy season, a rain barrel would be quickly filled in less than a day.

The average rainfall in Antananarivo is 4.3mm/day. However, precipitation mostly happens during the rainy season, between November and March. During about 50 days the rainfall is 9.5mm/day, and in 20 of those days, 24mm/day. A house with a 60m^2 roof would be able to store 312lt of rainfall in one day considering the average rainfall of 4.3mm, and even 689l per day in the days where the rainfall is 9.5mm/day. Since a commonly used barrel can store only 224lt, for a 60m^2 roof, at least two rain barrels would be recommended, so enough water could be store and later used in that household.

Underground or surface cisterns are another solution that allows harvesting rainwater. In that case, the storage capacity is greater, but given the large size and need for more maintenance and operation (e.g. pump), it could be suitable for larger buildings, such as schools or institutional buildings.

Rain barrels could reduce the daily costs of water supply for a household, provided that the implementation costs are covered by a third party (e.g. NGO, government program) in the case of the most vulnerable families.

Solar street lights

Street lights are scarce in Antananarivo, which is a problem, especially during nighttime evacuation. Solar street lights are a suitable solution that provides uninterrupted public lighting while reducing both implementation and maintenance costs. The implementation of solar street lights could be set up in two phases: a first phase focusing on the 10 evacuation sites and immediate surroundings, and a second phase focusing on the connecting routes, including the routes that lead to off-site locations.

Solar street lights are proven to reduce the implementation costs by 25%, electricity costs by 40%, and maintenance costs by 60%, with a cost of USD$1,600 per solar street light pole, versus the USD$2,150 that a conventional street light pole costs (Gillar et al., 2019).

In addition, other ongoing initiatives could be linked to the implementation of solar street lights. For example, in Antananarivo, there is a company (Jiro-ve[2]) that provides solar-powered lights to households. The business model relies on a franchisee that arranges the charging of the lights, which are delivered to the families every evening. Families have to pay daily for this service, but it costs less than alternative sources of light, such as candles. A system such as this one could complement the installation of solar street lights, by, for example, supplying additional lights for families when they are in the refuge during a flood, or during an evacuation, if part of the routes does not have adequate lighting.

Urban agriculture

Urban agriculture is currently present in the city in two main forms: rice fields in the floodplains and small vegetable gardens in houses or schools. We focus on the second type because it could contribute to the food security of vulnerable families, and would need only basic additional resources since families could implement them at a very low cost in their homes.

After rice, some of the most popular crops in Antananarivo are carrots, potatoes, and chard. Only 3m^2 of land are needed[3] to provide one person with a supply of these vegetables. The larger the family, the larger the amount of land needed, as well as water requirements. Space is crowded urban areas is limited, but if used wisely, a patch of land used for urban agriculture could at least supplement the amount of vegetables that families have to buy. If in addition to this, households reuse greywater for the irrigation of the vegetable gardens, the maintenance costs would be minimal. Furthermore, many families keep a small stack of poultry at home, to ensure a fresh supply of meat, so they could make use of the excrements of the poultry to fertilize their vegetable gardens, implementing a circular system that maximizes resources.

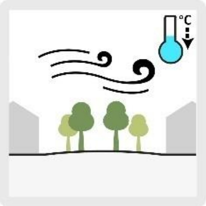
By implementing urban agriculture, the supply of food can be ensured not only in normal times but also during floods. Urban agriculture, in the form of small vegetable gardens, could be implemented also as part of the refuge itself, organized by the fokontany, and only if the community is committed to its maintenance.

[2] For more information visit https://jirove.com/2015/12/16/simplicity-is-beauty-our-model/

[3] Estimation based on the Vegetable Garden Size Calculator, available at https://morningchores.com/vegetable-garden-size/

SPECIFIC MEASURES

Urban forest

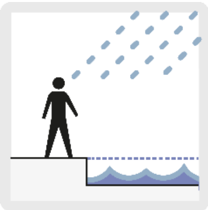


The presence of several open unused spaces around **sites 1** and **6**, some of them of large size, offers the possibility to implement urban forest patches at different locations. Like the previous measures, the presence of trees contributes to mitigate and even prevent soil erosion and landslides. Their roots also contribute to improving the infiltration capacity of the soil (Berland et al., 2017). When trees are present in larger quantities, their positive impact on the atmospheric temperature and air quality is higher. On sites 3 and 9, the urban forest could contribute to creating a border for urbanization, preventing further construction of houses in those areas.

Private green gardens

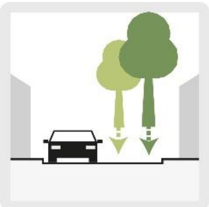
Houses around **sites 1** and **6** are located in bigger lots than houses on the East of the city, which makes the implementation of green private gardens a good alternative to allow for the slow infiltration of rainfall. Besides allowing to retain and infiltrate water on the site, private gardens could contribute to preventing soil erosion, by providing vegetation cover to otherwise exposed soil.

Bioswale + Elevated route (on stilts)



This combination of measures could be used in very flood-prone areas, such as around **sites 3** and **9**. In those areas, floods are very likely to happen, in which case an elevated evacuation route would be needed. An elevated route or boardwalk on stilts provides a safe evacuation route while allowing the free flow of water underneath. These boardwalks could be built with recycled plastic, to reuse materials, reduce costs and potentially create jobs around plastic recycling. Bioswales could be added in this case to improve the drainage and infiltration of water into the subsoil. However, if the flood is too severe, a bioswale will not be sufficient.

Tree line



Trees could be added along main evacuation routes, to make them more noticeable from the distance. They should be located only on one side of the road, preferably on the north side in north-south roads, so they cast a shadow to the south during the day. They are especially useful during the dry season when temperatures are higher. Trees could mitigate and even prevent soil erosion and landslides, by enabling the slower infiltration of rainfall.

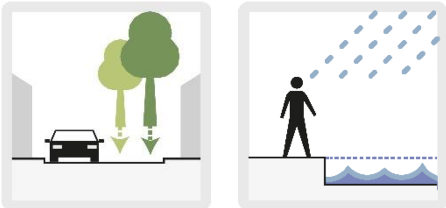
Around **sites 2** and **4**, the main evacuation routes (orange and red) do not need to be raised, and a line of trees along with adequate street lights are enough to provide safe evacuation. This is the case because those sites are located on the highest point of an island-like area, so the rainfall runs off towards the lower areas. Several areas are either paved or have insufficient vegetation cover, so the soil is exposed. This could lead to erosion, especially during the wet season, where most rainfall occurs, may even cause landslides. Trees could contribute to mitigating this effect.

Potential tree species suitable for Antananarivo and/or that have worked well under similar conditions are: *Melia azadirach, Cassuarina equistifolia, Eucalyptus, Calophyllum inophyllum, Araucaria columnarism, Albizzi lebbeck, Acacia Ariculiformis, Anacardium occidentalis, Pinus elliottii caribea, Grevillea banksia, Moringa oleifera, Teminalia mantaly, Dalbergia baronii, Aberia caffra, Mangifera indica, Gliricidia robusta, Musa, Litchi chiniesis, Cocotier, Ravinala, Perseu america, Psidium guajava*.

Tree line + Bioswale + Elevated route (elevated soil)

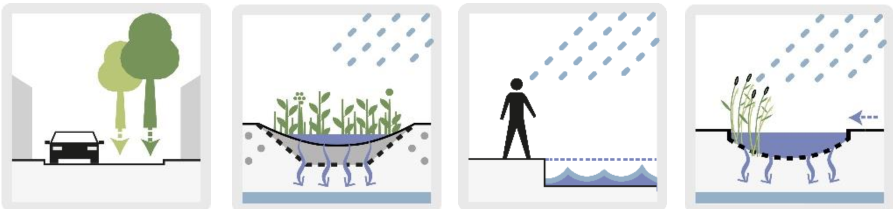
Along orange and red routes leading to **sites 1**, **5** and **6**, trees should be planted, together with an elevated route (elevated soil) that allows for the safe evacuation of people. Bioswales should be implemented in combination with these measures along the routes to direct the runoff towards the lower swampy areas while allowing for its better infiltration into the subsoil.

Tree line + Elevated route (elevated soil)



On specific locations where there is not enough space to implement both trees and bioswales along the evacuation routes, trees should be prioritized, since trees are relevant for the visibility of the routes. This is the case for example in the densely populated areas to the south of **site 9**. This combination of measures is also suitable for areas next to canals or retention basins, because the excess water is drained directly into them. This is the case along the Anosibe basin, on **site 3**. There, there is enough room for bioswales, but there is no need for them along the route on the border of the basin. Hawker stalls could be installed temporarily along it, to facilitate the informal trade that is already taking place on that site.

Tree line + Bioswale + Elevated route + Retention pond



This combination of measures could be implemented on **sites 3, 7, 8, 9** and **10.** Bioswales act as surface drainage systems, and therefore they should be connected to the main canals or retention pond/basins. The bioswales serve to drain and slowly infiltrate the excess rainfall, directing it to other bigger canals that can drain it outside the city. They could also drain rainfall to retention ponds/basins that can store it while it slowly infiltrates. Both elevation and the slope of these sites are low, so special attention should be given to water flows, to avoid that the implementation of elevated routes acts as a dike, enclosing water on this specific area in a pool-like situation. Sites 3 and 8 can connect to the C3 canal and Anosibe basin, site 9 to both the C3 canal and the Adriantany canal, and sites 7 and 10 to the GR canal. A helophyte filter could be included as part of the retention pond, to filter the water in the pond, and ensuring its quality.

Elevated refuge + Park + Tree line

Elevated refuges could be developed as a park-like area, surrounded by trees that define its borders while providing shade. This combination of measures could apply to all sites, especially site 3, where there is enough available space. A park-like intervention on this site could be used for recreation, social events, and informal trade (weekly market), and only be used as a refuge during floods.

2.4 Relevant stakeholders

Given the complex nature of the project, which combines NbS, disaster evacuation, and flood risk reduction, the stakeholders that are relevant for the design, planning, and implementation of this project are diverse. **Figure 25** shows the main stakeholders relevant for each site, and the ones that are relevant for all sites organized according to their level of action (site, city, national).

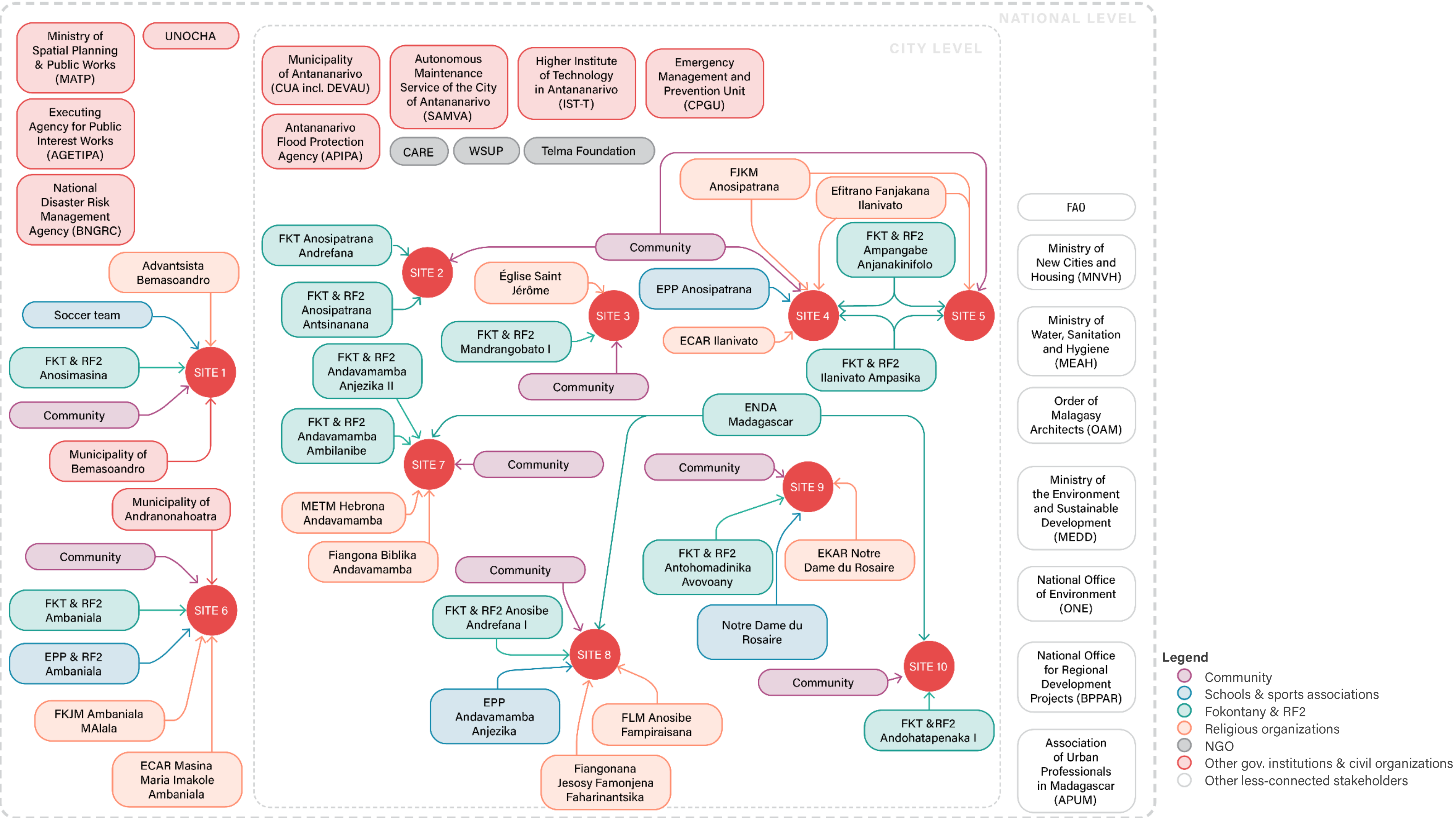


Figure 45. Overview of the relevant stakeholders for each site

The current level of engagement and action of the different fokontany varies. The same applies to the level of community participation. Some fokontany, such as Ambaniala (site 6) and Antohomadinika Afovoany (site 9), are very active, engaged, and committed to their community. In other cases, such as Anosimasina (site 1), even though the fokontany is not very active, the community is engaged and willing to participate in activities that improve their environment (e.g. organized community cleaning[4]).

Overall, the 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. Moreover, **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 as well. This also relates to the historic organizations in Antananarivo responsible for the maintenance and operation of the hydraulic infrastructure (**see section 1.1 of the Diagnostic report**) to protect the inhabitants of the city from floods.

In the first stage, such a setup could be implemented on the fokontany where the chosen pilot sites are, to test their feasibility. At a later stage, they could be expanded to cover all the fokontany in the city. It is important to keep in mind that not all RF2 are equally engaged and active, therefore this should be accompanied by intensive training and other educational activities that support this work, as well as community engagement activities.

2.5 Beneficiaries

2.5.1 Estimated population exposed to floods

The population exposed to floods was estimated per fokontany (**see Annex A**). In this section, we present these estimations in relation to each one of the 10 selected sites, providing an overview of the potential population that would need refuge on those sites.

[4] Source *Note sélection des sites de projets pilotes* (Hydroconseil - Urbaconsulting – ARAFA, October 2020)

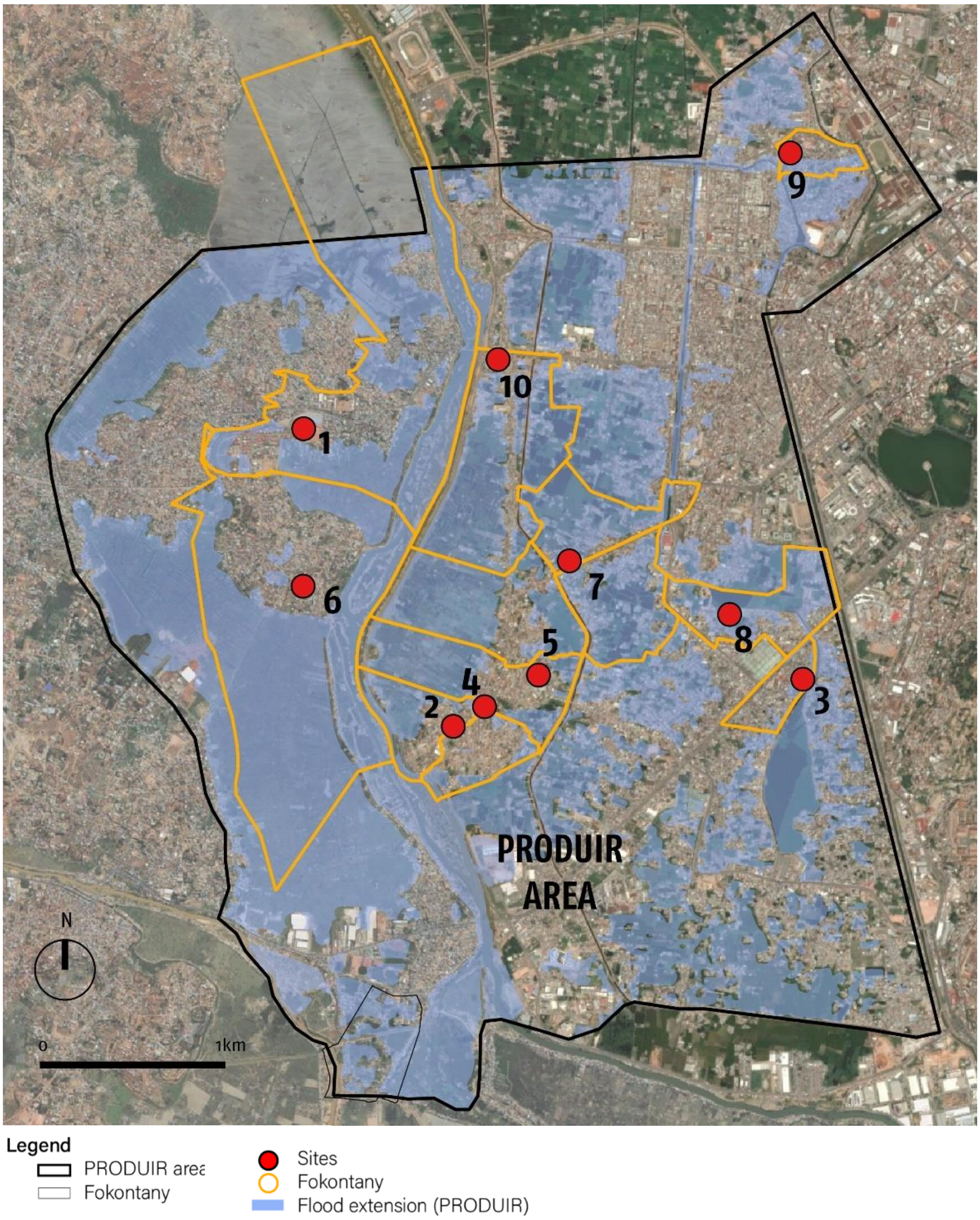


Figure 46. Overview of the 10 selected sites in relation to the estimated flood extension from PRODUIR and the fokontany which population is expected to evacuate to the site during floods.

We have focused on identifying opportunities for the implementation of NbS for disaster evacuation and flood risk reduction. This has led to a rationale where firstly a potential site is identified and assessed, estimating what is the capacity of such a site for refuge. Because the rationale gives importance to the replicability of the solutions, it is not expected that one site will be sufficient to accommodate all the exposed population in its surroundings. Considering that, this estimation of the population exposed to floods serves to: (a) assess whether or not the proposed sites can accommodate the population exposed to floods, and (b) prioritize the future implementation of solutions.

Table 2. Overview of the 10 selected sites, their capacity for refuge, and the population exposed in the fokontany around them. The red circles within each fokontany show the location of each site in relation to the extent of the fokontany.

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%)

Some remarks about these results:

- Only site 1 is capable of accommodating the exposed population around it and more. This supports the use of this site not only as an on-site refuge but also as an off-site one, accommodating people from other fokontany as well.
- Sites 6, 3 and 9 can accommodate over 60% of the population exposed. Around site 6 there are several potential alternative refuge sites to compensate for that difference. On sites 3 and 9 there are very limited open areas that could be used for this purpose.
- Site 10 can accommodate almost 40% of the population exposed. Even though the population of this fokontany is high, many of them inhabit slightly higher grounds and are not exposed to floods.
- Sites 2, 4, 5 and 7 can accommodate between 10-20% of the population exposed. This is mostly because the sites are located on the border between two or three fokontany, so they should accommodate the population exposed to all of them.
- Site 8 can only accommodate 10% of the population exposed. This site is located in a very flood-prone area, in a densely populated fokontany. The space available for refuge is very limited.
- **The estimated total population that would benefit from the implementation of the refuges in the ten selected sites is 37,128 persons**.

2.5.2 Beneficiaries of the NbS co-benefits

Nature-based Solutions (NbS) provide several co-benefits, depending on the type of solution, location, and scale. **Figure 28** shows the measures proposed in relation to the co-benefits they provide and the expected beneficiaries of those co-benefits. This is a conceptual and simplified diagram since there are several more variables and interrelations, but it provides an overview of the main links that we are considering. The main expected co-benefits are:

- **Heat stress reduction.** Trees can decrease the air temperature between 2-5°C in the immediate vicinity (Pötz et al., 2012). This effect can be further increased in areas where several trees are planted together, such as an urban forest.
- **Improvement of food supply and reduction of household expenses**. When households implement small-scale urban agriculture (e.g. vegetable gardens) they are more self-sufficient and depend less on their monetary income to access healthy food. This is particularly relevant for the most vulnerable families who have limited resources and highly depend on their daily income to provide food to their families. During the current pandemic, these families risked their safety to go out and earn their daily income and be able to buy food, even though that was not allowed. Urban agriculture could at least reduce the pressure on many families who work to be able to pay for their food. In addition, it could contribute to reducing the expenses per household, by supplementing the vegetables that families need to buy.
- **Recreation areas for well-being and social cohesion**. The World Health Organization recommends that cities provide at least 9m^2 of green areas per person (WHO, 2010). The number of green areas in Antananarivo is well below this number, with only a handful of areas formally designed as parks or squares. Most of the areas that appear to be green are rice fields or basins that are covered with water hyacinth. While these areas are technically green, they do not provide the benefits expected of green areas, such as improvement of people's wellbeing through the provision of spaces for recreation, among others. Even though the proposed measures do not achieve the recommended number, they at least contribute to increasing the green area per person, which is particularly beneficial for the community where the green area is located.
- **Increase biodiversity.** Urban wetlands and forests are larger areas with vegetation that can contribute to increasing the biodiversity
- **Reduction of erosion and landslide risk.** The increase of the vegetation cover can decrease soil erosion by lowering soil moisture. Trees in particular also contribute to reinforcing the soil layers, which decreases landslide risks.

- **Improvement of air quality and water quality**. Trees produce oxygen and remove pollutants from the air, improving air quality. Vegetation like certain types of grasses, when placed in bioswales and retention ponds can improve water quality by reducing nutrients and pathogens, and absorbing pollutants.
- **Improvement of spatial quality**. The addition to NbS will change the aesthetics of the area, improving its spatial quality.

Beneficiaries of these co-benefits are divided into four main categories: household, neighborhood community, city, and communities downstream of Antananarivo.

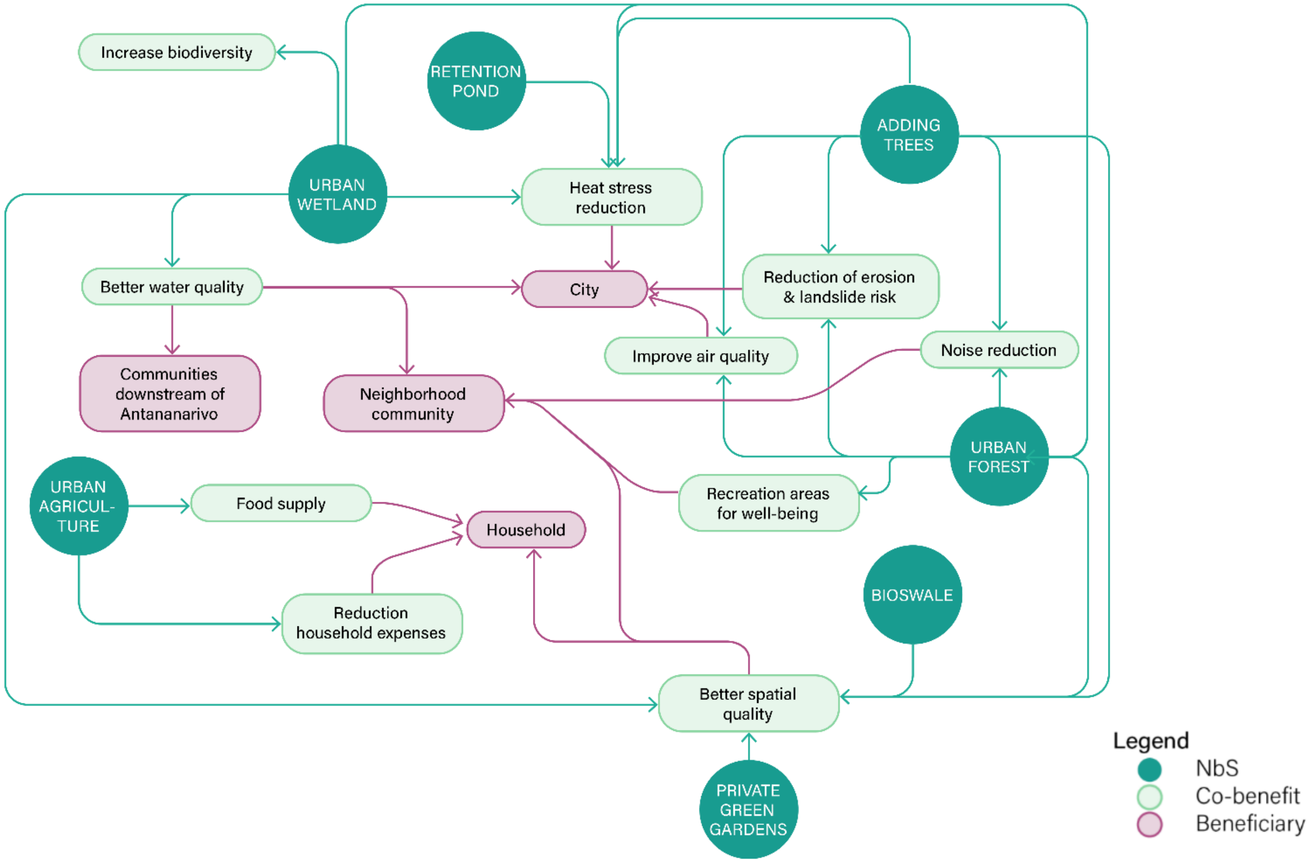


Figure 47. Overview of NbS, co-benefits, and beneficiaries. Urban wetland is an umbrella that includes retention ponds with helophyte filters.

2.6 Synergies with other initiatives and future projects

Building on the findings from the Scenario Building and Synergies presentation, we work with two main approaches: shared location and shared costs.

Shared location: it involves the multifunctional use of space. There are currently several works planned within the PRODUIR area. In some of them, we see the suitability of the shared location approach, combining planned infrastructure works with the implementation of NbS. The most relevant ones for this project are:

- Dredging of Anosibe basin and renovation of its border | Site 3
- Renovation of road north of Site 9 | Site 9.
- Urban upgrading along with dredging and renovation of basin and C3 canal | Site 8
- New pluvial drainage system from PIAA (Cuoton et al., 2018) | Site 7, 10
- Retention basins from PIAA (Cuoton et al., 2018) | Site 10

Shared costs: measures (NbS and other measures) can be expensive, so it is more convenient to try to combine them or look for the right moment for implementation, to reduce their cost. With this in mind, the future infrastructure and housing projects could be combined with NbS to minimize costs and provide co-benefits. For example, new housing projects could consider measures such as rain barrels or bioswales as part of their design; or the construction of new roads could include a participatory reforestation component, where the community contributes to plant trees as part of the works required to build the road.

In the short-term, ongoing projects could connect to proposed interventions on the ten selected sites. At a later stage (medium to long term), NbS could be integrated already into the design of new projects. **Figure 29** provides a timeline with ideas to achieve quick wins.

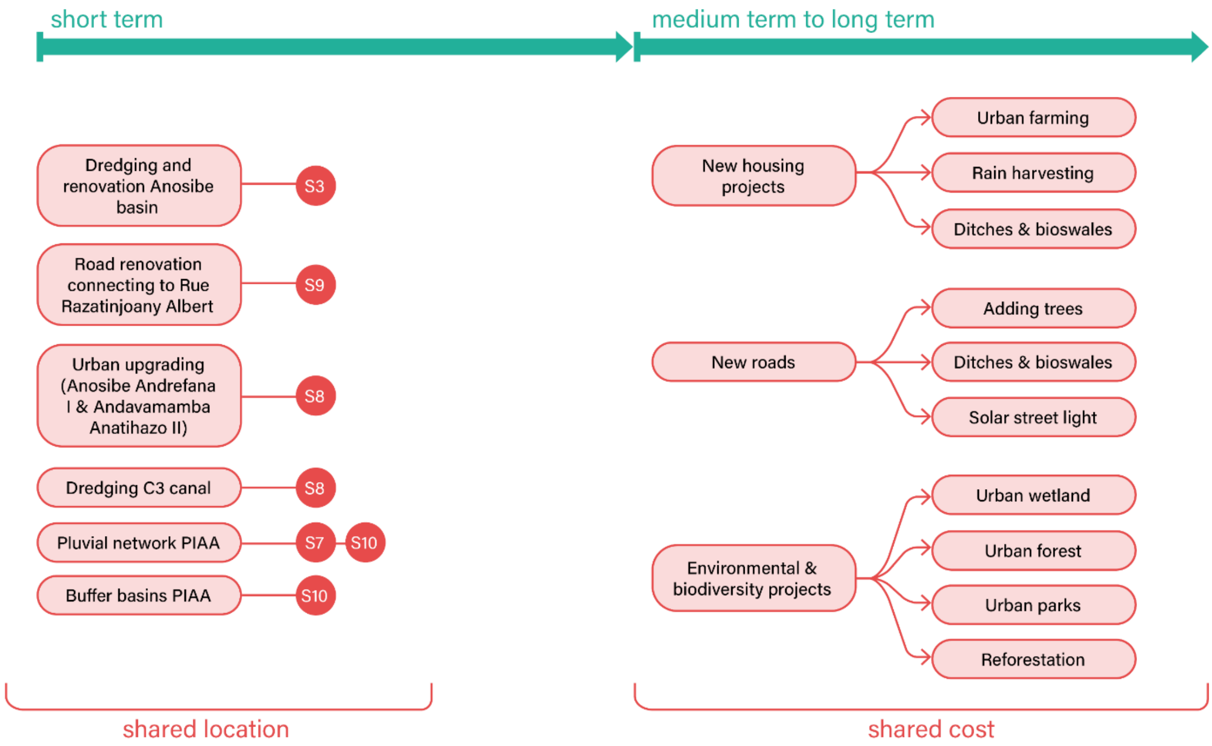


Figure 48. Overview of possible synergies with other initiatives and future projects

Using the shared locations and shared costs approaches, we envision the following synergies in the short term:

- **Dredging of Anosibe basin and renovation of its border | Site 3**. A detailed design is not yet available for this project, but the following aspects could be considered to maximize synergies:
  - construct embankments to elevate pedestrian roads along the basin, providing safe evacuation routes and enough room for the discharge of ditches leading to the basin
  - plant trees along the pedestrian routes to provide shade (reduce heat stress) and mark evacuation routes.
- **Renovation of road north of Site 9 | Site 9.** While renovating the road, consider planting trees on its north side, to provide partial shade to both pedestrians and informal traders. If possible, and after conducting the necessary studies about the detailed groundwater levels and elevation, the new road could already include drains from the flood-prone area to the C3 and Adriantany canals
- **Urban upgrading along with dredging and renovation of basin and C3 canal | Site 8**. The edge of the basin could be marked using trees to show a clear edge that prevents further expansion of the informal settlements. The evacuation route along the basin could be planted with trees as well, to emphasize where the evacuation takes place, as well as to provide shade to pedestrians.
- **New pluvial drainage system from PIAA (Cuoton et al., 2018) | Site 7, 10.** Build drains from the surface water storage areas in sites 7 and 10 (e.g. wetlands, bioswales) so when they reach their capacity, excess water can be drain using the new pluvial drainage system.
- **Retention basins from PIAA (Cuoton et al., 2018) | Site 10.** One of the retention basins planned as part of PIAA partially overlaps with site 10. This allows using the excavated material from the basin to elevate the refuge and evacuation routes.

2.7 Shortlist of sites for prefeasibility

Based on the review provided in the previous sections, we selected three sites to conduct the prefeasibility assessment: sites 1, 3 and 9.

Site 1 was chosen primarily because it is both a refuge site indicated in the UNOCHA plan as well as used by the community, which makes it a robust refuge option. Even though it is not flood-prone, it is located next to a flood-prone area, so it can have a great impact on evacuation and refuge in the area. In addition, it is in an area of the city that is not fully urbanized yet, so there is still great potential for the implementation of NbS. If unplanned urbanization continues, it could make this area more impermeable, preventing adequate infiltration and increasing runoff, which increases flood risk, especially in areas with lower elevation. Instead, if NbS are implemented, they can stir the process in a direction that decreases risks while maximizing opportunities.

Site 9 was chosen because it does not share the same characteristics and potential as site 1. Site 9 is located in a flood-prone and densely urbanized area, with an urgent need to provide safe and expedite disaster evacuation, but few opportunities to do so. These opportunities are threatened by the ongoing encroachment, so it is a challenging site, strategic measures at this point could have a positive impact on disaster evacuation and flood risk reduction.

Site 3 was chosen last, and it has several similar characteristics to site 9, but with a distinctive additional opportunity: there is a large empty site with the potential of becoming a refuge site, next to a basin that will be dredged and renovated in the short term. The site is used temporarily as a market and for other activities, and it is privately owned. It was not chosen initially due to the lack of information about the renovation project in the basin and its edge, and the lack of data about the community, because the household survey did not cover this area. However, we believe that including this site could be useful to provide recommendations for the renovation project that will take place in the basin.

Below, there is an overview of the main aspects that were relevant for choosing the sites.

Site 1

- **Urban typology**. Located on the urban typology E2 – Island city (latest occupation). This is a more recently urbanized area, where there are still several empty lots, therefore potential opportunities for the implementation of NbS. 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**. Given the current expansion of the city and the growth of the commune of Bemasoandro, it is expected that urbanization will continue as the population of the city increases. For example, in several fokontany that are part of the Informal city landscape type, this process is well underway. In those areas, urbanization has continued to stretch from the hills on the East towards the floodplains, which has increased the population exposed to floods. On site 1 this is not yet the case, but it can be argued that if urbanization continues in that area, people will settle in low-lying areas, and will be more exposed to floods. Besides floods in the areas south of this site, there is a risk of landslides, caused by soil erosion.
- **Priority.** The sense of urgency to implement solutions on this site is low. However, if we take into account the implementation times of NbS and the fact that if nothing is done, future urbanizations will reduce current opportunities for implementation, this is a good time to begin planning for flood resilient interventions in the area.
- **Soil**. The roofs of houses and compacted soil of roads in the new urbanized areas are more impermeable than the original soil. This, in addition to the elevation differences of over 10m in this area, causes rainfall to run off on the surface and is not easily infiltrated, triggering erosion.
- **Evacuation opportunities**. UNOCHA has selected this site (soccer field) as one of the refuge sites of their plan. This is also a site where the community evacuates intuitively.
- **Governance**. The fokontany of Anosimasina is not very active at the moment, but the community is very involved in organizing and implementing activities to improve their neighborhood. This fokontany is part of the commune of Bemasoandro, different than CUA, but also part of Antananarivo.

Site 3

- **Urban typology**. Located on the border of urban typologies C – The water basins and F2 – Informal city densely built. This is a very urbanized area, well connected by land and water (across the Anosibe basin). There are some open spaces with the potential to be used for the implementation of NbS, but only one of them is large enough to be used as a refuge site. That site has a temporary use as a marketplace, but it has been urbanized in recent years. Given its strategic and central location, this site could serve several purposes, catering to the needs of a large group of people, both from Mandrangobato I as well as the surrounding fokontany.
- **Hazards**. This is a very flood-prone area, so its increasing densification leads to an increase in the population exposed to floods. This area also suffers from sanitation problems that worsen the impact of floods. Interventions on this site could contribute both to improve the evacuation of the population, as well as limited the further densification of this flood-prone area.
- **Priority.** The sense of urgency to implement solutions on this site is high. Drainage is not optimal, because of the unorganized disposition of the houses, the presence of solid waste in most existing ditches, and the subsurface characteristics. The increase in population (including migrants)could likely increase the production of solid waste, increasing this problem further.
- **Soil**. The soil is of alluvial deposits. Specific characteristics of the soil are unknown, but it is expected that this is sandy soil. However, because the groundwater level is shallow, regardless of the porosity of the soil, there is not a lot of space in the subsurface to store water. After heavy rainfall, this causes the water to stagnate in multiple locations.

- **Evacuation opportunities**. UNOCHA has defined this site as an assembly point. In addition, there are two other assembly points in the immediate surroundings and one refuge site less than 200m from this site. Accessibility in some areas within this site is poor, even though it is quite central.
- **Governance**. The fokontany of Mandrangobato I is active and committed, as well as the RF2. The population is aware of the existing risks and interested in improving their current environment[5].
- **Other**. This site was not initially selected, because it had not been part of the household survey. However, there is a project in progress for the renovation of the Anosibe basin and surroundings, so the prefeasibility of this site could contribute to that project. There is also a waste sorting and recycling initiative that could be connected to interventions on this site. In addition, this site was visited during the field visit in February 2020.

Site 9

- **Urban typology**. Located on the border of urban typologies B – The canals and F2 – Informal city densely built. This is a very urbanized area, well connected by land and water. There some open spaces with the potential to be used for the implementation of NbS, but this constantly changes due to the increasing densification of the area by means of informal settlements, including migrants from other regions of the country.
- **Hazards**. This is a very flood-prone area, surrounded by canals. Its increasing densification leads to an increase in the population exposed to floods. This area also suffers from sanitation problems that worsen the impact of floods. Interventions on this site could contribute both to improve the evacuation of the population, as well as limited the further densification of this flood-prone area.
- **Priority.** The sense of urgency to implement solutions on this site is high. Drainage is not optimal, because of the unorganized disposition of the houses, the presence of solid waste in most existing ditches, and the subsurface characteristics. The increase in population could likely increase the production of solid waste, increasing this problem further.
- **Soil**. The soil is of alluvial deposits. Specific characteristics of the soil are unknown, but it is expected that this is sandy soil. However, because the groundwater level is shallow, regardless of the porosity of the soil, there is not a lot of space in the subsurface to store water. After heavy rainfall, this causes the water to stagnate in multiple locations.
- **Evacuation opportunities**. On the surroundings of these sites, there are 3 assembly points defined by UNOCHA. From the household survey, we discovered that the community uses part of site 9 as a refuge. Moreover, they proposed site north of site 9 as a potential refuge.
- **Governance**. There is no information about the level of engagement and participation of the fokontany and RF2.

[5] Source *Note sélection des sites de projets pilotes* (Hydroconseil - Urbaconsulting – ARAFA, October 2020)

3 Assessment of measures

This section addresses the assessment of the measures in terms of the effectiveness of routes and refuges and the effectiveness of NbS for both flood reduction as well as co-benefits.

3.1 Effectiveness of Routes and Refuges

The first part of this section consists of assessing the effectiveness of routes and refuges for disaster evacuation. First, we map the location of existing evacuation routes connected to the site, including the ones indicated during the household survey. Second, we analyze the population mobility, including the characteristics of the route (e.g. length, type of pavement, etc.). Third, we propose alternative refuge sites and adjust the evacuation routes if needed.

SITE 1

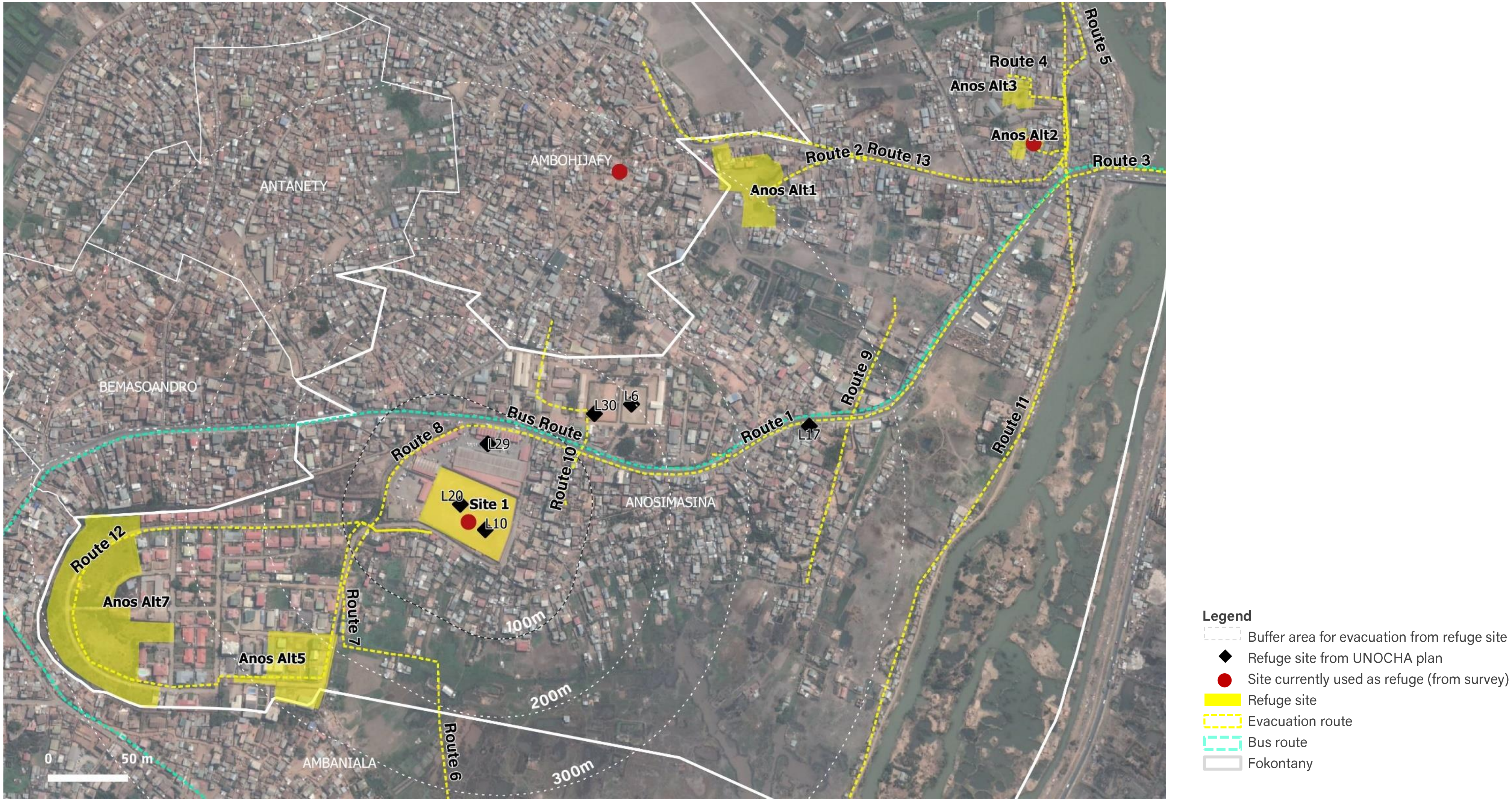


Figure 49. Overview of refuge site 1, evacuation routes, and alternative refuge sites.

Evacuation routes and refuge sites

According to the household survey results, people are warned when there is an imminent flood risk. Taking into account that during an evacuation event people can travel 500m, then it is possible to recommend several other locations for on-site evacuation. During phase II of the evacuation plan, when this site is used for off-site refuge, these additional locations could accommodate the remaining people that exceed the capacity of site 1.

Within the Anosimasina Fokontany – based on aerial photography not all of the fokontany is occupied by residential settlements. Places for people to evacuate should be within the area that is currently settled. The seven alternative sites that have been identified may not be of equal quality and value. Considering purely the size of an area based on aerial photography is only an indicator of suitability. Some of the proposed alternative sites correspond with responses to the household survey and workshops (e.g. Anos Alt 2). **Table 2** shows the main characteristics of the different refuge sites and evacuation routes shown in **Figure 30**.

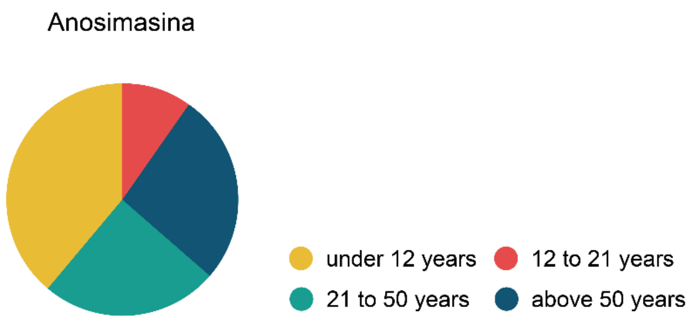
Table 3. Alternative sites and Catchment Population details for Site 1

Fokontany: Anosimasina Total population: 19,097 Estimated exposed population: 4,679 in Anosimasina					
		Evacuation Routes			
Sites		**Name**	**Length (m)**	**Information source**	**Type of route**
Location:	**Site 1**	Route 1	779	Surveys - Evac	Grass Pavers
Public/ Private:	Public (soccer field) / Private (parking lot)	Route 2	129	-	Boardwalk
Elevation (m):	1,257	Route 3	257	-	Boardwalk
Surface Area (m²):	8,800	Route 4	368	-	Boardwalk
On-site (n. persons):	5,867	Route 5	757	Surveys - Evac	Paths
Location:	**Anos Alt1**	Route 6	344	Surveys - Evac	Boardwalk
Elevation:	1,251	Route 7	242	Surveys - Evac	Boardwalk
Surface Area (m²):	5,729	Route 8	621	Surveys - Evac	Paths
On-site (n. persons):	3819	Route 9	385	Workshop 2	Boardwalk
Location:	**Anos Alt2**	Route 10	304	Workshop 2	Boardwalk
Elevation (m):	1,256	Route 11	2293	-	Paths
Surface Area (m²):	962	Route 12	1046	-	Paths
On-site (n. persons):	641	Route 13	612	-	Grass Pavers
Location:	**Anos Alt3**	Bus Route	2803	OSM Bus Route	Bus Route
Elevation (m):	1,253				
Surface Area (m²):	1,156				
On-site (n. persons):	771				
Location:	**Anos Alt4**				
Elevation (m):	1,253				
Surface Area (m²):	2,094				
On-site (n. persons):	1396				
Location:	**Anos Alt5**				
Elevation (m):	1,256				
Surface Area (m²):	7,521				
On-site (n. persons):	5,014				
Location:	**Anos Alt6**				
Elevation (m):	1,253				
Surface Area (m²):	813				
On-site (n. persons):	542				

Location:	**Anos Alt7**
Elevation (m):	1,254
Surface Area (m^2):	22,704
On-site (n. persons):	15136

Vulnerability Indicators

In May 2020 a household survey was conducted with 40 Anosimasina residents participating in the survey.



The survey results indicated the following:

- Only a small amount of the residents were over 50 years of age.
- 4 disabled people were identified as part of the surveyed group (±2% of the residents of the households surveyed).
- The number of young residents – those up to the age of 12 is high considering they make up roughly a quarter of the population included in the survey group.

Technical design of evacuation routes and refuges

The images for Site 1 show these elements:

- Existing soccer field as a refuge
- Lighting around the soccer field
- Boardwalk made of recycled plastics as evacuation route on lower areas
- Tents for temporary shelter on the refuge site
- Medical facilities
- Water stations to supply clean water

Figure 50. Context of different upgrades to Site 1. View from north to the south-west.

Figure 51. Soccer field as refuge site. The soccer field has been constructed as a terrace on the slope, with its surroundings at a lower elevation, except for the buildings and road on the north. Our preliminary assessment indicates that the flood extent does not cover the soccer field, so it would not be necessary to raise this area further, as it was initially proposed.

Figure 52. Simulation of evacuation by boat. Even though this is a common practice during floods, this type of evacuation is not preferable, since it is not considered safe enough by the government.

Figure 53. Elevated houses on stilts. This type of solution is preferable for future urbanization projects in areas with lower elevation, more exposed to floods

Figure 54. Boardwalk on stilts are suggested on the areas with lower elevation

Figure 55. Bird's eye view of site 1 from the south, where the swamp is located.

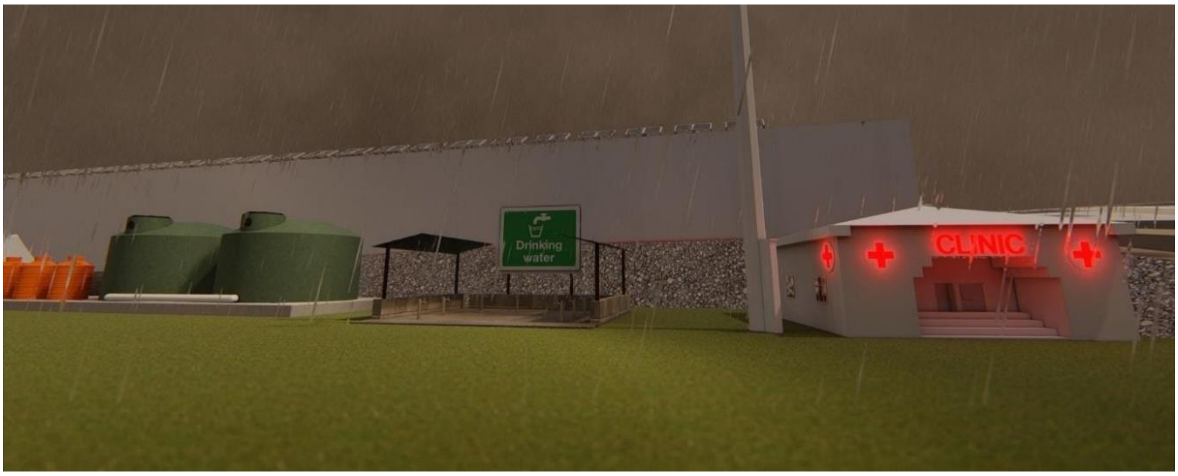


Figure 56. Medical facilities and water supply on the refuge site

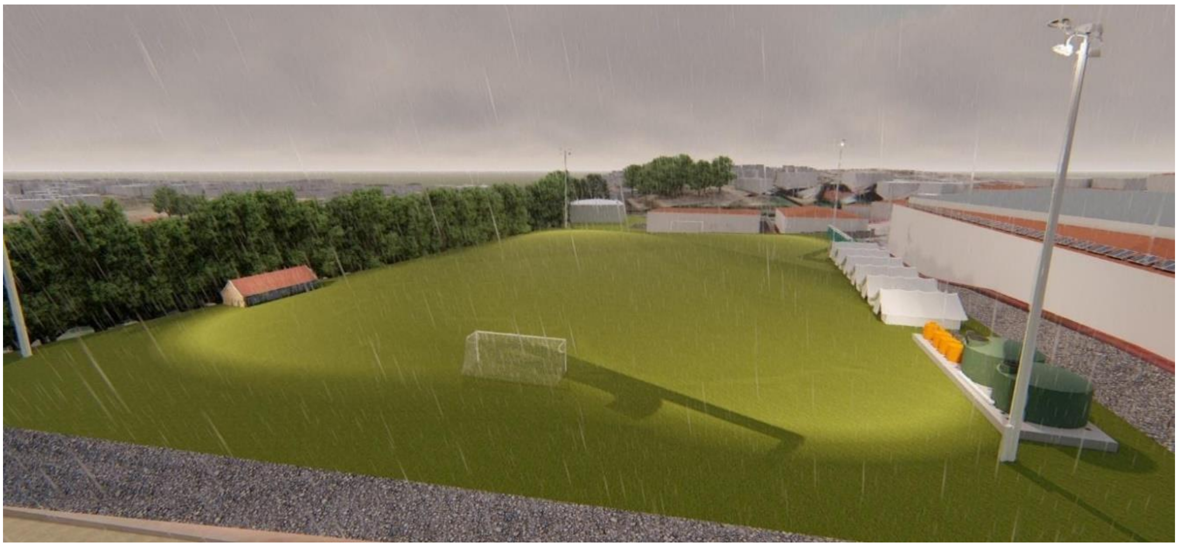


Figure 57. East-West bird's eye view of the soccer field

SITE 3

Figure 58. Overview of refuge site 3, evacuation routes, and alternative refuge sites.

Evacuation routes and refuge sites

This site is located within the Mandrangobato I fokontany, near an evacuation location identified by UNOCHA as Assembly Point 70. There are further evacuation sites proposed that would accommodate some of these people.

For all considered fokontany it is possible, based on responses from the household survey and two workshops, to suggest various evacuation routes. Most of these routes will need to be upgraded and maintained to ensure they can be useful. **Table 3** shows the main characteristics of the different refuge sites and evacuation routes shown in **Figure 39**.

Table 4. Alternative sites and Catchment Population details for Site 3

Fokontany: Mandrangobato I Total population:12,600 Estimated exposed population: 9,261					
Sites		**Evacuation Routes:**			
		Name	**Length (m)**	**Information source**	**Type of route**
Location:	**Site 3**				
Public/ Private:	Public	Bus route	748	OSM Bus Route	Bus Route
Elevation (m):	1,250	Route 1	289	Work2 - offsite rout	Paths
Surface Area (m^2):	5360	Route 2	448		Grass Pavers
On-site (n. persons):	3,573	Route 3	125		Boardwalk
Location:	**Mand Alt1**	Route 4	157		Boardwalk
Elevation (m):	1,250	Route 5	145		Boardwalk
Surface Area (m^2):	873				
On-site (n. persons):	582				
Location:	**Mand Alt2**				
Elevation (m):	1,250				
Surface Area (m^2):	426				
On-site (n. persons):	284				

Vulnerability indicators

The household survey did not cover this area, so no relevant information is available on this topic.

Observations

- Areas probably need to be raised
- Capacity could be a problem
- Main access roads could be the roads along the canal/lake.
- Houses are clustered, in a low, but not very swampy area. Dikes could be used to improve the site.

Technical design of evacuation routes and refuges

Image for site 3 shows the raised soccer field including tents, hawker stalls, medical and water facilities, and trees.

Figure 59. Overview of various improvements to the site for evacuation and refuge for site 3

Figure 60. East-West bird-eye view of site 3, from across the Anosibe basin.

Figure 61. East-West view of site 3, including an elevated route along the basin. This was a preliminary design. The type of elevated route was later change to an elevated route on elevated soil.

Figure 62. Park-like elevated refuge, including a playground area.

Figure 63. East-West bird's eye view of site 3, including a tree line along the evacuation route and the hawker stalls. This was a preliminary design. The type of elevated route was later changed to an elevated route on elevated soil.

Figure 64. Multifunctional use of the space of an elevated refuge during normal times.

SITE 9

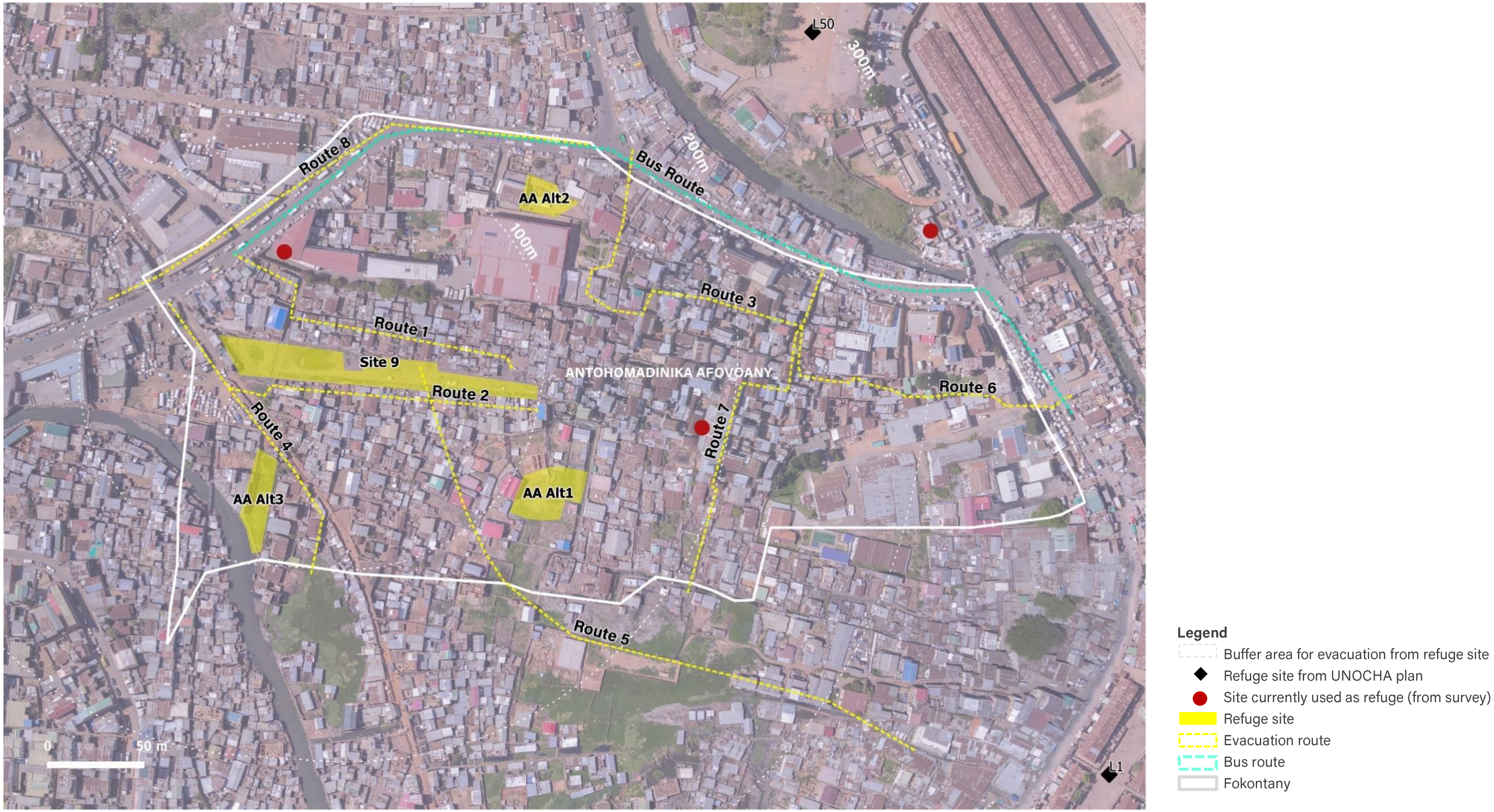


Figure 65. Overview of refuge site 9, evacuation routes and alternative refuge sites, within the fokontany Antohomadinika Afovoany (solid white line).

Evacuation routes and refuge sites

This site is located within the Antohomadinika Afovoany fokontany, in the far north-east of PRODUIR area. The site is also near to an evacuation location identified during the workshop.

The population of this fokontany is 3,534. According to estimations, 3,030 of those people are exposed to floods. The site can accommodate a maximum of 2,027 persons for on-site refuge. As a result, there are roughly 3,000 people still to be accommodated. There are three further evacuation sites proposed that could accommodate most of these people.

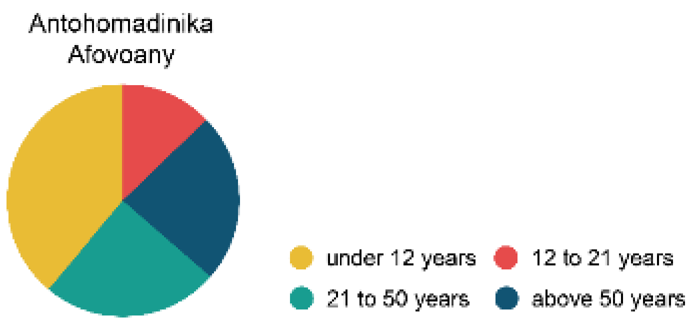
For both fokontany, it is possible – based on responses from the household survey and two workshops to suggest various evacuation routes. Most of these routes will need to be upgraded and maintained to ensure they can be useful. **Table 4** shows the main characteristics of the different refuge sites and evacuation routes shown in **Figure 45**.

Table 5. Alternative sites and Catchment Population details for Site 9

Fokontany: Antohomadinika Afovoany Total population: 3,534 Estimated exposed population: 3,030					
Sites		**Evacuation Routes:**			
		Name	**Length**	**Information source**	**Type of route**
Location:	**Site 9**	Route 1	173.68	Surveys – Evac	Boardwalk
Public/ Private:	t.b.c.	Route 2	164.45	Surveys - Evac	Boardwalk
Elevation:	1,251	Route 3	241.67	Workshop 2	Boardwalk
Surface Area (m^2):	2200	Route 4	167.13	Surveys - Eva	Paths
On-site (n. persons):	1,467	Route 5	356.08	Workshop 2	Boardwalk
Location:	**AA Alt1**	Route 6	176.25	Workshop 2	Boardwalk
Elevation (m):	1,252	Route 7	176.19	Surveys – Evac	Boardwalk
Surface Area (m^2):	800	Route 8	272.69	-	Grass Pavers
On-site (n. persons):	533	Bus Route	510.31	OSM Bus Route	Bus Route
Location:	**AA Alt2**				
Elevation (m):	1,252				
Surface Area (m^2):	400				
On-site (n. persons):	267				
Location:	**AA Alt3**				
Elevation (m):	1,251				
Surface Area (m^2):	586				
On-site (n. persons):	391				

Vulnerability Indicators

In May 2020 household survey was conducted with 51 residents of Antohomadinika Afovoany participating in the survey.



Deltares

The survey results indicated the following:

- Only a small amount of the residents were over 50 years of age.
- 1 disabled person was identified as part of the surveyed group
- The number of young residents – those up to the age of 12 is high considering they make up roughly a quarter of the population included in the survey group.

Observations

- Access not possible by walking along a canal (only by boat or other roads)
- Mainly used for people living in SE of nr 9. Low, but not very swampy area.
- People living on the west side of the canal need to cross the canal, existing bridges are not always sufficient (and safe)

Technical design of evacuation routes and refuges

The images for Site 9 show these elements:

- Boardwalk made of recycled plastics
- Bioswales
- Tents
- Medical facilities
- Water stations

Figure 66. Elevated houses and boardwalks on stilts, elevated refuge site, and bioswale. Elevated houses and boardwalks are encouraged as a solution for areas with a low elevation that are more exposed to floods.

Figure 67. Elevated houses including a rain harvesting system, a boardwalk on stilts, and a bioswale

Figure 68. South-North bird's eye view of site 9

Figure 69. West-East bird's eye view of site 9

3.2 Effectiveness of selected NbS

As explained earlier in section 2.3 on NbS prospects and complementary measures, NbS can address several challenges at the same time, which in turn is translated into benefits for the community and the environment, and potentially to the local economy. The objective of this section is to assess the effectiveness of NbS in reducing floods and promoting other benefits. We worked with a design-based approach, following research-by-design methodology, where we developed a preliminary conceptual design for the three sites that we tested, refined, and then tested again following an iterative process.

To test the measures, we used the Adaptation Support Tool (AST[6]), a publicly available online tool that allows the user to assess the relevance and efficiency of pre-defined measures in terms of storage capacity, heat stress reduction, and water quality improvement. The measures are mostly NbS or hybrid (NbS combined with traditional infrastructure). Other benefits were assessed qualitatively, based on literature and expert knowledge. We focused on the measures that ultimately provided the greater impact for each site (i.e. the most efficient).

Based on a previous assessment during the diagnostic phase of this study, we expect that the NbS will not be sufficient to completely prevent floods, but they could contribute to reducing flood risks. In addition, we expect that the measures will contribute to other societal, economic, and environmental benefits while being a fundamental part of disaster evacuation infrastructure.

3.2.1 Preliminary Plan for the integration of NbS and disaster evacuation

The main idea for the plan is to create a safe, elevated, and multipurpose space that can serve as a refuge during a disaster event, namely a flood. During normal times, space could be used for recreation activities, such as sports and social meetings, as well as small-scale informal trade (i.e. weekly market). It should be easily accessible through a network of elevated routes that safely connects to main evacuation routes. In terms of water management, the main strategy is dealing with water locally, first storing excess rainfall, then infiltrating it, and finally- if needed - draining it.

[6] The tool is publicly available at https://antananarivo.crctool.org/

SITE 1

Figure 70. Location of proposed NbS and complementary measures for flood risk reduction for site 1.

Strategy

This site is not flood-prone, but the surrounding areas on the south are. Considering the site characteristics, which include elevation difference, scarce public greenery, and the existence of a public sports facility, the strategy for this site is based on:

- Manage rainfall locally by:
  - Storing rainfall on-site for a later use
  - Infiltrating rainfall slowly and as clean as possible, reducing pollution on the subsurface
  - Drain excess water to the 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 reducing potential heat stress
- Develop a network of safe evacuation routes, that are elevated and well indicated, from the swampy areas towards safer higher areas.

Measures proposed

The selected measures for this site are:

Urban forest / Adding trees

Figure 71. Warje Urban Forest, Pune, India. The urban forest was developed on a slope, in a plot of land that used to be barren land surrounded by informal settlements. Credits Rohits Pankar

Trees are used to make main evacuation routes and refuge sites more visible, with tree lines along main routes, and around the refuge site. Urban forests are proposed for large empty lots with a slope, to reduce landslide risks by increasing vegetation cover which improves rainwater infiltration and reduces runoff. They also provide attractive spaces for recreation. If properly and sustainably managed, some of these urban forest patches could be used to produce wood.

Helophyte retention pond

Figure 72. Inspiration image (section) of a helophyte retention pond

A retention pond on the side of the soccer field, to capture and clean the stormwater runoff from the large roofs next to it. Considering the mainstream use of this site for sports, this measure could be used to make water management more visible and educate the youth about the benefits of such measures. The helophyte retention pond helps to clean the water before it is infiltrated into the subsurface.

Private gardens/urban farming

Figure 73. Private garden in Antananarivo, with grass, bushes and trees which increases vegetation cover. Credits Secret Garden

We suggest promoting the construction of private green gardens and urban farming in the houses of this area. This adds vegetation cover, which promotes a better and more effective infiltration of rainfall. Urban farming can also contribute to the household economy.

Elevated refuge

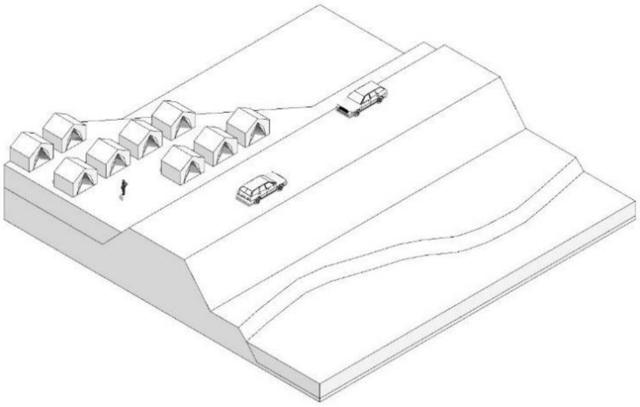


Figure 74. Conceptual sketch of temporary refuges on elevated ground, as part of an existing levee system

The refuge site has already a higher elevation than the flooded area, so there is no immediate need to raise it. The refuge should be surrounded by trees, to make it more visible, as well as to provide a comfortable shade.

Elevated routes

Figure 75. Inspiration image of an elevated route over a rice field.

The main evacuation routes are constructed on elevated soil, with a line of trees next to them. On lower swampy areas, elevated routes should be constructed on stilts, to enable the free flow of water in the swamp, while also allowing the safe evacuation of people.

Rain harvest

Figure 76. Example of rain barrel for rain harvest. Credits unknown

When large roofs are present, rain harvest using rain barrels is a good source of water for different uses. If a filter is added to the barrel, this water could also be used for drinking. Rain barrels could also be implemented in small buildings, such as houses, to provide an additional source of water.

SITE 3

Figure 77. Location of proposed NbS and complementary measures for flood risk reduction for site 3.

Strategy

The main strategy focuses on 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
- 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)
- Develop a network of safe evacuation routes, that are elevated and well indicated

Measures proposed

The selected measures for this site are:

Urban forest / Adding trees

Figure 78. Trees along the C3 canal in Antananarivo, with people using the shaded area below them to rest.

Trees are used to make main evacuation routes and refuge sites more visible, with tree lines along main routes, and around the refuge site. An urban forest on the South-West end of the refuge site marks a clear border with the increasing urbanization.

Bioswale

Figure 79. Bioswale in Short Road Park with grasses and stones cover. Credits KH Landscape Architects

A network of bioswales in combination with retention ponds contributes to improving local stormwater management. Bioswales constitute a surface drainage system, that connects to the Anosibe basin.

Helophyte retention pond

Figure 80. Trounce pond in Canada. Source Wikimedia Commons

As this area lacks a proper sanitation system, helophyte retention ponds, as well as bioswales, are suggested to contribute to improving water quality before it infiltrates into the subsurface or drains into the Anosibe basin. Along with this measure, it is encouraged to maintain existing surface water storage areas clean, to avoid that their storage capacity decreases over time.

Private gardens/urban farming

Figure 81. Vegetable garden, part of an urban farming initiative in Kigali, Rwanda. Credits ARDE Kubaho

We suggest promoting the construction of private green gardens and urban farms in the houses of this area. This adds vegetation cover, which promotes a slower infiltration of rainfall. Urban farming can also contribute to the household economy.

Elevated refuge

Figure 82. Inspiration image of an elevated refuge site on an embankment over 1m higher than its surroundings.

Refuge sites should be elevated (+1m). It would be better to elevate the refuge site further, however, this could increase flood problems in the neighboring properties. The refuge should have a bioswale around it, to enable the conveyance of stormwater runoff, as well as trees that form a clear border where no further densification should occur. The refuge should include a clinic, to provide emergency services during an evacuation, as well as everyday services to the community during normal times.

Elevated routes

Figure 83. Inspiration image of an elevated route on stilts (green routes) with a bioswale next to it to convey storm water runoff.

Elevated routes on elevated soil are suggested for the main routes, along with a line of trees. This allows for the informal trade activities to continue, while also improving the quality of the space. These main evacuation routes are located along the RN1 and the edge of the Anosibe basin. In both cases informal trade is common. These routes should also include solar street lights, to enable nighttime evacuation. On the route along the Anosibe basin, the street light could be on the side of the basin, while the trees and hawker stalls should be positioned on the opposite side. By doing so, trees cast a shade on the side areas that are used for informal trade, while the other side is kept clearer, in case evacuation is needed. Green routes should be constructed as boardwalks on stilts, with a bioswale next to them.

Rain harvest

Figure 84. Inspiration image of rain barrels placed under a house, to harvest rain to be used later to water the vegetable garden next to the house.

When large roofs are present, rain harvest using rain barrels is a good source of water for different uses. If a filter is added to the barrel, this water could also be used for drinking. Rain barrels could also be implemented in small buildings, such as houses, to provide an additional source of water to the one from water kiosks, and to e.g. irrigate the crops in urban farms.

Figure 85. Before (above) and after (below) situation. Inspiration image of the multifunctionality of refuge on site 3. This refuge could be developed as a park-like area with trees, and tree lines in the border to mark its edge and highlight it in case of evacuation.

SITE 9

Legend

- Urban forest
- Refuge site
- Retention pond
- Green garden/Urban farm
- Rain barrel
- Drainage
- Health facilities

Type of lines:

- Evacuation route (embankment) + tree line
- Evacuation route (embankment) + tree line + bioswale
- Evacuation route (boardwalk on stilts) + bioswale

Color of lines:

- Red route (main)
- Orange route (secondary)
- Green route

Figure 86. Location of proposed NbS and complementary measures for flood risk reduction for site 9.

Strategy

Considering the limited open spaces, the proximity to the C3 canal and the increasing informal settlements, the strategy for this site is based on:

- Increasing the storage capacity of the site by creating retention ponds at different locations, that increase surface water
- Drain the excess water to the C3 and Adriantany canals
- Decrease heat stress by increasing the surface covered by vegetation and by water.
- On empty lots, create elevated refuges that are safe from floods, for on-site refuge (phase I of evacuation plan)
- Develop a network of safe evacuation routes, that are elevated and well indicated. Red and orange routes are marked by trees
- Use trees to design a border that prevents further urbanization in empty lots

Measures proposed

The selected measures for this site are:

Urban forest / Adding trees

Figure 87. Auckland Park in Johannesburg, including an urban forest with different types of vegetation cover (grasses, bushes, trees). Credits Your Neighbourhood

Trees are used to make main evacuation routes and refuge sites more visible, with tree lines along main routes, and around the refuge site. An urban forest on the South-East the refuge is proposed as a way to avoid more informal settlements on the site and preserve some of the existing open spaces.

Bioswale

Figure 88. Bioswale in the neighborhood of Diepsloot in Johannesburg, three months after implementation. Credits University of South Africa.

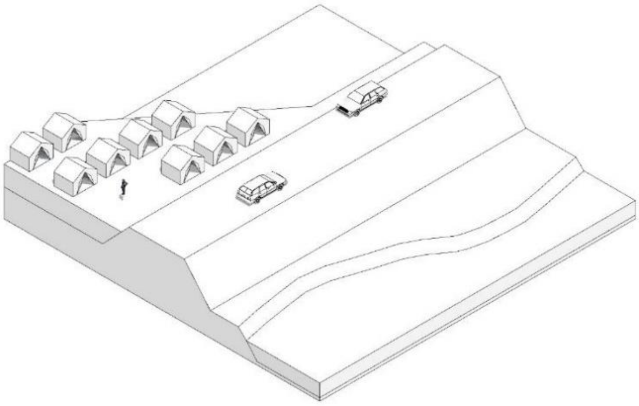
A network of bioswales in combination with retention ponds contributes to improving local stormwater management. Bioswales constitute a surface drainage system, that connects to retention basins and ultimately to the C3 and Adriantany canals.

Helophyte retention pond

Figure 89. Inspiration image (section) of a helophyte retention pond

As this area lacks a proper sanitation system, helophyte retention ponds, as well as bioswales, are suggested to contribute to improving water quality before it infiltrates into the subsurface or drains into the canals.

Elevated refuge



We propose three refuge sites, that should be elevated from their surroundings (+1m), to allow for on-site refuge during floods. The refuge should have a bioswale around it, to enable the conveyance of stormwater runoff, as well as trees that conform a clear border where no further densification should occur.

Figure 90. Conceptual sketch of temporary refuges on elevated ground, as part of an existing levee system

Elevated routes

Elevated routes on elevated soil are suggested for the main routes, along with a line of trees. Green routes should be constructed as boardwalks on stilts, with a bioswale next to them. These boardwalks could be built using recycled plastic (**see section 2.3**).

Figure 91. Inspiration image of an elevated route on stilts.

Rain harvest

When large roofs are present, rain harvest using rain barrels is a good source of water for different uses. If a filter is added to the barrel, this water could also be used for drinking. Rain barrels could also be implemented in small buildings, such as houses, to provide an additional source of water to the one provided by the water kiosks.

Figure 92. Inspiration image of rain barrels for rain harvest next to a house.

3.2.2 Effectiveness of NbS for flood reduction

The assessment of the selected NbS in terms of flood reduction focuses on the water storage capacity of the measures. This has been estimated using the Adaptation Support Tool (AST[7]), conducting a simulation for a return period of 10 years[8]. The findings from this simulation led to modifications in the original design. The assessment presented in this section refers to the final design.

Table 5 shows an overview of the storage capacity targets for each site based on the results of the Urban Water Balance Model (for more details, refer to **section 1.4.1 of the Diagnostic repor**t).

Table 6. Resilience targets overview for each selected site for T=10

Site	Area (m^2)	Storage capacity T=10 (m3 per m^2)	Targets		
			Storage capacity (m3)	Heat reduction (C°)	Water quality improvement (%)
1	32,127	0.125	6,500	0.5	10
3	77,724	0.125	9,700	0.5	10
9	72,680	0.125	9,085	0.5	10

More information on the estimation of targets can be found in https://publicwiki.deltares.nl/display/AST/Key+Performance+Indicators

Figure 73 shows the area that is covered in the assessment of each site. These areas reflect the scope of the conceptual design. It is relevant to note that for calculations, the smaller the area, the most noticeable is the impact that each measure has on flood reduction. Site 1 is less than half the size of sites 3 and 9. We decided this because there were already several locations with potential in a small area (vicinity of the soccer field, which would serve as a refuge). Around sites 3 and 9, this is not the case, and the locations with potential for the implementation of NbS are fewer and more spread out. This meant that the surface of sites 3 and 9 had to be bigger to include the different sites with potential.

Figure 93. Overview of the area (yellow line) of sites 1, 3 and 9 indicated in **Table 6**

[7] https://antananarivo.crctool.org/

[8] From the preliminary assessment conducted during the Diagnostic (section 5.3.1 Diagnostic report), we found that the limited space available at the moment is not enough for the selected measures to reach the target water storage capacity for each site. Considering that, during this assessment for flood reduction effectiveness, we focused only on the 10 year return period.

SITE 1

Table 7. Assessment summary for the measures on site 1

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**

Legend
Project area
Adding green to the streetscape
Retention pond
Urban forest

Figure 94. Screen capture from the assessment performed with the AST for site 1

The target set for storage capacity was 6,500m^3, but the measures proposed only reach 3,103m^3. There was still open space available, but we opted for not compromising existing sport facilities, and also decided to keep the parking spaces. During the design-testing iteration, we tested bioswales along the main routes. That measure only contributed to the storage capacity of the site in around 300m^3. Considering the limited resources, we decided the contribution was not significant enough for this case, especially taking into account that floods only occur downstream. Adding trees is a very successful measure in terms of storage capacity, that is both easy to implement and maintain. To get closer to the set target, private urban gardens and urban farms (vegetable gardens) could be implemented in the houses on this site. However, even if these measures are implemented, is very likely that the site will not reach the target. We consider this is not a problem, since this is not a flood-prone area. Still, the low-lying areas should be preserved as a swamp, avoiding further urbanization, so they are capable of storing the excess runoff from the elevated areas.

SITE 3

Table 8. Assessment summary for the measures on site 3

Measure	Surface (m²)	Storage capacity (m³)
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**

Legend
- Project area
- Adding green to the streetscape
- Retention pond
- Urban forest or private gardens with abundant vegetation
- Bioswale

Figure 95. Screen capture from the assessment performed with the AST for site 3

The target set for storage capacity was 9,700m³, but the measures proposed only reach 3,209m³. The storage capacity of the design is very low in comparison to the target water storage capacity. Implementing rain barrels on the houses in this area could contribute to increasing the storage capacity by at least 400m³, but even then, the target would not be reached.

The lack of open spaces and the fast growth of informal settlements in this area, limit the implementation of measures. The design aimed at increasing the surface water storage capacity of the site, but since the groundwater level is very shallow, there is not enough room on the subsurface to store water. Results support the current approach of draining excess runoff downstream to the Anosibe basin and then the C3 canal. Overall, the flood reduction potential of this site is low, supporting the need and urgency for a safe evacuation system.

SITE 9

Table 9. Assessment summary for the measures on site 9

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

Figure 96. Screen capture from the assessment performed with the AST for site 9

The target set for storage capacity was 9,085m³, but the measures proposed only reach 4,738m³. Like site 3, this site has very limited open spaces available and a shallow groundwater level. Implementing rain barrels on the houses in this area could contribute to increasing the storage capacity by at least 300m³, but even then, the target would not be reached.

The lack of open spaces and the fast growth of informal settlements in this area, limit the implementation of measures. The design aimed at increasing the surface water storage capacity of the site and drain the excess runoff. Since the groundwater level is very shallow, there is not enough room on the subsurface to store water. However, this site is surrounded by canals, so it is possible to drain the excess runoff to either the C3 canal or the Adriantany canal. Overall, the flood reduction potential of this site is low, supporting the need and urgency for a safe evacuation system.

3.2.3 Effectiveness for other benefits

This section presents the estimated effectiveness of the measures for other benefits. For some of those benefits, we can provide quantitative estimations, such as heat stress reduction and water quality, based on the type of measures. The estimation of heat stress reduction and water quality improvement was estimated using the AST, based on the type and surface area of the measure[9]. Others, such as social cohesion are not possible to quantify. However, some estimations can be done regarding the effectiveness of the selected NbS for other benefits, based on literature and the findings from:

- **Household survey** and **focus groups** (refer to **section 3.2 of the Diagnostic report**)
- **Semi-directive interviews** with selected members of the community, suggested by the fokontany leaders, given their social status and strong opinions during the focus group sessions.
- **Semi-directive interviews** to representatives from institutions or the government
    - Alphonse Rabefakatro, Mayor of Bemasoandro
    - Alain Razafintsalama, General Secretary of Bemasoandro
    - Harivelo Ramalala, Fokontany leader of Anosimasina
    - Théodore Andrianjakarivelo, Fokontany leader of Antohomadinika Anatihazo
    - Ramahery, neighbor from the fokontany Andavamamba Anjezika II
    - Rolland Ratsimba, from the Vigilance Committee
    - Jean Benjamin Rakotozanatsimba, Deputy of the fokontany leader
    - Lalaina, ENDA OI
    - Léonie Mandanirina, ARAFA
    - Ihaja L. Rajaonarison, Director of Project Coordination at the CUA

GENERAL BENEFITS

Improvement of air quality. The improvement of air quality cannot be estimated, but it is expected that the addition of trees at several locations, will contribute to CO_2 sequestration[10], and therefore to the reduction of pollution. The improvement of air quality also has an impact on the health of the community, reducing the medical expenses associated with respiratory diseases. Moreover, the linear planting of trees is strategically planned so it does not produce a tunnel effect along roads, where the CO_2 is trapped along high-traffic roads. The design takes this into account and includes lines of trees on one side of the roads only.

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[9] More information about the estimation of the heat stress can be found in **https://publicwiki.deltares.nl/display/AST/Urban+heat+stress**. More information about water quality estimations can be found in **https://publicwiki.deltares.nl/display/AST/Key+Performance+Indicators**

[10] As a reference, a forest can improve carbon sequestration by ~20%. This estimate was taken from the work of Domke et al. (2020), which assesses several cases in the United States. Although it cannot be extrapolated directly to the situation in Antananarivo, it serves as a reference of the potential that a forest can achieve.

Recreation areas for well-being. The effectiveness of recreation areas for well-being is estimated based on the added green open areas for recreation. For site 1, 11,775m^2 of green open areas are created or upgraded by implementing the selected measures. These areas can be used for sport, social interactions, or other related recreational activities. For site 3 the green open areas are 8,400m^2, and for site 9 is 4,320m^2. Site 9 is the one with the least amount of open areas, with only small lots that are unbuilt. This site is also very flood-prone, which results in several linear measures, and retention ponds that contribute to flood reduction but do not provide large recreation areas.

Social cohesion. It is not possible to quantify the effectiveness of the measures in terms of social cohesion. However, 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).

Improvement of spatial quality. It is not possible to quantify the improvement of spatial quality, but it is expected that the implementation of measures contributes to this. Local communities have made their priorities clear in terms of the improvements that they appreciate the most. For example, the priorities for the fokontany of Anosimasina, are the maintenance of the alleys and the cleaning of the canals, while for the fokontany of Anosibe Mandrangobato I, the priority is general sanitation. Overall, the measures that are most in-demand are related to access to water, the establishment of sanitary infrastructures, and urban agriculture. 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 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 barrels and graywater reuse reduce the amount of water families need to buy)
- Promoting neighborhood development

HEAT STRESS REDUCTION AND WATER QUALITY IMPROVEMENT

Site 1

Table 10. Summary of the assessment for the measures on site 9

Measure	Heat reduction	Water quality improvement		
		Pathogen reduction (%)	Nutrient reduction (%)	Absorbing pollutants (%)
Adding green to the streetscape	0.23	< 1	< 1	1
Bioswale	0.05	2	1	2
Retention pond	0.07	1	0	1
Urban forest	0.38	1	< 1	1
Total	**0.73**	**< 5**	**< 2**	**5**

The increase in green areas, predominantly with trees, on site 1, has an important positive impact on heat stress, reducing it in 0.7°C. The impact of the selected measures on water quality improvement is estimated in terms of the contribution to reduce pathogens and nutrients, as well as absorb pollutants. The impact of the selected measures is low, with the absorption of pollutants being the most noticeable impact. If urban agriculture is implemented on houses, nutrients might increase as a result. The selected measures for this site do not compromise the existing use of the space. Moreover, measures such as the lines of trees or the urban forest, provide a comfortable space for recreation that complements the existing use of the space for sports. The improvement of the vegetation cover for site 1, mainly by planting more trees, is expected to reduce soil erosion, and as a consequence, reduce landslide risks[11].

Site 3

Table 11. Summary of the assessment for the measures on site 3

Measure	Heat reduction	Water quality improvement		
		Pathogen reduction (%)	Nutrient reduction (%)	Absorbing pollutants (%)
Adding green to the streetscape	0.37	< 1	1	1
Bioswale	0.05	< 1	< 1	< 1
Retention pond	0.09	2	1	2
Urban forest	0.06	< 1	< 1	< 1
Total	**0.57**	**< 4**	**< 3**	**< 4**

The increase in green areas and surface water on site 3, has a positive impact on heat stress, reducing it in 0.6°C. The impact of the selected measures on water quality improvement is estimated in terms of the contribution to reduce pathogens and nutrients, as well as absorb pollutants. The impact of the selected measures is low, with less than 4% reduction of pathogens and absorption of pollutants, and less than 3% reduction of nutrients. The implementation of a wetland would have a greater impact on water quality since the vegetation that is part of wetlands not only improve biodiversity but also contribute to purifying water. However, the existence of scarce open areas limits the implementation of such a measure, since wetlands need to be big enough space and vegetation to perform adequately.

Site 9

Table 12. Summary of the assessment for the measures on site 9

Measure	Heat reduction	Water quality improvement		
		Pathogen reduction (%)	Nutrient reduction (%)	Absorbing pollutants (%)
Adding green to the streetscape	0.53	< 1	1	2
Bioswale	0.05	< 1	< 1	< 1
Retention pond	0.23	4	2	5
Urban forest	0.08	< 1	< 1	< 1
Total	**0.89**	**< 5**	**< 4**	**< 8**

The increase in green areas and surface water on site 9, has a positive impact on heat stress, reducing it in 0.9°C. The impact of the selected measures on water quality improvement is estimated in terms of the contribution to reduce pathogens and nutrients, as well as absorb pollutants. The impact of the selected measures is low, with less than 5% reduction of pathogens and nutrients, and less than 8% absorption of pollutants. The implementation of a wetland would have a greater impact on water quality, but the existence of limited open areas limits the implementation of such a measure.

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[11] The Bubulo Environmental Conservation Management Association Project (BECOMAP), is an example of a community-based solution to landslide risks by planting trees in Uganda.

4 Prefeasibility

The prefeasibility section covers the consolidated integration of measures in one plan per site, along with guidelines for their design and recommendations for their implementation, maintenance, and monitoring. In addition, we propose communication strategy recommendations, contributing to the implementation of non-structural measures. The objective of this section is to explore the prefeasibility of the plan that integrates NbS and disaster evacuation and refuge.

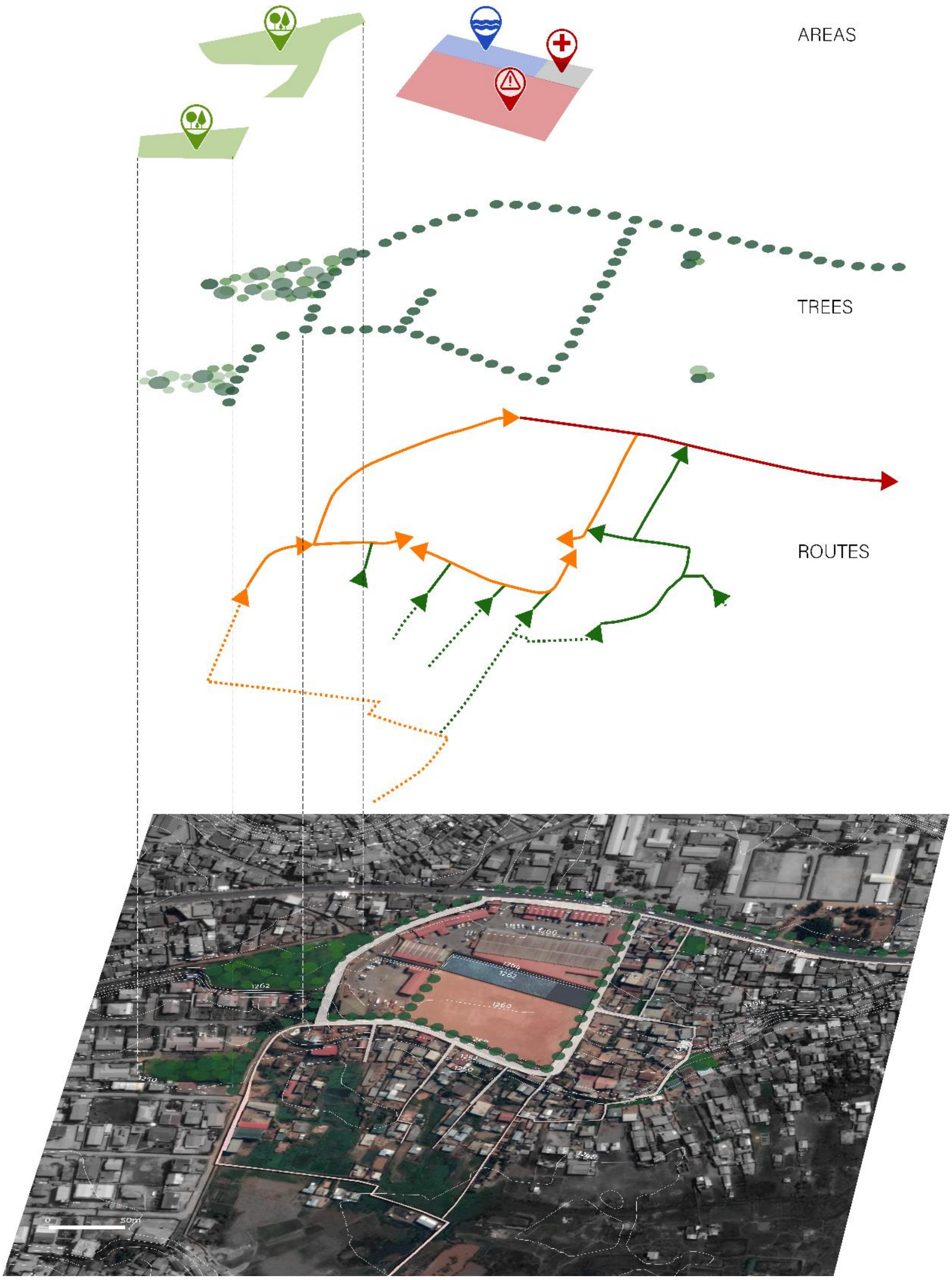
4.1 Plan integrating NbS and disaster evacuation and refuge

SITE 1

Figure 97. Plan integrating NbS and disaster evacuation and refuge for site 1

The main aspects of the plan for site 1 are:

- Reduce flood risk by storing and infiltrating water on the site, by means of a retention pond, rain barrels, and increasing the vegetation cover (urban forests and trees). The latter also contributes to reduce landslide risks and reduce heat stress.
- Improve disaster evacuation and refuge by developing a network of safe evacuation routes that provide evacuation from the swampy areas towards safer higher areas. The routes are elevated and well indicated with trees.
- Make use of popular recreation areas such as the soccer field, to boost awareness initiatives and develop a community-based implementation and maintenance arrangement. For example, the retention pond next to the soccer field could be used to generate awareness in the community about the benefits of rainwater harvest.



Legend

- Urban forest
- Refuge site
- Retention pond
- Green garden/ Urban farm
- Tree
- Bioswale
- Rain barrel
- Drainage
- Health facilities

Type of lines:

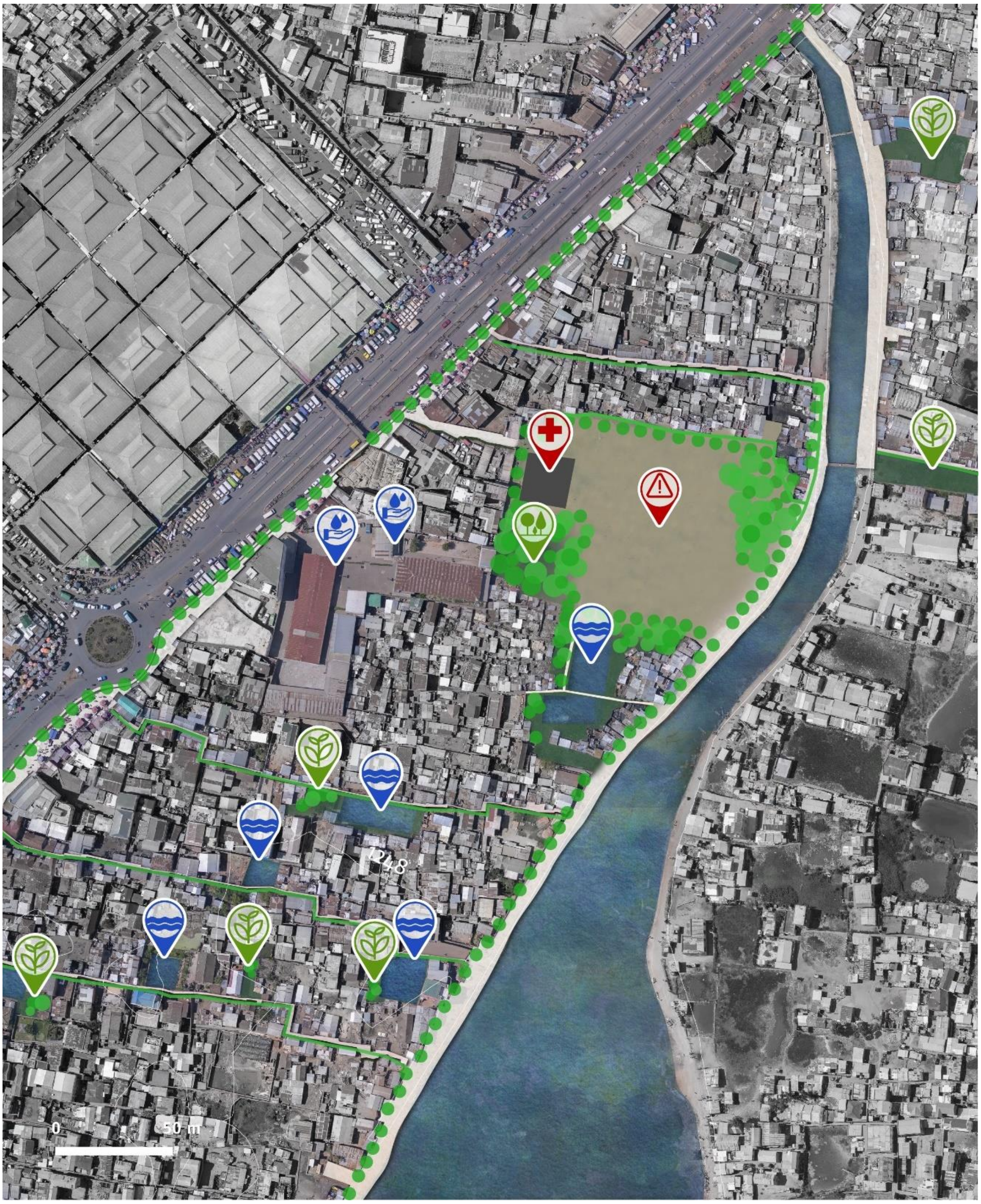
- Evacuation route (embankment) + tree line
- Evacuation route (embankment) + tree line + bioswale
- Evacuation route (boardwalk on stilts) + bioswale

Color of lines:

- Red route (main)
- Orange route (secondary)
- Green route

Figure 98. Overview of the plan for site 1, disaggregated in areas, trees, and routes

SITE 3



Legend

- Urban forest
- Refuge site
- Retention pond
- Green garden/Urban farm
- Tree
- Bioswale
- Rain barrel
- Drainage
- Health facilities

Figure 99. Plan integrating NbS and disaster evacuation and refuge for site 3

The main aspects of the plan for site 3 are:

- Reduce flood risk by creating a network of retention ponds and bioswales that allow the conveyance of stormwater runoff, the increase of surface water storage, and when necessary, the drainage of excess water to the basin and ultimately to the C3 canal. The use of bioswales also contributes to improving the quality of the water that is being infiltrated.
- Improve disaster evacuation and refuge by developing a network of safe evacuation routes that provide evacuation from the swampy areas towards higher refuges on-site for phase I of the evacuation plan. The main routes (red and orange) are elevated on embankments and well indicated with trees, while the secondary routes (green) are elevated on stilts, with a bioswale next to them.
- Reduce heat stress by increasing the surface covered by water (retention ponds) and vegetation (private green gardens, trees, etc.). Trees and retention ponds also provide a boundary for green areas, preventing further encroachment.
- Make use of a well-connected area, that is popular and easily recognizable by the community, as a refuge site. By implementing multiple and compatible programs that combine basic services (e.g. medical facilities, disaster evacuation) with temporary uses (e.g. hawker stalls, recreation), a robust governance structure can be developed to ensure the implementation and maintenance of the measures at this location. For example, the fokontany and Rf2, with funding from the CUA, could arrange for the implementation of basic infrastructure and NbS, while the community could contribute with labor to implement and then maintained the NbS. In addition, the congregation of the Église Saint Jérôme could contribute to the functioning of the health facility on the site.

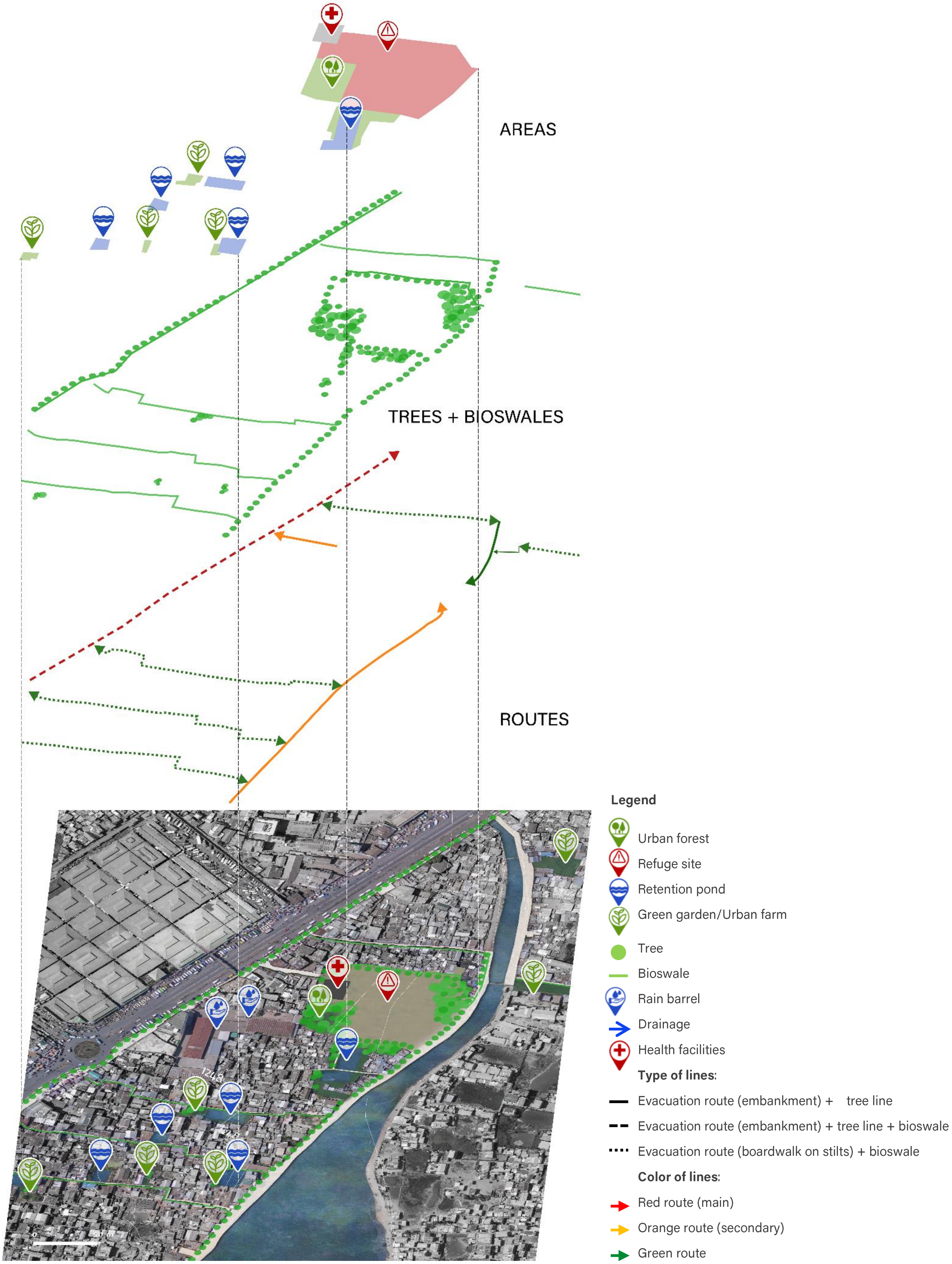


Figure 100. Overview of the plan for site 3, disaggregated in: areas, trees and routes

SITE 9

Figure 101. Plan integrating NbS and disaster evacuation and refuge for site 9

The main aspects of the plan for site 9 are:

- Reduce flood risk by creating a network of retention ponds and bioswales that allow the conveyance of stormwater runoff, the increase of surface water storage, and when necessary, the drainage of excess water to the basin and ultimately to the C3 and Adriantany canals. The use of bioswales also contributes to improving the quality of the water that is being infiltrated.
- Improve disaster evacuation and refuge by developing a network of safe evacuation routes that provide evacuation from the swampy areas towards small elevated refuge sites for on-site refuge during phase I of the evacuation plan. The largest available area could be used as a refuge site, with medical and recreation facilities, while other smaller elevated refuge sites can be designed as small green areas for both disaster refuge and recreation. Most of the main routes (red and orange) are elevated on embankments and well indicated with trees, while the secondary routes (green) are elevated on stilts, with a bioswale next to them. This allows for the free flow of water in those areas in case of extreme floods.
- Reduce heat stress by increasing the surface covered by water (retention ponds) and vegetation. Trees and retention ponds also provide a boundary for green areas, preventing further encroachment.
- Develop a robust governance structure for the implementation and maintenance of NbS at these locations, that combines the local institutions and the community. Since NbS are small-scale, their implementation and maintenance could be arranged accordingly, involving the community. For example, the Notre Dame du Rosaire congregation could contribute to the implementation and maintenance of NbS in the larger refuge site, while the neighbors could do the same for the smaller refuge sites and other NbS.
- Design guidelines for selected NbS and disaster evacuation and refuge measures

This section provides design guidelines to both further develop the conceptual design and later upscale it to other locations within Antananarivo.

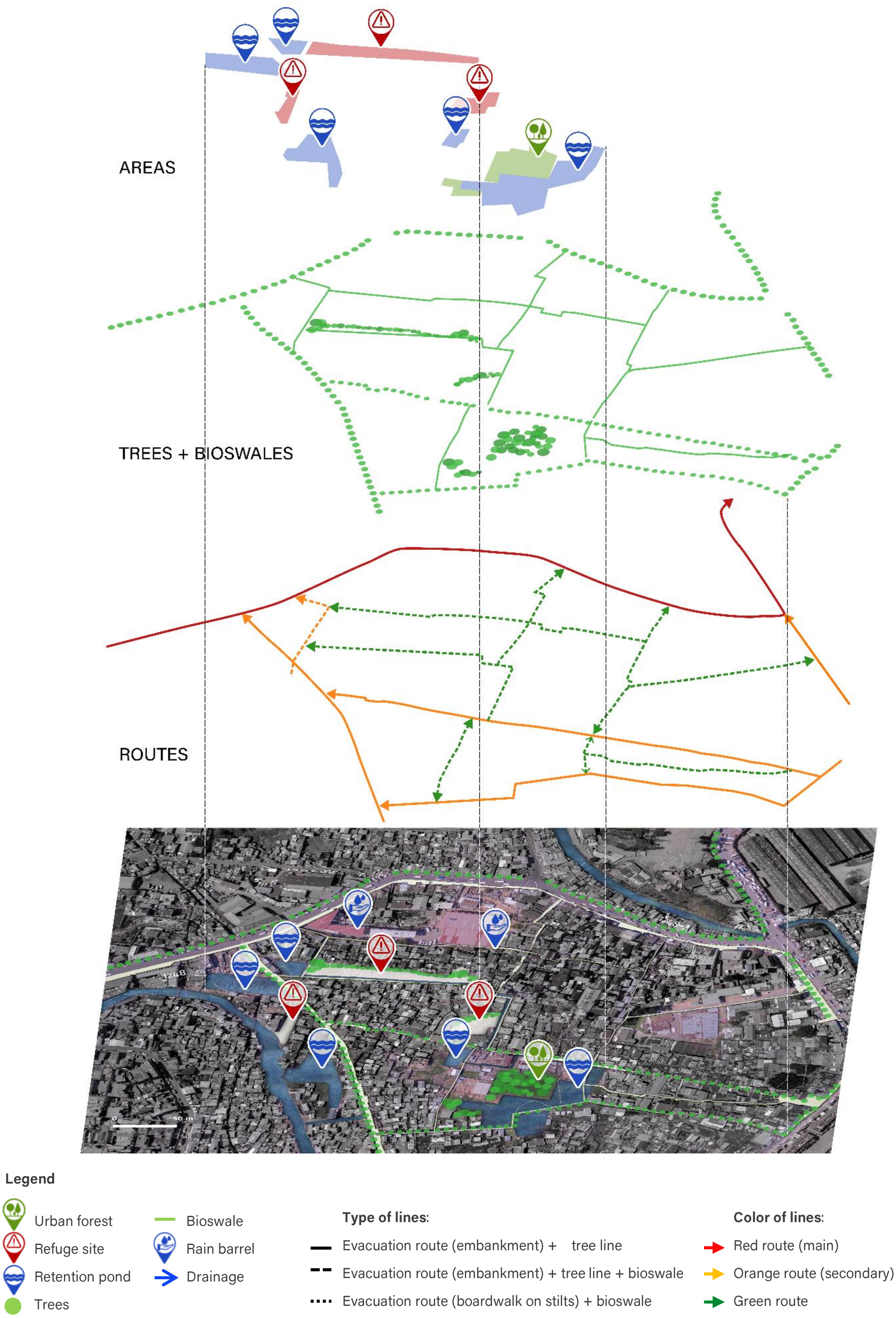


Figure 102. Overview of the plan for site 3, disaggregated in areas, trees, and routes

4.1.1 Design guidelines for selected NbS

This section provides design guidelines for the selected NbS and complementary measures. Earlier in **section 4.1** we developed a plan with site-specific measures per site. The guidelines can be especially useful when upscaling NbS and complementary measures.

Table 13. Design guidelines for selected NbS and complementary measures

Structural & architectural

- Elevated routes: embankment
    - To be used on main evacuation routes (red and orange), along with trees that make them more visible
    - Local materials should be used to raise the ground level, like the soil excavated from the bioswales.
    - The banks should have a slope of 3:1 maximum (width/height). It is preferable that they are covered by short vegetation, to slow down runoff and reduce erosion
- Elevated routes: boardwalk on stilts
    - To be used on secondary evacuation routes (green routes) in flood-prone, or in swampy areas, connecting to higher ground
    - In flood-prone areas, they should be accompanied by a bioswale, that conveys stormwater runoff
    - They should be installed at least 500mm above flood level
    - The boardwalk should be made of recycled plastic. If not possible, wood could be used for this purpose. They should consider a 90cm high railing made of the same material. As an alternative, a rope could be used for this purpose.
- Bioswale
    - Native grasses should be used as vegetation
    - A longitudinal slope between 1 and 2%. If the slope is higher than 5%, check dams should be added
    - Banks should have a slope of 3:1 maximum (width/height), and a total width between 0.6 to 3.5m.
- Trees
    - To be used along evacuation routes and around refuge sites
    - Tree lines should be implemented on the north side of evacuation routes, to maximize their shade
    - Native species are preferred, due to their adaptability to the local environment and their low water requirements
- Retention pond
    - To be used in combination with bioswales as part of a network that provides stormwater runoff conveyance and storage
    - Banks should have a slope of 3:1 maximum (width/height), size varies according to the available space
    - Depth depends on the groundwater level. When it is intended as a helophyte retention pond, its depth should be at least 80cm.

Circularity
- Rain harvest in rain barrels at every location where this is feasible, especially buildings with large roofs - Graywater reuse for toilets and other uses (except drinking water) - Urban agriculture at small-scale (houses), that reuses rain and graywater - Recycle plastic locally and transform it into pieces of the boardwalk
Water
- Use retention ponds with helophyte filters to clean the water before it infiltrates into the subsurface or reaches a surface body of water
Electrical installations
- Solar-powered street lights in refuges and along evacuation routes

4.1.2 Design guidelines for selected evacuation routes and refuges

The following are design guidelines for the implementation of the evacuation routes and refuges designed. They include the ideal set of guidelines that should be followed, but this could be adjusted according to the resources available and the implementation of other complementary measures (e.g. water needed for flushing toilets could be solved by harvesting rain and reusing greywater).

The minimum requirements for a refuge site are:

- A tent
- Drinkwater
- Lighting
- Sanitation
- Cooking space
- Playground
- Trash bins
- Medical facilities
- Security
- Access to information (radio, tv, etc.)
- Lockers
- Radio

Table 14. Design guidelines for refuge site and evacuation routes

Location and accessibility
- Minimum 500mm above the identified flood level. If the flood level is unknown, the location should be at least 1m above its surroundings, to allow for on-site refuge - Easily accessible for the disabled (ramp for wheelchairs) - Centrally located in the community and well connected to main roads - Be located on geotechnical stable land to avoid the risk of landslides, especially for locations with higher slopes. - No nearby large trees, structures use/store hazardous materials or high voltage power lines - Be close to a health facility (where possible)
Structural & architectural
- Fitted with provision for people with disabilities, including ramps with the necessary and adequate design for unimpeded wheelchair access - Provision of all services and facilities to cover the basic needs, gender and protection aspects

Occupancy capacity
- Refuge sites should have a capacity of a minimum of 1.5 m2/person for on-site refuge (short-term, up to 3 days)
Food preparation facilities
- The kitchen should be equipped for the hygienic food preparation - Provision of utensils and provision of water tap inside the kitchen - Sinks for washing utensils - If using gas cylinders, must be installed outside. Gas cylinders regulators must be positioned outside in secure cages away from the facility - If wood will be used for fire, an adequate amount of wood must be available as well as an adequately sized storage area - Fire safety measures must be in place e.g. fire extinguishers, sand/water buckets - Food preparation facility must be provided with adequate ventilation - Adequate waste storage points
Water sanitation and hygiene
- Minimum 3-5 liters per person per day drinking water - Minimum 2 liters per person per day for basic hygiene - Minimum 3 liters per day per person for cooking - 10-20 liters of water per person per day if the conventional flushing toilet is provided. .5-3.0 liters per person per day if pour flushing is used > Graywater could be reused. - Gender segregated toilets, with a minimum of one toilet per 30 females and a minimum of one toilet plus one urinal per 50 male or one toilet per 40 males - Conventional handwashing facilities one hand washbasin per 10 toilets - The toilet should be at least 20m away from the kitchen but no more than 30 meters away from the main building and ideally be all-weather accessible. Minimum one toilet for people with disabilities - Gender segregated shower facility one shower/ 30 person - Laundry block be provided where possible - Protection and gender aspects should not be overlooked during the design and site planning facilities (for instance male & female toilets should not be face to face, water point should not be in dark areas, etc. general guidance protection & gender principles) - Toilets are internally lockable and adequate waste storage points for nappies and female hygiene products.
Electrical installations and emergency power supplies
- Adequate electrical installation and an alternate/emergency backup system (Alternate not necessarily generator or UPS, it can also be a Kerosene lamp) - If alternate/emergency backup is a generator a manual changeover switch at the switchboard to connect the generator should be provided - If alternate/emergency backup is a solar panel, batteries/UPS are to be provided with an adequate inlet for the battery/UPS to connect with the switchboard.

- Generator and fuel tank ideally be located outside and should be protected from rain, wind-born debris. Access to fuel and generator should be all-weather - Inspection of electrical installation should be done upon completion by an electrical engineer to issue a certificate (despite new or old, an old installation could be vulnerable, and inspection can help to know and mitigate the risk) - All corridors, toilet areas, shower points, drinking water points, and hand washbasin areas should be lit during the night
Safety and protection
- Ensure the facility is properly secured and that all dark areas, toilets, washrooms, showers, water points, etc. are provided with appropriate lighting - Where possible provide moveable partitions to give privacy for women and girls - Ensure an adequate emergency exit and provide fire safety equipment and first aid kits

4.2 Implementation and maintenance of selected measures

This section covers the implementation and maintenance of NbS and complementary measures for the three sites. We first provide the approach along with general considerations and outline the potential risks associated with them. Then we outline the main steps for the development of a maintenance plan and finally, we provide specific recommendations only for the selected NbS.

4.2.1 Approach and general considerations

Building on our overall approach for this project, where we developed medium and small-scale interventions on strategic locations, that can be upscaled, we propose a community-based approach for the implementation and maintenance of the NbS and complementary measures for disaster evacuation and flood risk reduction. By following this type of approach, we try to ensure that the interventions, made of several NbS and other complementary measures, can last and perform efficiently and effectively. In addition, it is important to keep in mind the lifecycle of the measures as well as their operation and maintenance (**Annex B – Introduction**).

We envision that the interventions will form a **network of infrastructure for disaster evacuation and flood risk reduction, where the communities will play an important role**, by being both the main actors in their implementation and maintenance and also the main beneficiaries.

The following general considerations reflect **social, cultural, and economic aspects that are relevant for the implementation** of the designed NbS and complementary measures.

- Although floods have a negative impact on the communities, they also contribute to strengthening social cohesion, by uniting the community towards a common goal
- Information, Education, and Communication are important and needed as part of disaster planning, as confirmed by the results of the focus groups. This contributes to structure and strengthen the capacities of local actors. In addition, local actors should be supported for a progressive transfer of skills and knowledge
- As for project execution, it is important to sign contracts of objectives with the communities and empower them to act. A progressive learning framework should be designed to build the capacity of communities along the implementation process.
- Stakeholders should collaborate during the various implementation phases (detailed design, implementation, and management of solutions, monitoring and control, maintenance and rehabilitation, reconstruction).
    - Selection of appropriate tools for developing the pilots, monitoring and self-evaluating the projects

- Attention should be given to the implementation of accountability and feedback mechanisms, as well as the periodic evaluation of the assigned objectives
- Define partnership and resource mobilization strategies, preferring permanent and complementary partnerships between different actors. Also, the source of income of the fokontany should be diversified.

4.2.2 Potential risks of selected measures

We foresee two main types of risks associated with the implementation of NbS and complementary measures: risks related to the performance of measures, and the ones related to social aspects, namely the institutional structure and community engagement.

Risks related to performance:

- **Inadequate maintenance** of the NbS, which might lead to their underperformance.
- **Unplanned modifications after implementation**, which reduces the function they were designed to perform (e.g. if embankments are built within a retention pond)
- **Removal of essential components** that are part of the measures implemented, which reduce or cancel the function they were designed to perform (e.g. if trees along an evacuation route are stolen)
- **Inadequate species.** If species with high maintenance requirements are chosen, but not enough resources are available for their maintenance, this could lead to the failure of the measure, underperformance, and even negative impacts on the environment. E.g. vegetation of a bioswale that grows too quickly, and is not trimmed, can interfere with the free flow and infiltration of rainfall. The same applies to invasive species, which should be avoided.

Risks related to governance structure:

- **Social acceptance**. For an efficient implementation of NbS, projects must be technically and socially validated.
- **Lack of understanding of the benefits of NbS**. Household surveys show that more than half of the respondents accept NbS, while the remaining surveyed households do not have any knowledge about them.
- **Lack of sufficient articulation in the cooperation between the Commune and the Fokontany** has negative impacts on the support that the Fokontany and the Commune are supposed to give to the actors intervening in the area.
- Within the framework of the inter-Fokontany collaboration, the waste that is among the causes of flooding is managed according to the administrative perimeter of the institutions in charge: i.e. at the CUA scale for SAMVA and at the Fokontany scale for RF2.
- **Land ownership** needs to be taken into consideration (use and maintenance of measures).

4.2.3 Development of a maintenance plan

In this subsection, we provide the starting point for the development of a maintenance plan following a **community-based approach with a lifecycle and operation and maintenance in mind**. For more background information about this approach, refer to **Annex B – Maintenance of Assets**.

The development of a maintenance plan starts with **creating an asset register**, followed by **determining the criticality per asset type**, and finally the **development and implementation of the asset care plan**.

A. CREATE AN ASSET REGISTER

The following is a preliminary asset registry. The assets are applicable for the three sites, but the priority will change per site because each site has different requirements.

- NbS (Green Infrastructure and Drainage Systems): bioswale, tree lines and urban forest, retention pond, private green gardens

- Transportation Systems: elevated footpath (embankment), boardwalk on stilts
- Water Supply Systems: rain barrels for rain harvesting
- Energy Systems: Solar street lights
- Community Facilities: medical facilities (clinic), elevated refuge

B. DETERMINE CRITICALITY PER ASSET TYPE

The criticality of each asset according to their probability of failure, should be discussed and designed in collaboration with the stakeholders and the responsible for the maintenance of the measures. The specific design of the measure will also influence how critical the asset will be. Assets can be classified between A, B or C, where C is the least critical asset.

For NbS, the criticality highly depends on the maintenance of the measures. Unlike traditional infrastructure, which can either work or fail, NbS function in a range of levels. To this end, it is important to understand the lifecycle of NbS and map the level of service that measure provides (**Annex B – Maintenance of assets**). By doing this, it is possible to understand how likely it is for an asset to fail and how critical it is (how important are the consequences of its failure). It is also important to take into account the twofold aim of the planned measures: disaster evacuation and refuge, and flood risk reduction.

As an example, in **Table 14** we provide an overview of the NbS assets for site 3. This is only a first estimation that should be discussed and refined along with the stakeholders.

Table 15. Main NbS assets of site 3, their probability of failure and criticality

Asset	Probability of failure	Criticality
Bioswale	High, if not regularly maintained	A. If it fails, it will not be able to convey stormwater runoff and floods are more likely to occur on the site. It should be regularly monitored to prevent this, especially before the rainy season.
Tree lines Urban forest	Medium. As long as they are maintained during the first months after implementation, they are not likely to fail	B. If it fails, it will not contribute to infiltrate rainwater and decreasing heat stress. This could be easily prevented with regular monitoring during the first year after implementation and later, annual monitoring to check that the trees are still in place.
Retention pond	High, if not regularly maintained (e.g. if solid waste is abundant)	A. If it fails, it will considerably decrease surface water storage, and floods are more likely to occur.

C. DEVELOP AND IMPLEMENT THE ASSET CARE PLANS

These two steps of the development of a maintenance plan should be developed in collaboration with the stakeholders, based on the results from the previous steps. The development of the asset care plan is important for the allocation of limited resources.

Table 15 provides a summary of the asset care plan for the assets planned for site 3.

Table 16. Summary of the NbS assets for site 3, along with their maintenance and monitoring actions

Asset	Maintenance	Monitoring
Bioswale	Action: Pruning and mowing Frequency: 2 times per year Action: Mulching and remove of excess mulch. Mulch should be maintained at 2.5- to 7cm Frequency: 2 times per year. Action: Watering Frequency: 2 times per month for 2 months after construction, then sporadically, only during the dry season Action: Fertilization Frequency: 1 time per year Action: Other maintenance (e.g. removal of trash, weeds, and invasive species) Frequency: once a month. At least one time after a major storm event. Action: replacement and renewal. Remove and replace dead plants and remove any excess sediment. Frequency: depending on monitoring (only if necessary)	Action: (1) visual inspection of inlet and outlet to check for the accumulation of sediment on the inlet, and erosion on the outlet, (2) visual inspection to check that there is no accumulation of solid waste and/or invasive vegetation that prevent stormwater runoff conveyance and infiltration Frequency: monthly, including one before and one after the rainy season
Tree lines and urban forest	Action: Trimming, to promote tree health and control their growth. Frequency: 1 time per year Action: Watering Frequency: during the first three months after planting, they should be watered periodically, until the roots are established. After that, no watering should be needed, except during long periods of drought. In that case, the watering will depend on the tree species, soil, and groundwater level.	Action: visual inspection to check that the trees are in the right place and good condition Frequency: bi-yearly
Retention pond	Action: removal of solid waste, weeds, and invasive species Frequency: 12 times per year. At least one time after a major storm event. Action: removal of sediments, removal of solid waste, and replacement of species Frequency: depending on monitoring (only if necessary) **Only in the case of a helophyte retention pond** Action: redesign or improve the current design Frequency: depending on monitoring (only if necessary due to poor water quality)	Action: (1) visual inspection to check for erosion and pollution in the system; (2) check the water passage for clogging; (3) check should be performed if a helophyte filter is designed a part of the pond, paying attention to the growth and development of the helophyte filter. Frequency: weekly Action: Check that the depth of the pond has not been compromised Frequency: bi-annually, at the beginning and end of the rainy season Action: test the quality of water Frequency: monthly

4.2.4 Specific considerations for selected NbS

The following section presents specific considerations for the design, implementation, and maintenance of the selected NbS. This could be used later by stakeholders during the detail design, as well as to develop the asset care plan. It is expected that for bioswales, trees, urban forest, and retention ponds, the failure can be detected through monitoring, which is considered a predictive (condition-based) type of planned maintenance. This type of maintenance usually accounts for up to 55% of the maintenance cost. If a problem is encountered during maintenance, a replacement (e.g. replant a tree) or renewal can take place (**Figure 92**, **Figure 93**).

BIOSWALE

Construction. Bioswales[12] are engineered with gravelly soil, so stormwater is absorbed quickly and deeply. An underdrain pipe is not necessary for naturally well-drained soils. In cases where soils do not drain well, bioswales are typically lined and convey runoff to a dry well or soakage trench. The site where bioswales are applied should be designed so that runoff water is directed or drained into the bioswale. In bioswales in the streets or parking lots, this can be achieved by using curb cuts in planting areas. The ideal longitudinal slope of a bioswale should be between 1 and 2%, and no higher than 5%. The banks of the bioswale should have a slope of 3:1 maximum (width/height), and a total width between 0.6 to 3.5m. For areas with a slope higher than 5%, check dams should be installed across the bioswale so its slope is not higher than 5%, and to help slow and detain the flow while extending the time for infiltration.

On sites 3 and 9, the groundwater table is very shallow (<1m), therefore, an underdrain pipe is needed to drain excess water during extreme events. In these areas, there is a network of channels and ditches that will be renovated (Cuoton et al., 2018). The outlets could be connected to it, or, if not possible, drain directly into the existing canals. The groundwater level on site 1 is unknown. Because it is an elevated area, and there is a direct link between topography and groundwater levels (Andriamamonjisoa and Hubert-Ferrari, 2019), we assume that the groundwater level on that site is deeper than 3m. While the design for site 1 does not consider a bioswale, the potential implementation of a bioswale in the future will not require an underdrain pipe.

Capacity. Bioswales should be used to serve areas less than 4 hectares, while the total surface area of the swale should be 1% of the area from which it is receiving stormwater.

Vegetation. Bioswales can be planted with a variety of vegetation, including shrubs, wildflowers, and grass. Thicker and heavier grass in the bioswale can filter out contaminants better, while deep-rooted native plants are preferred for infiltration and reduce maintenance. It is also very important that a bioswale can be designed as a decorative greening element, which greatly enhances its landscaping potential. Some possibilities for grasses that cover edges/slopes are Vetiver, Bermuda grass, *Cynodon dactylon*, Kikuyu grass, *Pennisetum clandistinum*.

Maintenance and monitoring. The most important aspect of the maintenance of bioswales is that it needs to be performed regularly and thoroughly, and the bioswales should be monitored regularly to prevent malfunction or spot it on time if it happens.

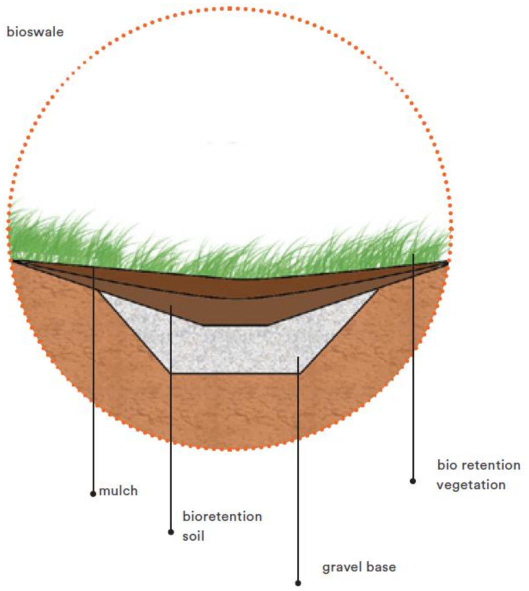


Figure 103. Diagram of the composition of a bioswale in detail

[12] https://www.3riverswetweather.org/green/green-solution-bioswales

Since the maintenance of this type of NbS requires regular attention, we foresee that the community where the measure has been implemented could play an important role in its maintenance. We proposed bioswales as part of the plans for sites 3 and 9. For both sites, the community, organized by the fokontany leader and the RF2, could provide the labor for the maintenance of bioswales, while the cost of the maintenance could be covered by the CUA. The DEVAU, which is the department of the CUA that deals, among others, with the maintenance of public green areas, could contribute with capacity building of the community, and support in the period after implementation. This, to make sure that the community is capable of maintained the bioswales properly. For maintenance activities refer to **Table 15.**

TREES

Construction. Trees can be planted as a forest patch or in isolation. In both cases, a shovel or excavator (only for big trees) will be needed to dig a planting hole that is 2 to 3 times larger than the diameter of the tree's root ball. The trees should be planted as big as possible, so they are more robust. If the trees are young and not so robust, they should be stabilized with posts in the opposite direction and flexible ties, to allow for some movement.

The soil around the root ball of the tree should be of good quality, and the tree should have enough space for the roots to grow, with no pavement on top. They should be planted at a distance from houses and electric lines as much as possible, to prevent the trees from becoming too large and endanger them.

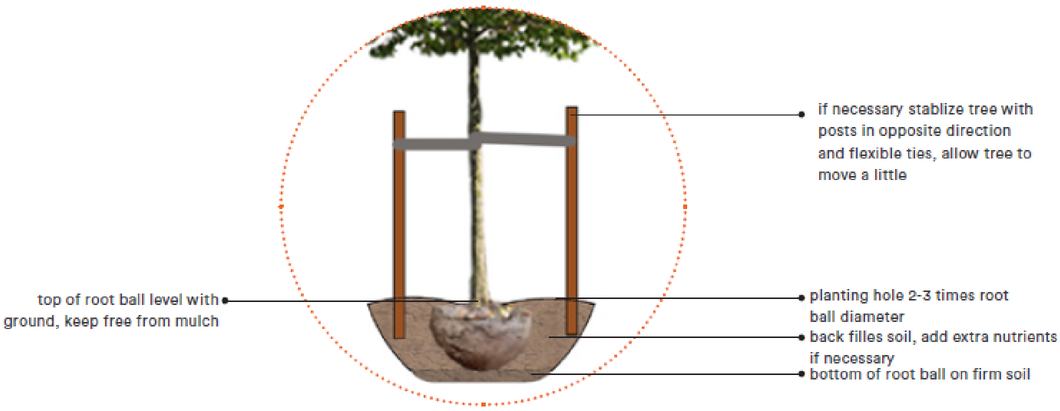


Figure 104. Detail of a planted tree

When planting trees along roads, they should be placed on the north-west, so they cast a pleasant shadow during the warmer hours of the day. When the roads are very transited, trees should be planted only on one side, to avoid that trees trap the pollution from cars, which happens in cases where the crowns are very dense and prevent the free circulation of air.

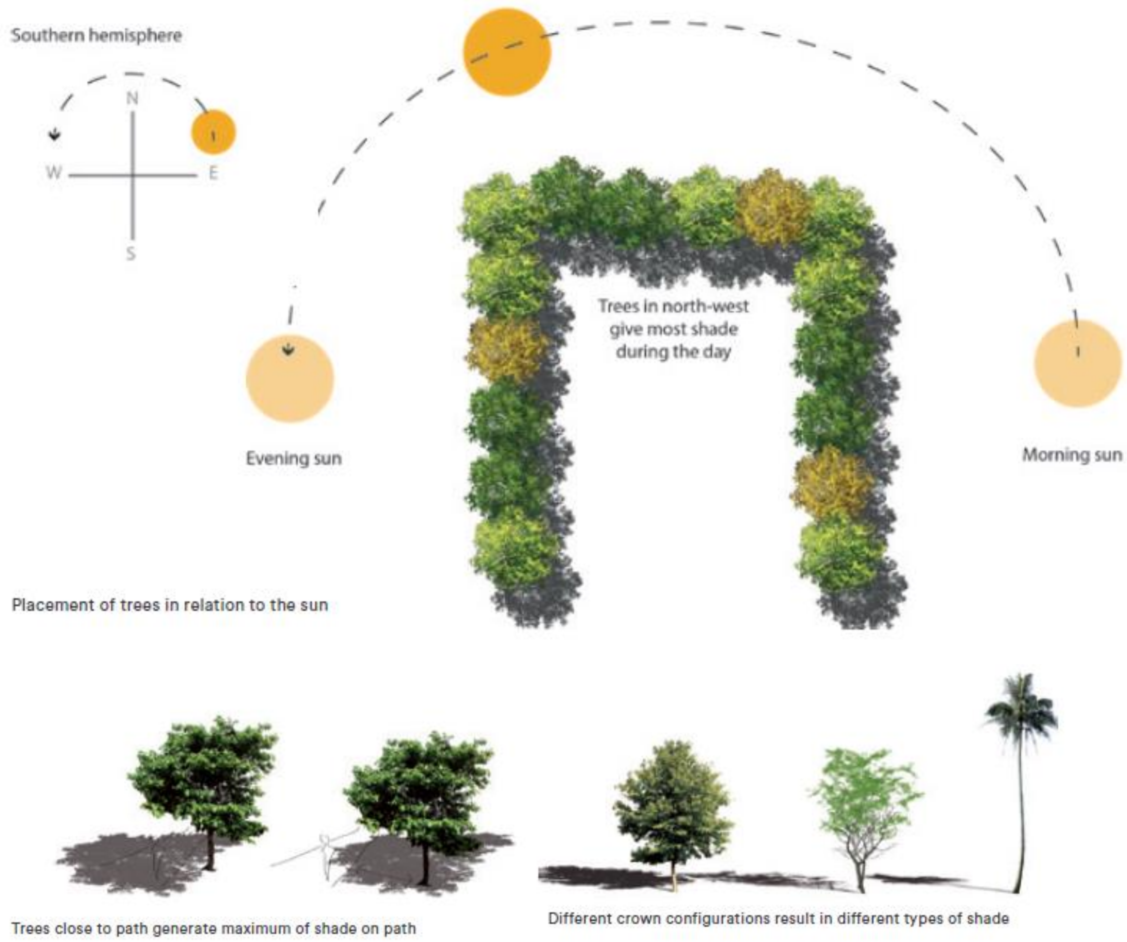


Figure 105. Diagram of the sun trajectory and the shadow of trees (above) and the comparison of different types of trees (below).

Capacity. Interception, infiltration, transpiration. Trees also improve soil infiltration by creating macropores[13]

Vegetation. Potential tree species suitable for Antananarivo and/or that have worked well under similar conditions are: *Melia azadirach, Cassuarina equistifolia, Eucalyptus, Calophyllum inophyllum,Araucaria columnarism, Albizzi lebbeck, Acacia Ariculiformis, Anacardium occidentalis, Pinus elliottii caribea, Grevillea banksia, Moringa oleifera, Teminalia mantaly, Dalbergia baronii, Aberia caffra, Mangifera indica,Gliricidia robusta, Musa, Litchi chiniesis, Cocotier, Ravinala, Perseu america, Psidium guajava*. For sites 3 and 9, the tree species chosen should be able to withstand possible longer periods of floods, when their roots and part of the trunk could be covered in water. Also, the root system should not penetrate deep into the soil, because the groundwater level is too shallow, and the tree could lose stability or even rot because of permanent contact with groundwater. Trees planted on site 1 should have strong roots, so they can be placed on slopes and contribute to decreasing landslide risks. In both cases, species with roots that grow underground should be preferred, so the root system does not interfere with evacuation routes.

Maintenance and monitoring. If planted in the right conditions, trees need little maintenance. The first year after implementation (**Figure 85**) is key for the adequate maintenance of trees and urban forests. Different tree species will have different requirements, but, ideally, during the first year, the tree is monitored and watered if necessary, to ensure that is well established and can grow adequately in the future.

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[13] https://www.deeproot.com/blog/blog-entries/how-trees-affect-soil-infiltration-rates

Since the maintenance of this type of NbS requires attention predominantly during the first year, we foresee that the community, coordinated by the fokontany and RF2 will maintain and monitor the trees. Little technology and tools are need for this, which could be provided by the municipality. For site 1, part of the water requirements for the trees could come from the retention ponds, and even rain barrels if enough water is available. For sites 3 and 9, as much water as possible could come from the various retention ponds. This reduces the maintenance costs and ensures that enough space is available for surface water storage. Capacity building about tree planting and maintenance could be provided by the relevant department of the different municipalities. For maintenance activities refer to **Table 15.**

RETENTION POND

We proposed the implementation of retention ponds at different locations as part of the design. They can be used to store rainwater on the surface, and slowly infiltrate it into the subsurface. Only when the characteristics of the site are adequate, and maintenance is ensured, a **retention pond with a helophyte filter could be implemented**. This would not only serve to increase surface water storage, but also improve water quality.

Helophyte filters are also known as constructed wetlands, or urban constructed wetlands when located in an urban area. They are artificially created zones of reeds (or other water-based plants) that are designed to purify surface water naturally and have an expected lifecycle of 20 years. Thanks to its extensive network of roots and large quantity of biomass, reeds have a large living surface for bacteria and other micro-organisms. These are responsible for a sizeable part of the purification effect, especially the concentration of nutrients. Helophyte filters could generate additional income for the community through e.g. the creation of reed products or biomass. They could also be used for educational purposes about nature-based water purification systems.

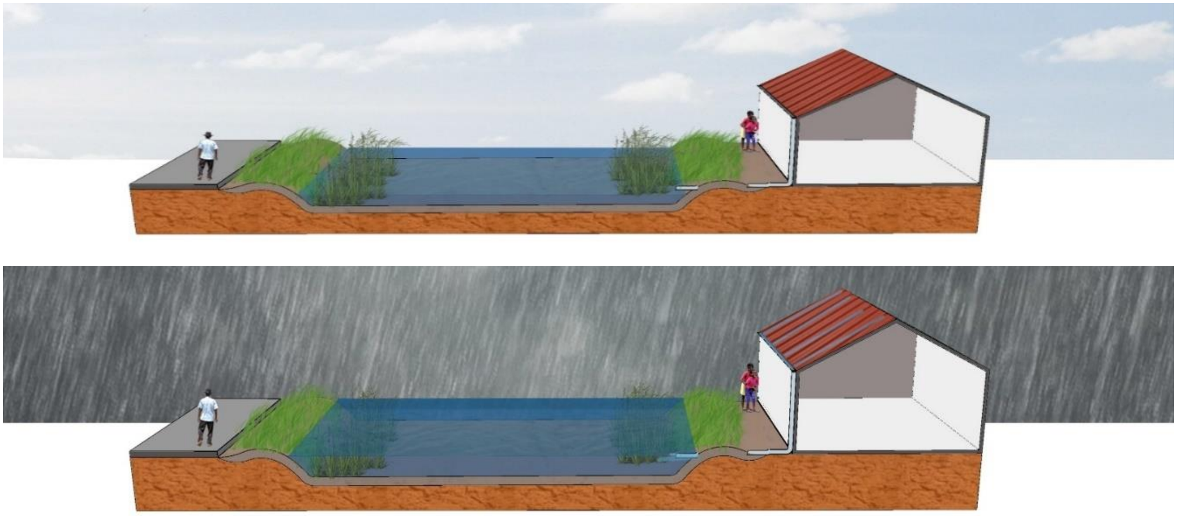


Figure 106. Diagram of a retention pond during a normal situation (upper image) and during floods (lower image)

Construction. The pond should be installed in the areas with the least elevation, so gravity will lead the water from other areas into the pond. The depth depends on the groundwater level. The bed of the pond should be covered with at least 30cm of compacted heavy clay soil.

Figure 107. Retention pond used for stormwater management in northwest Oakville. Source Wikimedia Commons

No vegetation is needed for the implementation of a traditional retention pond (**Figure 88**). However, if a helophyte filter is considered, vegetation is necessary to filter the water. In that case, the bed can be compartmentalized to prevent the wind from blowing away the plants. The dimensions of the helophyte filter vary according to the amount of water that needs to be purified, but they should be approximately 80cm deep, to allow for the adequate functioning of the system.

Vegetation[14] (only when a helophyte filter is considered). Potential types of vegetations could be reeds such as cattail (*Typha*), bulrush (*Scirpoides holoschoenus*), and juncus (*Juncus spp.*). Other helophytic species, that are native to Madagascar, could be tested and considered for this measure. Because of the predominantly warm temperatures of Antananarivo (above 10°C) the macrophytes that are part of the helophyte filter function all year long removing the pollutants from the water.

Maintenance and monitoring. Retention ponds need to be monitored regularly to notice if there is solid waste, vegetation, and or sediments that prevent their adequate functioning. In case any of these are observed, they need to be removed immediately (see **Table 15** for detailed activities). Maintenance is predominantly about cleaning, so the community could perform this activity with minimum technology. However, monitoring should be performed or at least supported by someone with technical knowledge to ensure that potential issues are solved in time. The RF2, in collaboration with the university (IST-T) could train individuals and coordinate adequate monitoring. For sites 1, 3 and 9, monitoring could be linked to an awareness-raising initiative, where the community, especially children, understand the importance of retention ponds for flood risk reduction by increasing surface storage, as well as the importance of keeping them clean.

If a helophyte filter is included as part of the retention pond, it will need to be closely monitored, especially the quality of the water to ensure that the vegetation is removing pollutants at the desired rate.

[1414] http://www.fao.org/3/i1141e/i1141e05.pdf

4.3 Communication strategies for disaster evacuation and flood risk reduction

This section provides a general communication strategy for disaster evacuation and flood risk reduction. It also contains recommendations regarding the type of information that needs to be communicated, by whom, and how.

The general approach for this is an **ongoing and inclusive communication strategy** that ensures that the community, whether old settlers or newcomers are informed. The communication strategy should contribute to the timely dissemination of information for both disaster evacuation and flood risk reduction. Both types of information should be part of awareness and education initiatives, with the main difference being, that disaster evacuation information focuses mainly on early warning and disaster response, while flood risk reduction information focuses on the efforts to prevent disasters.

Awareness and education should be ongoing, to assure that inhabitants of the city (including new generations and migrants) are educated in the relevant topics. It requires a diverse source of funding/financing and a variety of activities that reach the different groups and segments of the population. For example, awareness campaigns could be implemented locally in different neighborhoods by NGOs; and education could be part of the curricula in schools, especially the ones located in flood-prone areas, as well as universities.

Some of the aspects to be addressed **before the floods** are:

Are there risks? What are the risks? Awareness should be encouraged as part of NGO campaigns door to door, in preschools and schools, in sports and civil organizations. Awareness about risks and also about opportunities, e.g. urban farming.

How do we prevent the risks? What do we do if we are exposed to them? 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).

Figure 108. Cartoon from the news site Mada-Actus Info[15], generating awareness about the impact of poor waste disposal in the occurrence of floods. A similar type of graphical information could be used to explain the evacuation plan.

Some of the aspect to be addressed **immediately before and during floods** are:

Where and how do we evacuate? What should we take? Follow the evacuation routes towards the designated refuges according to the evacuation plans. From the findings of the community survey, we found that some of the most used methods to communicate this information are bells,

[15] https://mada-actus.info/faits-divers/inondation-a-antananarivo-faute-tananariviens/

megaphones, TV, word of mouth, radios, cellphones, flag systems, etc. During this time, people should make use of evacuation kits that have been prepared in advance, with the basic items to be used during an evacuation. An example of items to be included in such a kit are: flashlight, whistle, first aid kit, important documents, radio/cell phone where possible, water, rain jackets, and bright or reflective clothing.

There are several **information sources** relevant to the communication of disaster evacuation and flood risk reduction information. The most relevant ones for this study are shown in **Table 16**.

Table 17. Main sources of official relevant information for this study

Source	Information
BNGRC and CPGU	Information about cyclones and floods at a national level through the media and SMS
APIPA	Flood forecasting and warning system for the Ikopa and its tributaries
General Directorate of Meteorology (DGM)	Meteorological events
CUA, Municipality of Bemasoandro and Municipality of Andranonaoatra	Various, including disaster recovery aid
Fokontany of Anosimasina, Mandrangobato I and Antohomadinika Afovoany	Disaster evacuation
Emergency relief committee	Disaster evacuation

While these sources are important, they do not cover all the necessary knowledge that needs to be communicated, especially in terms of NbS and their importance. As proposed in **section 2.4 about Relevant stakeholders**, the RF2 could extend its mandate to include **NbS for water safety and security.** In that case, an option could be that the RF2 partner with local knowledge institutions - who can produce the baseline knowledge - to train individuals and educate the community on this topic.

The information on evacuation sites, the evacuation route, evacuation kit, and actions to be taken at a fokontany level for before, during, and after evacuation.

Roles and responsibilities should be defined per actor, specifying who is the lead, who supports, and what is the scope of the responsibilities. During workshop 2, stakeholders engaged in defining responsibilities per organization (see **Annex C**). Following the identification of roles and responsibilities, the contact information for the person in charge needs to be collected and communicated to the relevant parties. Finally, the actions for **Disaster Management Role Players** need to be defined, including what, who, where, when, and why. The Disaster Management Role Players must ensure that the activities mentioned in the disaster evacuation plan and design are implemented in case of flooding in the fokontany.

4.4 Monitoring and evaluation of Disaster Evacuation Planning and design

Monitoring and Evaluation (M&E) are crucial elements to ensure the efficiency, effectiveness, relevance, and sustainability of the project, and eventually the resilience of Antananarivo to flood events. The objective of this section is to provide a framework to monitor, report, and evaluate the effectiveness of the proposed disaster evacuation planning and design.

Monitoring is the systematic collection and analysis of information as a project/program progresses. It is aimed at improving the efficiency and effectiveness of the project and is based on targets set and activities planned during the planning phase. If done properly, it is an invaluable tool for good management, and it provides a useful base for evaluation.

Evaluation is the comparison of actual project impacts against the agreed strategic plans. It looks at activities set to be done, what has been accomplished, and how it has been accomplished. It can be formative (taking place during the life of the project, to improve the strategy or way of functioning of the project). It can also be summative (drawing learnings from a completed project that is no longer functioning).

The list below provides a guideline for the frequency and schedule of data collection to be developed and agreed upon by all stakeholders. Plans also need to be developed for compiling and analyzing the collected information and data.

- Type of Data Collected
- Data Source
- Data Set
- Frequency
- Responsible Person

While the activities are being implemented, the Government must regularly check if they have been carried out properly or not. Later, the Government should evaluate the plan.

Following the forms from **Annex C – Monitoring and Evaluation**, the Disaster Management Role Players first needs to fill in the **evaluation form for Disaster preparedness and response plan** to assess the current situation. Then, the following steps need to be taken:

- Stakeholders Engagement Consultation
- Describe the program
- Identify the relevant indicators that will inform the evaluation program
- Evaluation Design
- Gather credible evidence
- Justify conclusion Ensure use and share lessons learned
- Ensure use and share lessons learned

Finally, the Disaster Management Role Players need to lead the development of the plan for monitoring and evaluation of the disaster preparedness and response plan.

The monitoring of the individual measures' performance is also relevant, but that has been addressed as part of the maintenance considerations for each measure (**Table 15**, section **4.2.4 – Specific considerations for selected NbS**)

4.5 Main findings

The main findings from the prefeasibility section relate to the design, implementation, communication, and monitoring of the measures for flood risk reduction and disaster evacuation. They can be summarized as follows:

- The **combination of measures in both public and private areas** promotes different ways for the community to engage. They can be actively participating in the implementation and use of measures in the public space, and/or they can also implement measures in their own homes, like green gardens.
- **Simple low-tech measures** require minimum resources for their implementation, and the local capacities for that should be easy to build. This enables the use of a community-based approach to develop a network of infrastructure for disaster evacuation and flood risk reduction.
- **Strong governance** is necessary to ensure a transparent, accountable, equitable, and inclusive process of building resilience in time through the implementation of measures that contribute to reduce flood risks and improve disaster evacuation. For that, it is important that all scales of actors are involved, from the community to the government and other institutions.

- 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, instead of focusing only on the implementation and short-term performance of measures.
- An **ongoing and inclusive communication strategy** allows for the dissemination of clear and timely information. This ensures that both the people affected by floods as well as the institutions and organizations involved in disaster evacuation can act in time.
- **Regular monitoring and evaluation** are necessary to ensure the timely implementation of the disaster evacuation plan. Monitoring is also fundamental to identify potential issues in the performance of specific measures and solve them in time to minimize risks.

5 Findings and conclusions

This report covers the prefeasibility assessment of NbS and complementary measures for disaster evacuation and flood risk reduction in the PRODUIR area in Antananarivo. The assessment began with a review of previous steps: the scenarios that led to a phased evacuation and refuge strategy, and the site selection, reviewing the relevance, suitability, and potential of different measures for the preselected ten sites (see **Figure 90**). This led to a shortlist of three sites (sites 1, 3 and 9) to conduct the prefeasibility study. Then, we developed a draft plan for each of the three sites, and assessed the effectiveness of the measures, both in terms of flood reduction as well as other benefits. Later, we refined the plan and developed technical guidelines, and general strategies for the implementation, maintenance, communication, and monitoring of the measures.

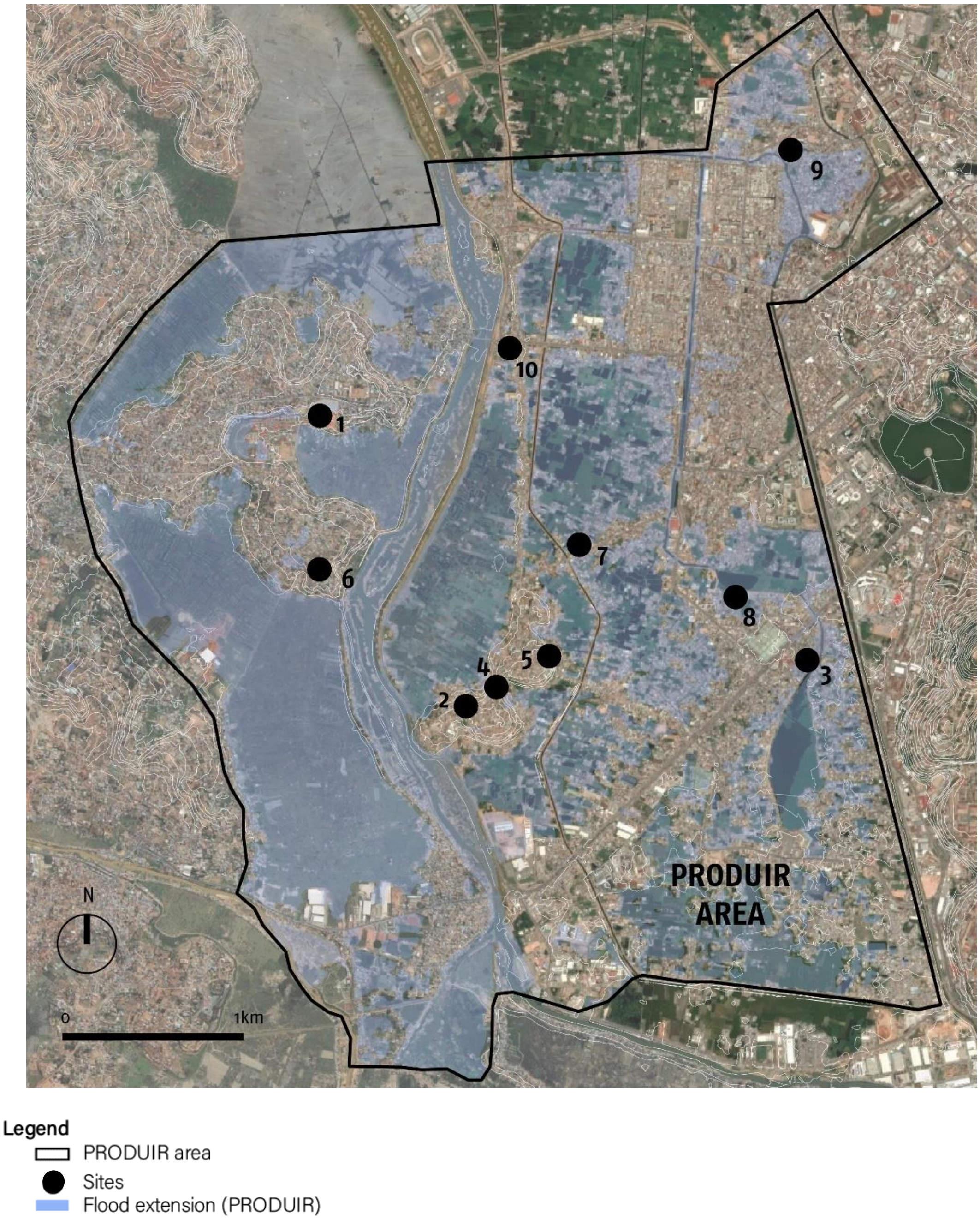


Figure 109. Map of the ten preselected sites in relation to the flood extent from PRODUIR.

In this section, we report our main findings from the prefeasibility assessment concerning the potential for NbS to be integrated with evacuation planning for flood risk reduction.

5.1 Findings

This section covers the main findings of the prefeasibility assessment regarding NbS for disaster evacuation and flood risk reduction. We start with the main aspects of the plans for each site where we conducted the prefeasibility assessment. Then, we present the main considerations in terms of the integration, implementation, and maintenance of NbS and other measures. Finally, we reflect on the advantages and disadvantages of the implementation of NbS from a socio-economic perspective, which is particularly relevant in this case, since we are proposing a community-based approach.

5.1.1 Plans for the three pilot sites

We selected sites 1, 3 and 9, which we consider are representative of a situation that can be found in several places within the city. There are particular challenges and specific characteristics for each site, which define the type of solutions that we envision. We developed a plan for each site, combining a series of NbS and other complementary measures that aim at improving disaster evacuation and reducing flood risks. Below we outline the main characteristics of the plan proposed for each site.

Site 1

- Reduce flood risk by storing and infiltrating water on the site, by means of a retention pond, rain barrels, and increasing the vegetation cover (urban forests and trees). The latter also contributes to reduce landslide risks and reduce heat stress.
- Improve disaster evacuation and refuge by developing a network of safe evacuation routes that provide evacuation from the swampy areas towards safer higher areas. The routes are elevated and well indicated with trees.
- Make use of popular recreation areas such as the soccer field, to boost awareness initiatives and develop a community-based implementation and maintenance arrangement. For example, the retention pond next to the soccer field could be used to generate awareness in the community about the benefits of rainwater harvest.

Site 3

- Reduce flood risk by creating a network of retention ponds and bioswales that allow the conveyance of stormwater runoff, the increase of surface water storage, and when necessary, the drainage of excess water to the basin and ultimately to the C3 canal. The use of bioswales also contributes to improving the quality of the water that is being infiltrated.
- Improve disaster evacuation and refuge by developing a network of safe evacuation routes that provide evacuation from the swampy areas towards higher refuges on-site for phase I of the evacuation plan. The main routes (red and orange) are elevated on embankments and well indicated with trees, while the secondary routes (green) are elevated on stilts, with a bioswale next to them.
- Reduce heat stress by increasing the surface covered by water (retention ponds) and vegetation (private green gardens, trees, etc.). Trees and retention ponds also provide a boundary for green areas, preventing further encroachment.
- Make use of a well-connected area, that is popular and easily recognizable by the community, as a refuge site. By implementing multiple and compatible programs that combine basic services (e.g. medical facilities, disaster evacuation) with temporary uses (e.g. hawker stalls, recreation), a robust governance structure can be developed to ensure the implementation and maintenance of the measures at this location. For example, the fokontany and Rf2, with funding from the CUA, could arrange for the implementation of basic infrastructure and NbS, while the community could contribute with labor to implement and then maintained the NbS. In addition, the congregation of the Église Saint Jérôme could contribute to the functioning of the health facility on the site.

Site 9

- Reduce flood risk by creating a network of retention ponds and bioswales that allow the conveyance of stormwater runoff, the increase of surface water storage, and when necessary, the drainage of excess water to the basin and ultimately to the C3 and Adriantany canals. The use of bioswales also contributes to improving the quality of the water that is being infiltrated.
- Improve disaster evacuation and refuge by developing a network of safe evacuation routes that provide evacuation from the swampy areas towards small elevated refuge sites for on-site refuge during phase I of the evacuation plan. The largest available area could be used as a refuge site, with medical and recreation facilities, while other smaller elevated refuge sites can be designed as small green areas for both disaster refuge and recreation. Most of the main routes (red and orange) are elevated on embankments and well indicated with trees, while the secondary routes (green) are elevated on stilts, with a bioswale next to them. This allows for the free flow of water in those areas in case of extreme floods.
- Reduce heat stress by increasing the surface covered by water (retention ponds) and vegetation. Trees and retention ponds also provide a boundary for green areas, preventing further encroachment.
- Develop a robust governance structure for the implementation and maintenance of NbS at these locations, that combines the local institutions and the community. Since NbS are small-scale, their implementation and maintenance could be arranged accordingly, involving the community. For example, the Notre Dame du Rosaire congregation could contribute to the implementation and maintenance of NbS in the larger refuge site, while the neighbors could do the same for the smaller refuge sites and other NbS.

5.1.2 Integration, implementation, and maintenance of NbS and complementary measures

The integration of NbS and complementary measures that both improve disaster evacuation and refuge while also reducing flood risk is complex. From this phase of the project, the following are the main findings regarding that integration, as well as the implementation and maintenance of those measures are:

- **NbS and measures that focus on providing safe evacuation and refuge can be complementary, but often there are trade-offs**. This calls for better coordination between both types of interventions that takes into account both urgency and long-term vision. For example, an elevated route built on a high dike of 4m in the low-lying areas would be very safe for evacuation purposes. However, such a dike would stir the flow of water and may cause that certain areas cannot be properly drained.
- The **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. For example, if the groundwater level is shallow, as it is the case in the sites located in the floodplains, there is limited space for the implementation of a deep retention pond, which results in a limited capacity to store water on the surface. In case of extreme storms, these areas will be likely to flood quicker than others, so it is urgent to implement elevated evacuation routes which at least ensure the safe evacuation of people to other areas.
- The integration of two different but complementary types of measures requires also the integration of the **institutional structures** that allow for their existence as well as a strong governance framework. Communities are interested and most of the time engaged in improving their environment. However, existing organizations are very sectorial, with a specific mandate that defines their actions. To implement successful NbS for disaster evacuation and refuge, the **collaboration between the different stakeholders along the process – from design to monitoring - is fundamental**.
- New interventions made of NbS and complementary measures, can be integrated into the development of other projects to be implemented in the short term. This **enables synergies**

that strengthen both projects and can increase their impact while facilitating the implementation of both projects.

- Further data is needed to fine-tune the design that integrates NbS and complementary measures. **More detailed information is needed** on ground elevation, floodwater levels, groundwater levels, and land ownership. The latter can greatly impact the implementation of measures, but because of the presence of informal settlements, this becomes sensitive information that neighbors are often not willing to share.
- The **simplest measures can be the most effective and easier to implement**. There is a wide range of NbS, from very simple measures to very complex ones. Trees are a very simple solution, easy to implement, that requires minimum maintenance. They can be combined with different other measures such as elevated evacuation routes and refuges and provide several benefits (see **section 3.2**), both in public and private areas. This also promotes different ways for the community to engage.
- 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, instead of focusing only in the implementation and short-term performance of measures. That, in combination with **regular monitoring,** is fundamental to identify potential issues in the performance of specific measures and solve them in time to minimize risks.
- An **ongoing and inclusive communication strategy** allows for the dissemination of clear and timely information about disaster evacuation as well as flood risk reduction. This ensures that both the people affected by floods as well as the institutions and organizations involved in disaster evacuation can act in time.

5.1.3 Advantages and disadvantages of NbS from a socio-economic perspective

From a socio-economic perspective, some **advantages** for the implementation of NbS are:

- The reduction of the flood risk through the use of NbS, as well as the other benefits of NbS, will have a **positive impact on the local economy** (trade, services, employment, etc.). For example, new jobs could be created in connection to the implementation and maintenance of NbS or with a byproduct from them (e.g. recycling plastic to build boardwalks); and the creation of new public spaces of good quality, could provide a better and safer place for trading activities.

- **Construction costs can be lower than those of traditional infrastructure**. Even though these costs can be substantial, they can be phased over the NbS lifecycle. For example, trees could be planted in phases: in refuges first, then along the main evacuation routes, and finally in urban forests. This allows splitting the implementation costs into three phases.

- Certain measures such as urban agriculture, not only contribute to reducing floods, but it can also contribute to **promoting the development of the neighborhood by making them less vulnerable**. For example, a family could implement a vegetable garden as a form of urban agriculture, which supplements their monthly food supply. This could reduce their expenses, making more resources available for other needs such as health. In addition, the economic impact of NbS, and particularly solutions such as urban agriculture, can promote the behavioral change of inhabitants who see the direct impact these solutions can have on their lives.

- NbS and complementary measures that **contribute to water sanitation and water supply are highly appreciated by the community** because they facilitate access to these services at a low cost. For example, retention ponds and rain barrels could serve to provide an additional source of water for certain uses such as irrigation.

- According to the communities, **the internalization of the process of implementing and maintaining NbS requires clear information and sufficient awareness** activities for the inhabitants of the same street, the fokontany, and the entire commune. For example, it needs to be clear to the community involved in the maintenance of measures, when, why, and how certain measures should be maintained, and what would be the effect if this is not done.

- The communities have understood that the integration of NbS, in this case, can be materialized by innovations such as renewable energy, energy-saving, use of ecological building materials, waste reduction and recycling, and environmental preservation.

However, there are also three main factors against NbS:

- The **behavioral logic of the inhabitants shaped by the lack of education** of communities as well as the increasing migration of inhabitants from other regions, which can potentially prevent people from valuing NbS.
- The **lack of a management structure for the implementation and maintenance of NbS**, which might result in measures that can be implemented, but becomes obsolete in the short term due to the lack of maintenance.
- The **insufficient impact** of NbS-related projects on the improvement of the population's income.

The surveys and focus groups carried out with the community-led us to conclude that the socio-demographic aspects shape any development project to be set up. For it to have real benefits for the entire community, it is essential to have a combination of the **adequate institutional structure and the motivation of the members of the community**.

5.2 Conclusions

In this section, we provide the main conclusions regarding the prefeasibility assessment of NbS and complementary measures for flood risk reduction and disaster evacuation. The conclusions build on the findings from previous phases of this study but focus on answering the question: **how can we ensure the prefeasibility of the selected measures?**

Governance and education/information aspects are the cornerstones for the success of the proposed design and its upscale. Technical aspects are relevant because they ensure that the measures will perform according to expectation. We focused on simple low-tech measures, trying to minimize their costs and the risk that they are not implemented properly. Moreover, the rationale for this project relies on its upscalability, but it is based on small-scale interventions. **Small-scale interventions can be easy to replicate, but they require a committed community that contributes to their implementation as well as their maintenance**.

At the beginning of this project, during workshop 1, stakeholders seemed inclined towards city-scale interventions when discussing the topic of NbS. Large urban parks, wetlands, and green avenues were the preferred solutions. However, these types of solutions, while attractive and useful, are costly, and do not necessarily generate a positive impact on the most vulnerable. Small-scale measures (neighborhood, street, and household scales) could be more beneficial for Antananarivo. Their implementation can be phased, responding to resource availability and the urgency for interventions in a certain area. For example, the urgency for flood risk reduction and disaster evacuation measures on site 1 is low, while for sites 3 and 9 it is high. In addition, in both of those sites (3 and 9), there are ongoing projects that could integrate one or several of the NbS proposed.

There is a risk to this approach, and that is that interventions are only reactive, when what we aim for is to be proactive and **prepare for both current and future challenges**. In addition, small-scale interventions proved not to be sufficient to achieve the flood reduction targets for the selected sites (see **section 3.2**), emphasizing the need for a safe evacuation and refuge system.

Overall, after assessing the likelihood of successful and sustainable implementation of NbS at the community level, the results are compelling. The potential for the implementation of NbS for disaster evacuation and flood risk reduction is encouraging, and favorable conditions are combined with existing efforts to turn potential into reality.

5.3 Recommendations

This section provides recommendations for the use of NbS to improve disaster evacuation planning and design as well as reducing flood risks. We first outline general key aspects, then we provide a matrix to guide the reader in the selection of measures, and finally, we outline the next steps for their implementation, which is outside of this project.

5.3.1 Key aspects

We consider the following key aspects for the implementation of NbS and complementary measures:

1. **Develop an education and awareness program**. There is a need for an ongoing educational and awareness program that allows the community and other stakeholders to understand the risks they are facing and how to address them. This is especially relevant for the migrants from other cities, who might not understand the landscape and the risks they are facing.
2. **Communicate the benefits of NbS in terms of the direct impact they have on people's lives**. E.g. Instead of referring to flood reduction, translate that into the reduction of damage costs; instead of urban agriculture to improve rainfall infiltration, refer to the reduction in the expenses per household.
3. **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. Also, the RF2 is more likely to have a better understanding of the community and their needs. As an organization, the RF2 could collaborate with other relevant organizations, strengthening the institutional network with a bottom-up approach.
4. **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, keeping the lifecycle of NbS in mind. Floods do not happen on the household scale, they happen in the landscape. You can manage water locally, but only up to a certain degree. A comprehensive strategy is needed so that all the small-scale interventions create synergies between each other, as opposed to trade-offs.
5. **Define stages for the implementation of measures**. You can start small, with community-driven NbS. If both successful, the measures implemented could be replicated at other locations in the same neighborhood, growing along with the education and awareness capacity of the community. This not only results in more robust interventions but also allows you to phase implementation and maintenance costs of the measures.
6. **Transfer skills and knowledge** about NbS, disaster evacuation, and flood risk reduction, so that the lessons learned in one case can be used by others.
7. **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 resilient and multifunctional spaces, so they can withstand disasters.

5.3.2 How to select NbS and complementary measures

We followed an approach that focused on **sites that are representative, upscalable, and multipurpose** (**section 2**), pre-selecting ten sites. Then, we shorten the selection to three sites – pilot sites - that we could study, analyzing and testing different measures that could be implemented there to learn about which solutions might be feasible. The aim was to develop a project-wide approach, to guide stakeholders at different scales in the implementation and upscaling of NbS and complementary measures for flood risk reduction and disaster evacuation.

More specifically, we recognize that certain combinations of measures are more suitable for certain locations, so we analyzed the characteristics of the area, and identified eight urban typologies (see **section 2.2**). The ten selected sites are representative of the different typologies, so we developed a disaster evacuation plan, using the ten sites as refuges, supported by a network of evacuation routes (**Figure 91**). We envision three different phases of the disaster evacuation plan, according to the severity of the flood.

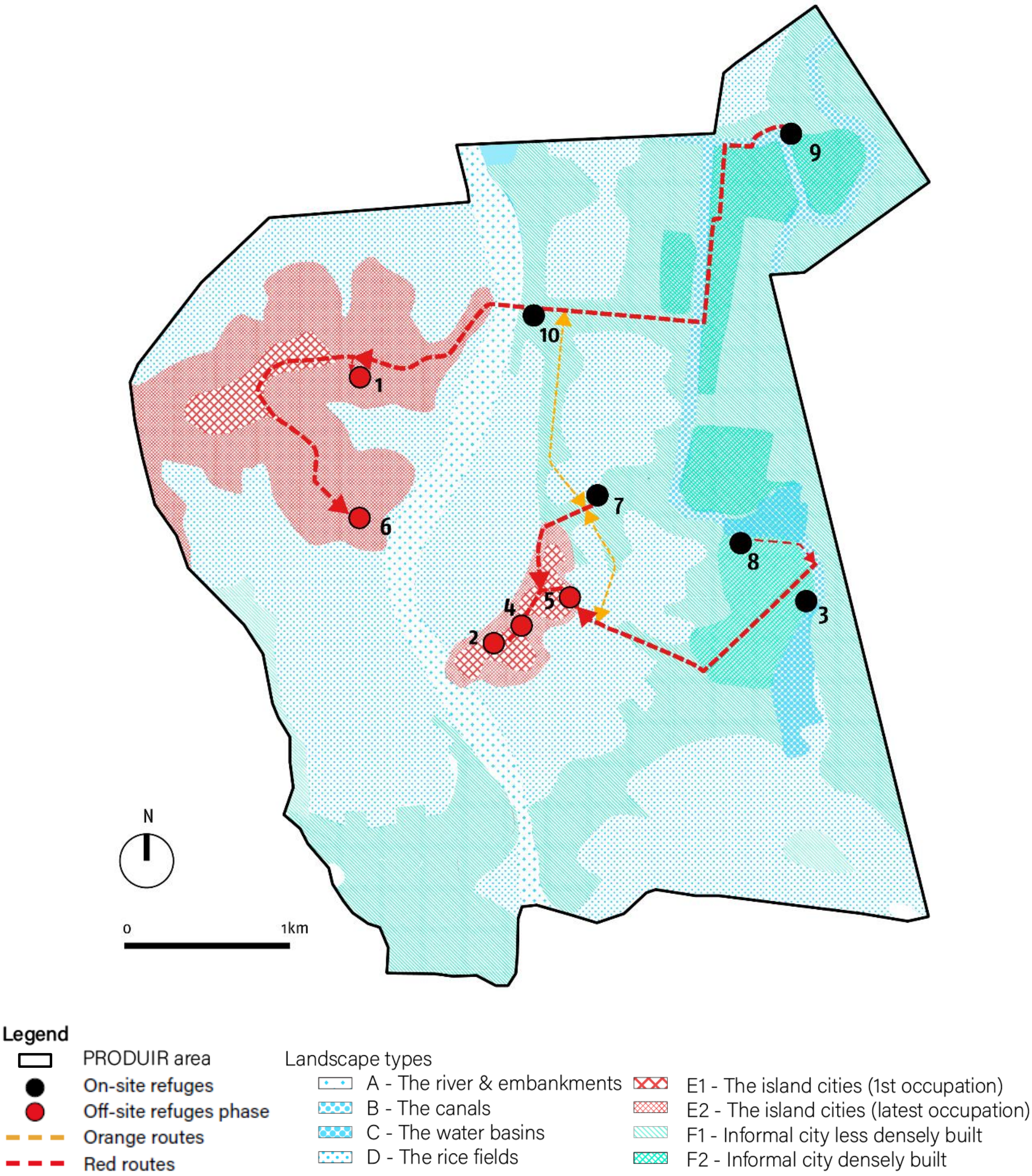
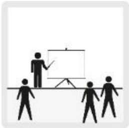
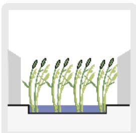
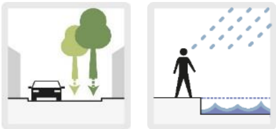
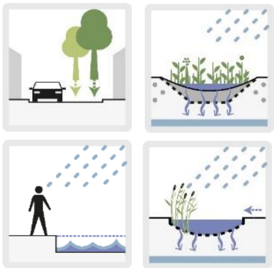


Figure 110. Pilot sites, urban typologies, and evacuation routes during phase II of the evacuation plan.

Each site, according to its characteristics, can serve a specific function as part of the plan, whether is an on-site refuge, or an off-site. Likewise, certain measures are more suitable for certain sites, depending on their specific characteristics. Since the ten sites are representative of the different urban typologies, based on the findings from this process, we developed a matrix (**Table 17**) summarizing the recommended types of measures per typology. We understand that within a certain urban typology, there are many different areas, with specific characteristics. However, the matrix serves as a first guide or filter for the selection of measures.

Table 18. Matrix with types of measures and urban typologies where they are most suitable

Measure	Urban typology	Why?
Solar street light, Awareness and 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. They can provide an additional water supply.
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. 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, **elevated boardwalks on stilts** allow for the mobility and safe evacuation of pedestrians while allowing the free flow of water
Urban wetland 	D – The rice fields F1 – Informal city less densely built	**Urban wetlands** could be implemented in swampy areas with more open spaces 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 locations, to allow for storm water runoff conveyance while allowing for safe evacuation. This could be either through embankments or boardwalks on stilts. The latter is preferred for locations where floods

Measure	Urban typology	Why?
		are most likely to occur. This way, the structure of the boardwalk will not interfere with the water flow.
Adding trees 	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 body (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 evacuate to E2.
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 most flat flood-prone areas. In this type of location, it is very important to make evacuation routes visible (trees) while also providing enough room for stormwater 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 most 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 reduces the availability of open areas for this purpose.

5.3.3 Next steps

The scope of this study was the increase of Antananarivo's resilience, focusing on NbS for flood risk reduction and disaster evacuation in the PRODUIR area. However, we understand that this only provides the starting point for future initiatives involving NbS. As such, we foresee some actions that constitute the next steps after this study:

- **Necessary detailed studies**. Conduct detailed studies in one or more of the pilot 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 pilot sites. E.g. adjust the height of evacuation routes, modify the location of drains or modify the implementation and maintenance strategy.
- **Testing**. Implement and test the measures that are part of the plan. This could be done using the AST, since it is free of use and already calibrated to the local context. The AST could provide a quick estimation of the impact of the changes. This should be discussed with the community and other stakeholders, to check the results. If necessary, refine and test again.
- **Upscaling**. Based on the results from the testing, upscale to other locations with similar characteristics. The matrix (**Table 17**) can guide the process of selecting measures for other locations. This should be carried out collaboratively with the stakeholders, to ensure that the combination of measures responds to the local needs and can be sustained over time.

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

References

Andriamamonjisoa, S. N., & Hubert-Ferrari, A. (2019). Combining geology, geomorphology and geotechnical data for a safer urban extension: Application to the Antananarivo capital city (Madagascar). *Journal of African Earth Sciences*, *151*, 417-437.

Antoine P. (1999). *Nuptialité et conditions de vie dans les villes africaines*. Chaire Quetelet. Populations et défis urbains, Louvain-la-Neuve, 26-29 octobre 1999, 21p. multig.

Bacchin, T.K., Ashley, R., Sijmons, D., Zevenbergen, C., van Timmeren, A. (2014). *Green-blue multifunctional infrastructure: an urban landscapesystem design new approach, 13th International Conference on Urban Drainage*, Sarawak, Malaysia, 7-12.

Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L., & Hopton, M. E. (2017). The role of trees in urban stormwater management. *Landscape and Urban Planning*, *162*, 167-177.

Blanchy, S. (1994). *Les sans-abri à Antananarivo : enquête réalisée par l'ASA (association pour l'accueil des sans-abri) de 1992 à 1994.* Credo-info

BPPA et Scet Agri (1994). *Etude des Casiers d'Andavamamba et d'Anosibe.*

Camacho M. (1986). *Les poubelles de la survie. La décharge municipale de Tananarive*. Paris, L'Harmattan, 208 p.

Canard, F., *Rabenarivo, S. (2001). Nos enfants, ces inconnus*. (Ouvrage bilinguefrançais/malgache). Paris, L'Harmattan, et Antananarivo, Tsipika, 2001, 121 p.

Center National de Recherches Sur l'Environnement (CNRE) (2015). *Eaux des villes et Eaux des champs ou le développement urbain non planifié*. 36 p.

Collective (1998), *La cité des mille, Antananarivo: Histoire, architecture, urbanisme.* Cite/Tsipika Ed.

Climate risks in urban and urbanizing geographies Madagascar, 2018

Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.). 2016. Nature-based Solutions to address global societal challenges. Gland, Switzerland: IUCN. xiii + 97pp.

Commune d'Andranonahoatra (2012). *Monographie de la CR d'Andranonahoatra*. 22p

Commune de Bemasoandro (2019). *Monographie de la Commune de Bemasoandro* Antananarivo, 16p

Coury, D., Roubaud (1997). *Le travail des enfants à Madagascar. Un état des lieux.* Note n° 9717/E, 1997,26 p. multig.

Couton, P., Martinella, U., Marty, D., Estienne, C., Labatte, B., Mazoyer, A., Recouvreur, R., Valfrey, B., Cheurfa, E., Fernandez, D., Janssen, J. (2018). *Mission de maitrise d'oeuvre pour le program intégré d'assainissement d'Antananarivo (PIAA)Tranche conditionnelle Activité 11: Schéma directeur d'assainissement des eaux pluviales, des eaux usées et des excréta (Final report)*

De Vries, S., Van Dillen, S. M., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: stress, social cohesion and physical activity as mediators. *Social science & medicine*, *94*, 26-33.

Declerck, P. (2002). *Les naufragés. Avec les clochards de Paris*. Paris, Plon - Terre humaine, 458 p.

Disaster Risk Profile: Madagascar 2018

Directorate-General for Research and Innovation 2015 Climate Action, Environment, Resource Efficiency and Raw Materials EN (full version)

Doig, 2020. https://reasonstobecheerful.world/japans-disaster-parks-help-explain-its-coronavirus-response/

Domke, G. M., Oswalt, S. N., Walters, B. F., & Morin, R. S. (2020). Tree planting has the potential to increase carbon sequestration capacity of forests in the United States. *Proceedings of the National Academy of Sciences*, *117*(40), 24649-24651.

Emergency Action Plan (EPoA); Madagascar: Tropical Cyclone Belna

Emergency Plan of Action Operation Update; Madagascar: Plague (Epidemic)

Emergency Appeal; Madagascar: Tropical Cyclone Enawo

Emergency Plan of Action Operation Update 3; Madagascar: Cyclone Enawo

Emergency Plan of Action Operation Update 4 Madagascar: Cyclone Enawo and Tropical Storm Ava

European Union, 2015. Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & ReNaturing Cities Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities'

Feltmate, B., Fluder, A. (2018). *Too Small to Fail: Protecting Canadian Communities from Floods*. https://waterbucket.ca/wscblog/wp-content/blogs.dir/7/files/sites/8/2018/11/Intact-Center_Climate-Change-Adaptation-Projects_Nov2018.pdf

From Climate Information and Services to Disaster Risk Reduction: Case of Madagascar

Gillard, R., Oates, L., Kasaija, P., Sudmant, A., & Gouldson, A. (2019). Sustainable urban infrastructure for all: Lessons on solar-powered street lights from Kampala and Jinja, Uganda.

Greater Antananarivo: Urban Poverty and Resilience Study

Grootenhuis, F., I. Duchhart & J. Mburu (1997) Make your town a green town - Facilitation guide for 3-day workshop in participation environmental planning for urban centers, Wageningen: Wageningen Agricultural University.

Guerin, C. (1998). *Antananarivo, espace urbain, espace culturel. L'empreinte de la culture malgache sur les pratiques et les représentations du milieu urbain.* Géographie et Cultures n° 25, Paris. pp. 91-109

Guerin-Fournet, C. (2001). *La ville mise en scène : quelques enjeux à propos des représentations écrites et iconographiques d'Antananarivo (Madagascar).* Géographie et Cultures n° 40, Paris, hivers 2001, pp. 93-108

Hector Lim, Jr. a, Ma. Bernadeth Lim B, Mongkut Piantanakulchai C. Journal of the Eastern Asia Society for Transportation Studies, Vol.10, 2013

Holloway, A. J., Roomaney, R., Pharoah, R., Solomon, F. J., & Cousins, D. (2008). Weathering the storm: Participatory risk assessment for informal settlements. Disaster Mitigation for Sustainable Livelihoods Program (DiMP).

HR Wallingford Contributors Darren Lumbroso, Bridget Woods Ballard Distribution FLOODsite team Document Reference T17-07-04

Integrated Urban Development and Resilience Project for Greater Antananarivo (P159756)

Interscene and Terroirs de Demain (2007). *Antananarivo: entre collines et rizieres, plan vert de la commune urbaine*

International Organization for Migration (2017). *Flood resilient shelter in Pakistan, Phase 2: Evidence-based Research. 277p*

Kabisch, N., N. Frantzeskaki, S. Pauleit, S. Naumann, M. Davis, M. Artmann, D. Haase, S. Knapp, H. Korn, J. Stadler, K. Zaunberger, and A. Bonn. 2016. Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecology and Society 21(2):39.

Kitunda, J. M. (2017). A history of the water hyacinth in Africa: The flower of life and death from 1800 to the present. Lexington Books.

Leemkuil M.M.A. (2016). *Culture as base for landscape design: the case of an earthquake-safe community center for the Nepali mountain village Ashapuri*. Master thesis. Wageningen University **https://edepot.wur.nl/397078**

Madagascar: Humanitarian Snapshot, 19 January 2018

Madagascar-Country Management Unit (2017). *Great Antananarivo: urban poverty and resilience study*. Antananarivo, 54p

Madio Project (1997). *La consommation et le rôle du secteur informel dans la satisfaction des besoins des ménages dans l'agglomération d'Antananarivo*. Premiers résultats de la phase 3. 49 p.

Madio Project (1997). *Le système scolaire et la demande d'éducation dans l'agglomération d'Antananarivo en 1997(Premiers résultats de l'enquête SET 1997*). 56 p.-

Madio Project (1997). *Transferts entre les ménages et réseaux de solidarité dans l'agglomération d'Antananarivo en 1997.(Premiers résultats de l'enquête SET 1997)*. 43 p.

Madio Project II (2000). L'emploi, le chômage et les conditions d'activité des ménages dans les sept grandes villes de Madagascar. 79 p.

Madio Project II (2002) *Dynamique du marché du travail dans les sept grandes villes de Madagascar entre 2000 et 2001.* 32 p.

Madio Project (1997). *L'état de santé de la population et la demande des soins dans l'agglomération d'Antananarivo en 1997 (Premiers résultats de l'enquête SET 1997*). 60 p.

Madio Project (1999). *Trajectoires biographiques dans l'agglomération d'Antananarivo. Emploi, famille, logement. (Premiers résultats de l'enquête BIOMAD 98)*. 75 p.

Marie, A. (1997) Une *Afrique des individus? Itinéraires citadins dans la société contemporaine (Abidjan, Bamako, Dakar, Niamey)*. 440 p.

Marguerat, Y (2003). *Antananarivo et ses marginalités sociales : Forces et faiblesses d'une société urbaine originale*. 16p

Medical and Evacuation Procedures Madagascar 2018

McIlwaine, S. (2003). Greywater Reuse in Jordan. CSBE, Amman. https://www.csbe.org/greywater-reuse-in-jordan

National Capacity Development for Emergency Food Security Assessment and Preparedness: Madagascar Plan of Action

National Disaster Management Framework South Africa

Pötz, H., Bleuzé, P., Sjauw En Wa, A., & Baar, T. V. (2012). Groenblauwe netwerken voor duurzame en dynamische steden= Urban green-blue grids for sustainable and dynamic cities. *Delft: Coop for life*.

Raharison, I. C (2005). *Les remblais dans la Capitale2005 : Cartographie et contextes internationaux.* Ecole Supérieure Polytechnique. 73 p

Rakotomalala, A. M. (2013). *Réduction des Risques et des Catastrophes liés aux déchets industriels. Cas de la décharge d'Andramiarana dans la Commune Rurale d'Antehiroka Antananarivo*. Faculté de Droit, d'Economie et de Gestion. 65 p

Rakotoson, V. (2006). *Mobilisation pour les déchets urbains - Madagascar «Témoignages»*. RE Antananarivo. 12p.

Rambinintsoa, T. M. (2012). *Simulation numérique de l'inondation de l'agglomération d'Antananarivo pour l'orientation des décisions en urbanisme.* Thèse de doctorat, Antananarivo Ecole Supérieure Polytechnique. 93 p

Razafindrakoto, M., Roubaud, F. (2002). Les entreprises franches à Madagascar : atouts et contraintes d'une insertion mondiale réussie", Afrique contemporaine n° 202-203 (n° spécial "Madagascar après la tourmente"), pp. 147-163.

Razafindrakoto, J. L. (2014). Résilience des habitations aux inondations en milieu urbain: le cas d'Andohatapenaka, un quartier de la ville d'Antananarivo »

Razafindratovo, J. (1966). *Isoraka.* Antananarivo, ORSTOM. 98 p. multig.

Pötz, H., Bleuze, P., Sjauw En Wa, A., & Baar, T. V. (2012). Groenblauwe netwerken voor duurzame en dynamische steden= Urban green-blue grids for sustainable and dynamic cities. *Delft: Coop for life*. Available at https://www.urbangreenbluegrids.com/heat/?s=heat%20stress

Sendai Framework for Disaster Risk Reduction 2015-2030

Schuster, C., Honold, J., Lauf, S., & Lakes, T. (2017). Urban heat stress: Novel survey suggests health and fitness as future avenue for research and adaptation strategies. *Environmental Research Letters*, *12*(4), 044021.

South Africa. 2014. Disaster Management Monitoring and Evaluation Framework

USAID (2018). *Risques climatiques dans les zones urbaines et en voie d'urbanisation, Madagascar, 27p*

Verin, P. (2000). *Madagascar. C*ollection "Méridiens". 270 p.

Voskamp IM, Van de Ven FHM (2015) Planning support system for climate adaptation: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. Building and Environment 83, p159-167.

WaterAid (2016). L'eau : à quel prix? L'état de l'eau dans le monde 2016. Note d'Information. Available at https://reliefweb.int/sites/reliefweb.int/files/resources/Water%20At%20What%20Cost%20French.pdf

WING KONG Léonce et TRONCHON Jacques (éd.) : Les sans-abri à Antananarivo. Rapport d'enquête,

World Bank. 2017. Implementing nature-based flood protection: Principles and implementation guidance. Washington, DC: World Bank.

World Bank. 2018. Nature-based Solutions for Disaster Risk Management. Washington, DC: World Bank.

World Bank Group August 2016 Urban Floods Community of Practice (UFCOP)The Role of Green Infrastructure Solutions in Urban Flood Risk Management

World Bank (1990) *Rapport d'evaluation Madagascar Projet de Developpement de la plaine d'Antananarivo*, 23 February 1990

World Bank (2011). *L'urbanisation ou le nouveau défi malgache*.Antananarivo 2011, 224 p.

World Health Organization (2010). Urban Planning, Environment and Health: From Evidence to Policy Action. From http://www.euro.who.int/ __data/assets/pdf_file/0004/114448/E93987.pdf?ua=1.

Annex A. Population exposed to floods

The calculation of the population exposed to floods is an estimation based on the available information. The degree of precision of this estimation depended on the available data. The results should only be used as a reference as part of this project.

DATA LIMITATIONS AND ASSUMPTIONS

- Population data per fokontany is from 2017. Considering the constant migration towards the city, it is expected that this number has increased in the last three years.
- Population affected per commune is based on the information provided by UNOCHA as part of their evacuation plan from 2015. Assuming that urban expansion has continued to increase in the last 5 years, as well as migration from other regions in the country, along with climate variability, it is expected that this number has increased as well.
- The flood map used as a reference is the Plan de Reperage des Batiments dans la Zone Inondable dans les fokontany du PRODUIR a Antananarivo

METHODOLOGY AND CALCULATIONS

Based on the available information, including Population census 2017, UNOCHA plan, PRODUIR flood exposed, HAND 2m flood extension map, and satellite image, we estimated the percentage of the inhabited area of each fokontany exposed to floods. We then translated that number into a percentage of the population of the fokontany. This is what we estimated as the **population exposed to floods**.

District: Antananarivo Renivohitra				
Commune: 1er arrondissement	Population: 247,882 Population affected UNOCHA: 190,500 (77%) Population affected (estimated*): 68,867 (28%)			
Fokontany	**Population (2017)**	**Total Surface (m2)**	**Estimated inhabited flooded area (%)**	**Estimated population exposed (n)**
67ha Avaratra Andrefana	10765	151,188	1%	107.65
67ha Avaratra Atsinanana	13557	199,901	10%	1355.7
Lalamby Sy Ny Manodidina	2601	340,012	2%	52
Antohomadinika Atsimo	8655	149,047	20%	1,731
Andavamamba Anjezika II	7412	259,614	50%	3,706
Ankasina	11843	732,757	2%	237
Antohomadinika Antsalovana Faa	9183	223,559	50%	4,592
Andohatapenaka II	19070	1,453,216	30%	5,721
Antetezanafovoany II	1968	20,234	10%	196.8
Andranomanalina Afovoany	7946	48,682	0%	0
Andranomanalina I	3632	30,906	45%	1634.4
Andohatapenaka I	15534	460,852	30%	4,660
Andohatapenaka Ili	8649	644,235	90%	7,784
Andavamamba Anatihazo II	12978	210,395	40%	5,191
Andavamamba Anatihazo I	7996	123,554	1%	80
Manarintsoa Anatihazo	2650	45,388	0%	0
Antohomadinika Avaratra Antani	3405	133,515	20%	681

Antohomadinika Ilig Hangar	14310	147,346	90%	12879
Manarintsoa Atsinanana	8215	209,165	0%	0
Antohomadinika Afovoany	3534	84,041	35%	1,237
Anatihazo Isotry	10408	83,977	35%	3642.8
Andranomanalina Isotry	6390	25,766	0%	0
Manarintsoa Isotry	1736	16,962	0%	0
67ha Afovoany Andrefana	6655	76,219	2%	133.1
Cite Ambodin'isotry	11544	115,862	15%	1731.6
67ha Atsimo	11901	136,439	0%	0
Manarintsoa Afovoany	4105	61,259	0%	0
Antetezanafovoany I	8942	221,095	60%	5,365
Andavamamba Anjezika I	12298	255,778	50%	6,149

District: Antananarivo Renivohitra

Commune: 4er arrondissement

Population: 214,813
Population affected*: 140,000 (65%)
Population affected (estimated*): 66,164 (31%)

Fokontany	Population (2017)	Total Surface (m2)	Estimated inhabited flooded area (%)	Estimated population exposed (n)
Anosibe Ambohibarikely	8929	217,763	65%	5,804
Madera Namontana	14681	584,736	1%	147
Ilanivato Ampasika	7134	460,582	10%	713
Ampangabe Anjanakinifolo	16416	371,744	10%	1,642
Anosipatrana Andrefana	7664	200,279	10%	766
Anosizato Atsinanana II	13442	918,588	30%	4,033
Ivolaniray	9499	194,885	80%	7,599
Andavamamba Ambilanibe	12100	302,726	60%	7,260
Anosibe Andrefana II	16593	249,464	35%	5,807
Anosibe Andrefana I	16510	294,555	60%	9,906
Mandrangobato I	12600	110,389	30%	3,780
Anosizato Atsinanana I	15545	931,040	5%	777
Angarangarana	14047	737,310	10%	1,405
Mandrangobato II	13448	337,574	40%	5,379
Andrefan'i Mananjara	11266	228,019	35%	3,943
Anosipatrana Atsinanana	11090	166,609	15%	1,664
Ambodirano Ampefiloha	13849	633,970	40%	5,540

District: Antananarivo Renivohitra

Commune: Bemasoandro

Population: 76,375
Population affected UNOCHA: 10,000 (13%)
Population affected (estimated*): 4,747 (6%)

Fokontany	Population (2017)	Total Surface (m2)	Estimated inhabited flooded area (%)	Estimated population exposed (n)

Anosimasina	19097	1,959,011	10%	1,910
Ambohidahy	15843	373,545	5%	792
Bemasoandro	6901	116,396	0%	0
Ambodiamberivatry	4677	382,100	20%	935
Ambohijafy	20300	514,531	5%	1,015
Antanety	9557	117,656	1%	96

District: Antananarivo Antimondrano

Commune: Anosizato Andrefana

Population: 28,387
Population affected UNOCHA: 25,000 (88%)
Population affected (estimated*): 7,912 (28%)

Fokontany	Population (2017)	Total Surface (m2)	Estimated inhabited flooded area (%)	Estimated population exposed (n)
Ankazotoho	3337	343,359	50%	1,669
Antokontanitsara	4790	342,950	10%	479
Ampefiloha	3300	434,664	70%	2,310
Antananambony	4431	73,222	10%	443
Ambanimaso	3738	115,384	10%	374
Antandrokomby	3854	213,663	30%	1,156
Ambodivona	4937	225,475	30%	1,481

District: Antananarivo Antimondrano

Commune: Andranonahoatra

Population: 38,936
Population affected UNOCHA: 0 (0%)
Population affected (estimated*): 7,912 (28%)

Fokontany	Population (2017)	Total Surface (m2)	Estimated inhabited flooded area (%)	Estimated population exposed (n)
Ambaniala	19659	1,666,133	5%	983
Ambanilalana	15258	378,194	3%	381
Akany Firaisana	4019	295,387	5%	201

FINDINGS

The estimations based on the PRODUIR flood map, the 2017 population data, and satellite images (Google Earth, Bing Maps Aerial, LIDAR) show that only 25% of the population (149,257 people) of the fokontany located in the PRODUIR project area are exposed and potentially affected to floods. This number is lower than the 60% (365,500 people) estimated as part of the evacuation plan of UNOCHA in 2015. Given the quality of the data, and the qualitative method used to conduct this analysis, it is not possible to come to a definitive conclusion about the population exposed to floods. However, some remarks can be made:

- UNOCHA plan estimated that 0% of the population from the commune of Andranonahoatra was exposed to floods. This includes the fokontany of Ambaniala, Ambanilalana, and Akany Firaisana. After careful observation of those areas, we noticed that houses located around or below 1250m, could be exposed to floods.

- According to the UNOCHA plan, 88% of the population of the Anosizato Andrefana commune were exposed to floods. However, after observing each one of the fokontany in this commune, we noticed that only in two cases a considerable percentage of the inhabited area was exposed to floods. This happens in Ampefiloha (50%) and Ankazotoho (70%). In the rest of the fokontany, only a small percentage of the population was exposed to floods.

- Our results underestimate the population exposed to floods when compared with the estimations per commune shown in the UNOCHA plan. Following a conservative approach regarding the population exposed, we decided to consider the estimations per commune from the UNOCHA plan but following the distribution from our estimations (see figure).

Table 19. Estimations per fokontany of the exposed population.

Fokontany	Estimated pop. exposed adjusted[16]	Fokontany	Estimated pop. exposed adjusted
Commune: 1e arrondissement		**Commune: 4e arrondissement**	
67ha Avaratra Andrefana	264	Anosibe Ambohibarikely	14,219
67ha Avaratra Atsinanana	3,321	Madera Namontana	360
Lalamby Sy Ny Manodidina	127	Ilanivato Ampasika	1,748
Antohomadinika Atsimo	4,241	Ampangabe Anjanakinifolo	4,022
Andavamamba Anjezika II	9,080	Anosipatrana Andrefana	1,878
Ankasina	580	Anosizato Atsinanana II	9,880
Ant. Antsalovana Faa	11,249	Ivolaniray	18,618
Andohatapenaka II	14,016	Andavamamba Ambilanibe	17,787
Antetezanafovoany II	482	Anosibe Andrefana II	14,228
Andranomanalina Afovoany	0	Anosibe Andrefana I	24,270
Andranomanalina I	4,004	Mandrangobato I	9,261
Andohatapenaka I	11,417	Anosizato Atsinanana I	1,904
Andohatapenaka Ili	19,071	Angarangarana	3,442
Andavamamba Anatihazo II	12,718	Mandrangobato II	13,179
Andavamamba Anatihazo I	196	Andrefan'i Mananjara	9,661
Manarintsoa Anatihazo	0	Anosipatrana Atsinanana	4,076
Ant. Avaratra Antani	1,668	Ambodirano Ampefiloha	13,572
Antohomadinika Ilig Hangar	31,554	**Commune: Bemasoandro**	
Manarintsoa Atsinanana	0	Anosimasina	4,679
Antohomadinika Afovoany	3,030	Ambohidahy	1,941
Anatihazo Isotry	8,925	Bemasoandro	0
Andranomanalina Isotry	0	Ambodiamberivatry	2,292
Manarintsoa Isotry	0	Ambohijafy	2,487
67ha Afovoany Andrefana	326	Antanety	234
Cite Ambodin'isotry	4,242	**Commune: Anosizato Andrefana**	
67ha Atsimo	0	Ankazotoho	4,088
Manarintsoa Afovoany	0	Antokontanitsara	1,174
Antetezanafovoany I	13,145	Ampefiloha	5,660
Andavamamba Anjezika I	15,065	Antananambony	1,086
Commune: Andranonahoatra		Ambanimaso	916
Ambaniala	2,408	Antandrokomby	2,833
Ambanilalana	935	Ambodivona	3,629
Akany Firaisana	492		

[16] The estimations are based on flood maps, census data and satellite images, and were adjusted on a 250% so the total number of exposed populations in the city disaggregated by fokontany, was similar to the exposed population disaggregated by commune, estimated as part of the UNOCHA plan.

Annex B. Background information for the development of implementation and maintenance strategies

INTRODUCTION

Unlike traditional infrastructure, NbS and green infrastructure usually required a different type of maintenance. Maintenance is key to their adequate performance. Since they mostly include some type of vegetation, once they are implemented, they require some time to perform the way they have been designed to. The maintenance, or lack thereof, is relevant because influences their performance. For example, if bioswales are not maintained, the grasses and sediments might accumulate and prevent proper stormwater runoff conveyance and infiltration.

It is therefore important that we **design with a lifecycle view in mind**. This means that during the planning and design phase we must already start to think about the needs of the operation and maintenance phase and even consider the implications of the end-of-life of the infrastructure or assets installed. Moreover, we should think about when the design will start performing in the way it was designed to perform. We also must **design with operations and maintenance (O&M) in mind**. This means we must think about how our designs lead to the need for different types of maintenance in terms of cost, skills, people, frequency, impact on use, replacement requirements, etc. We must consider the environment in which the O&M will take place, which covers not only the ecological environment but institutional, social, political, and financial environments as well. The process of designing with the lifecycle view and operation and maintenance in mind should be conducted collaboratively, engaging the different stakeholders. This way, the measures will reflect the local context more accurately, and their implementation and maintenance will be conducted more efficiently.

A major failing of many infrastructure projects is because of their lack of consideration of the total lifecycle cost of both building and operating/maintaining the assets installed. Minimizing the cost of the capital construction phase often leads to poor maintenance outcomes that in turn lead to higher lifecycle costs over the long term.

Another important consideration is that of replacements. The concept of a lifecycle implies that at some point the infrastructure assets will reach an “end-point”. The need for social infrastructure is ongoing and continuous. Therefore, the “end-of-life” of an individual asset may have meaning, but the system within which it sits will be continuous and therefore have no end-of-life. This means that during the design phase we need to think about how any individual asset will be replaced when it either reaches the end of its design life when it becomes functionally obsolete (no longer required) or when it becomes technically obsolete (newer, better solutions become available). This has major financial implications over the long-term and the responsible organizations need to understand the long-term commitment they are making and plan for it.

DESIGN OF NBS AND COMPLEMENTARY MEASURES: ASSETS

Various asset types will be installed as part of this project, some will be more traditional asset types (grey infrastructure) and some will be more environmentally friendly (green infrastructure). All assets installed must be designed such that:

1. Consideration is given to the **total lifecycle cost** (such that it is minimized). An example of a suitable lifecycle for this project is the recycling of plastic from the neighborhood, to be used in the construction of boardwalks on stilts for disaster evacuation. In this example, the waste from everyday activities from the community it is transformed into a component for a complementary measure for disaster evacuation, which also reduces waste. Boardwalks made out of plastic can be more durable than the ones from wood and require less

maintenance, while the recycling process also contributes to the local economy by developing a new type of local business.

2. Careful consideration is given to **how maintenance will be executed and by whom**.
3. We **use appropriate technology** for both construction, and operation, and maintenance (O&M). High tech solutions are sometimes not appropriate where local support is not available.
4. They **allow for community-based maintenance**. The objectives of community-based maintenance schemes revolve around:
   - They are **labor-intensive**.
   - They use **skills that can be transferred** to the community and that can ideally be extended to other services or opportunities.
   - They use **materials that are sourced locall***y* (as far as possible). This so that they support the local economy and reduce transportation costs and environmental impacts.
   - They **encourage the formation of SMMEs** (Small, Medium, and Micro Enterprises), like the recycling business from point 1. Community-based maintenance also requires that the technology requirements are kept as limited and as simple as possible (appropriate technology, low-tech).
5. The traditional RAMBO principle of **design for maintenance** still applies and is more important for community-based maintenance:
   - R= Reliability of the measures designed (NbS and complementary measures)
   - A= Availability of the materials to build the measures
   - M= Maintainability. Measures that are easy and cheap to maintain
   - B= Buildability. Measures that are low-tech and easy to build, so that the community can implement them.
   - O= Operability. Measures that are easily and cheaply maintained

MAINTENANCE OF ASSETS

A viable maintenance plan that is community-based must follow the KISS principle, ("Keep it Simple Stupid"). The true genius of design lies in simplicity. Part of the implementation plan for all the assets contemplated under this program must include the **development of asset care plans for each asset type.**

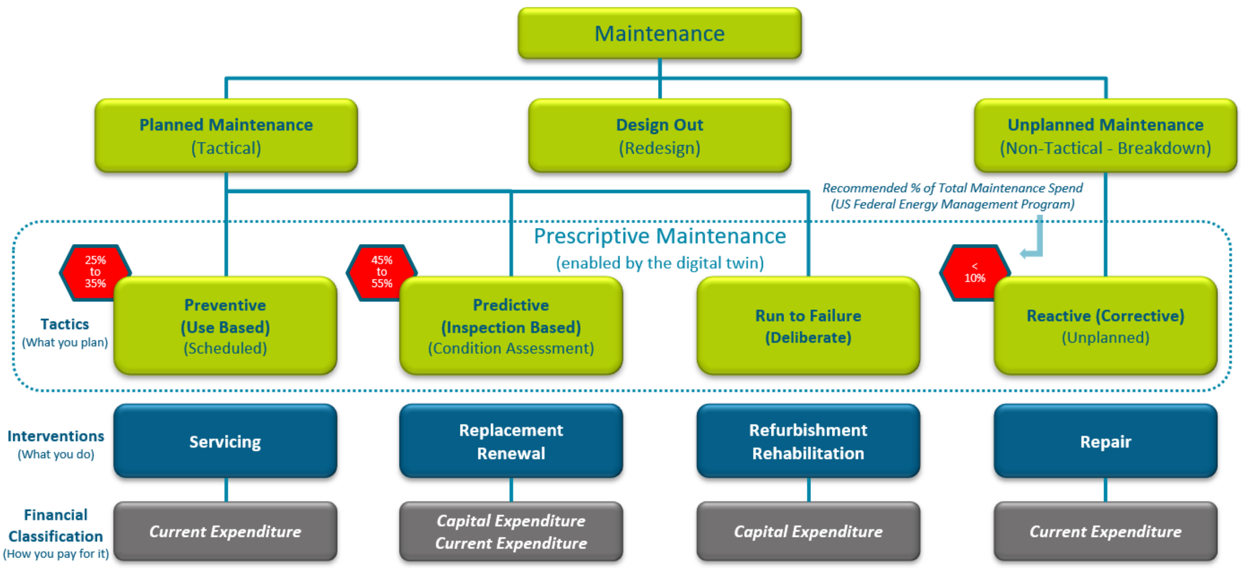


Figure 111. Types of maintenance

Figure 92 shows the types of maintenance. At the high level, there is planned maintenance, maintenance that we carry out to prevent breakdown or failure, and unplanned maintenance, maintenance that is reactive and takes place after an asset has failed in some way. Run-to-Failure is similar to reactive but is a deliberate tactic that allows failure before carrying out maintenance. A typical example is allowing a lightbulb to burn out before replacing it.

The red icons indicate typically recommended budget allocations per asset tactic. It is important to note that **the biggest expenditure should ideally be on Predictive Maintenance**. This is also known as condition-based maintenance. Condition-based maintenance lends itself to minimum overall expenditure because it both prevents failure by correcting before a breakdown, but at the same time does not carry out activities unless they are determined to be necessary, based on the condition-based inspection.

The steps for developing a **Maintenance plan** are:

- Create an asset register
- Determine Criticality per Asset Type
- Develop Asset Care Plans
- Implementing the Asset Care Plan (maintenance)
- Funding of maintenance

Create an Asset Register

An asset care plan starts with an asset register. All assets that form part of the solution developed under the program must be compiled into a comprehensive asset register that is componentized down to an appropriate level of detail.

The asset register is very important because **if you don't know what you have, you cannot manage it**. A good asset register is the foundation-stone of good maintenance management and it must be compiled as part of the capital development phase.

Determining the level of componentization is important because we do not want to make the maintenance system too complicated, but at the same time, we do not want to miss important maintenance tasks that could lead to failure of the assets and the systems within which they sit.

A useful place to start is to list all the key asset groups and then expand into an appropriate level of detail as the project progresses:

- Canals & Channels (Major drainage Systems)
- Levees & Dikes (Protection Systems)
- Minor Drainage infrastructure (Drainage Systems)
- Roads & Footpaths, including elevated footpaths (Transportation Systems)
- Bioswales and other Green Infrastructure (Green Infrastructure Systems)
- Sewerage (Sanitation Systems)
- Potable Water (Water Supply Systems)
- Electrical (Energy Systems)
- Community Facilities, including Sports Fields and Stadia (assembly points), etc.

Determine Criticality per Asset Type

In this step, we must determine the criticality of each asset by considering the consequences and the probability of failure. This is, in effect, a risk-based approach. The reasoning is that we do not wish to use any more resources than necessary to maintain any given asset.

Ideally, we categorize each asset into one of three criticality groups: A, B & C, with A being the most important and C the least important.

Develop Asset Care Plans

Then we compile asset care plans per asset type. The amount of effort we put into the maintenance tasks is dependent on the criticality of the assets (**Figure 93**). We put more effort into highly critical assets so that they are unlikely to fail, and we put less effort into low criticality assets, so we don't waste resources on assets the failure of which is of little consequence.

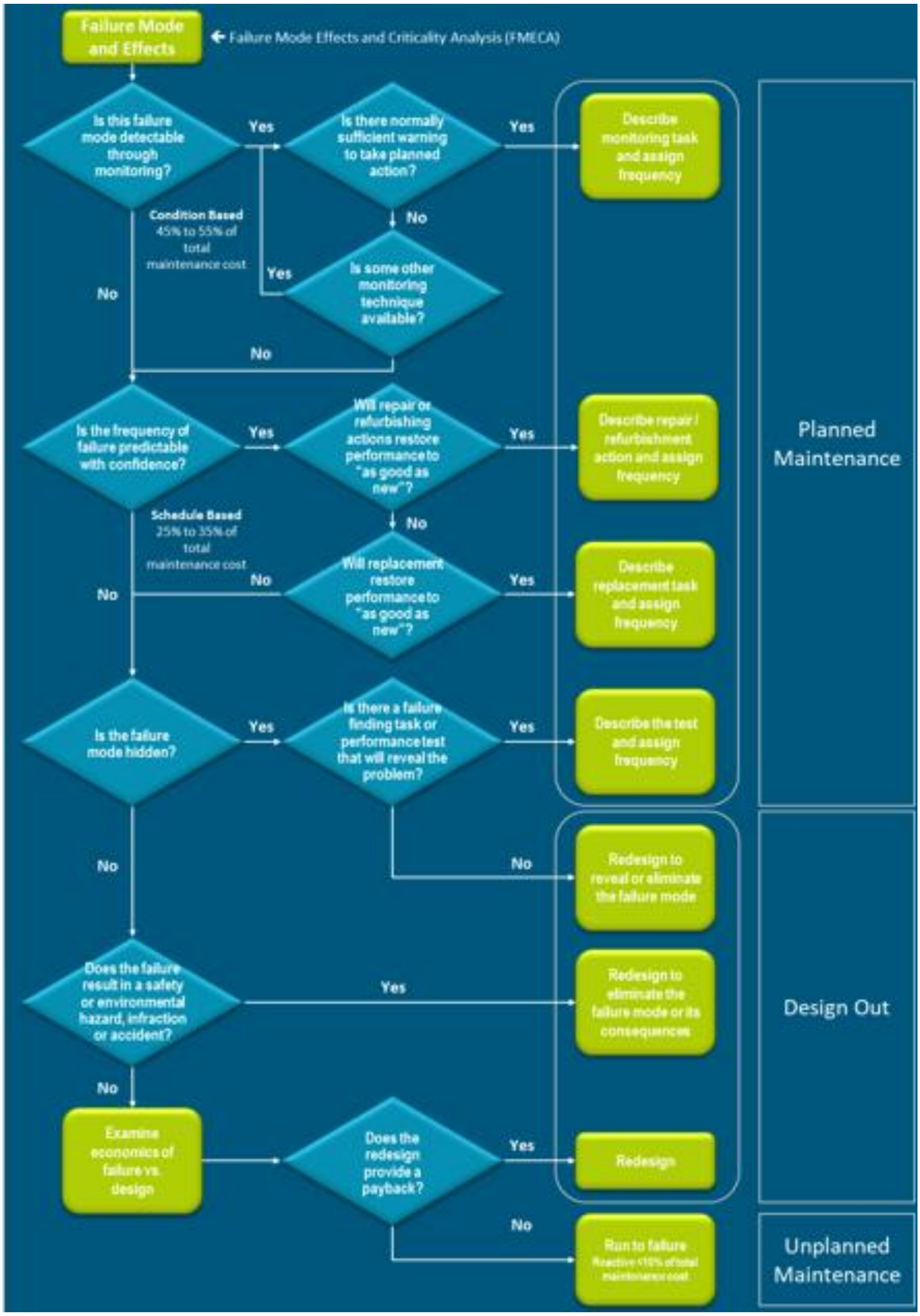


Figure 112. Decision diagram for the development of a maintenance strategy. Source Asset Management Excellence – Optimizing Equipment Life Cycle Decisions (2nd edition)

Put simply, an asset care plan combines people, skills, tools, material, and parts into maintenance tasks that are planned to take place every day/week/month/quarter/year or longer. These maintenance tasks might be planned based on time, or they might be initiated based on a measurement of some parameter, or they might be initiated based on a visual condition inspection. Some assets might only initiate a maintenance task once a failure has already occurred (as described above).

The compilation of these tasks is determined using various processes designed to ensure that we do everything necessary to keep the assets in good condition at the least cost possible, taking into account the cost of maintenance and the cost of failure of the asset when it is in use.

Much of the maintenance work will be simple housekeeping-type tasks suited to community-based maintenance. For bioretention systems, the most common maintenance activity is the removal of leaves from the system and bypass structures. Visual inspections are routine for system maintenance. This includes looking for standing water, accumulated leaves, holes in the soil media, signs of plant distress, and debris and sediment accumulation in the system. Mulch and/or vegetation cover is integral to the performance of these systems. Vegetation care is important to system productivity and health.

Implementing the Asset Care Plan (maintenance)

Some of the asset types and asset tasks will need to be carried out by the more formal institutional structures (government organizations). This is mostly because they need more resources in the form of skills, large equipment, or money. This will typically be more likely to apply to the grey infrastructure.

One of the benefits of green infrastructure is that it lends itself to micro-tasks, activities that can be broken down into small tasks suited to local community members. Things like inspecting bioswales to ensure they are working, cleaning away debris and plastic pollution, ensuring the filtration function works by removing fine material blocking the systems.

Where possible the local community should be used to carry out these tasks because doing this:

- Creates employment opportunities.
- Creates skills and training opportunities.
- Involves the local community in the infrastructure, thereby making them custodians of the assets. This makes the local community more likely to care for and ensure that the infrastructure is looked after and not neglected or vandalized.
- When the local community is actively involved in caring for the assets, they are also more likely to ensure that government institutions are held accountable for their responsibilities.

All of these aspects make the ongoing successful operation of the infrastructure more likely. It encourages responsibility and accountability across all stakeholders.

Funding of maintenance

This issue is of vital importance. In most cases where the long-term maintenance of infrastructure assets fails, it is because no attention has been paid to the need to fund maintenance over the long term. Insufficient funding is made available and the parties responsible for O&M are not able to carry out the necessary O&M tasks within their allocated resources.

When designing and constructing infrastructure, it must be mandatory to include a long-term operations and maintenance section in the business plan. The funding mandate for this must be clear, the long-term financial implications must be defined and the parties responsible for funding and O&M must be made aware of their responsibilities and **must actively accept this responsibility**.

We propose the use of the Financing Framework for Water Security (FFWS), which introduces a shift in the existing NbS implementation paradigm, by using a collaborative approach to think of NbS in terms of the service they provide and how to get the best value for money. The framework is publicly available[17], and it provides a step-by-step guide to stakeholders from different backgrounds to implement NbS and hybrid solutions. The development of an implementation arrangement is out of the scope of this project, but we believe that during the upscaling of the pilots (sites 1,3 and 9) this framework could be used by the local government (the proponent of NbS) to guide the process.

The main aspect to consider is that this should be a collaborative process between the different stakeholders. During this process, NbS should be defined in terms of the type of good they are, the function they fulfill, and the type of service they provide to the community. Every service is measured by using a key performance indicator (KPI), that allows the comparison between the business as usual situation, and the situation where the project has been implemented.

By focusing on the service that the NbS provides, it is possible to identify who is the beneficiary of each service, and who/how are they willing to pay for that service. One NbS can provide several services, paid by different beneficiaries. Moreover, by being explicit about the service provided by NbS, and mapping its lifecycle, it is possible to know how long it takes for it to provide the expected level of service. For example, an urban forest provides services such as landslide risk reduction and heat stress reduction. However, if it is implemented during year 0, the forest will not provide these services until year 5-10, depending on the tree species used and the maturity of the trees at the time they are planted. Another example is a bioswale. They can be quickly built, using grasses and other fast-growing species. In less than 1 year they could be performing the services they were designed to provide.

The FFWS allows for the articulation of this process, to develop a suitable and successful implementation arrangement of projects that combine NbS with other complementary measures in one hybrid project. By using this framework, the funding becomes an aspect that is addressed since the beginning of the project. This means that it does not start with the development of a maintenance plan, but rather with the design of the measure itself.

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[17] A summary of the FFWS can be found in **http://naiad2020.eu/wp-content/uploads/2020/06/Results-in-Brief_Turning-NBS-projects-into-investable-propositions.pdf**. A handbook is being developed with specific instructions, a preliminary version can be found in the deliverable 7.3 http://naiad2020.eu/media-center/project-public-deliverables/

Annex C. Background information for Communication, Monitoring, and Evaluation

COMMUNICATION

Roles and responsibilities

The following is a preliminary list of organizations identified during workshop 1 that are relevant for the communication of disaster evacuation and flood risk reduction information. This list can be used as a starting point for a more detailed one, where both organizations and their specific responsibilities are identified.

- MEAH
- MATP
- MNVH
- BNGRC
- CCGRC
- CPGU
- CUA
- SAMVA
- RF2
- Fokontany
- APIPA
- NGOs
- Households
- Community
- Citizens
- NGOs (waste management, sanitation, citizen education)
- Urban and rural communes
- Municipalities (Anosizato Ouest, Andranonahoatra, CUA I to IV, Bemasoandro),
- ELS
- Informal merchants
- Fokon'olona
- SLC (local commerce structure)
- Neighborhood associations
- Religious and cultural associations
- Community agents
- Police and law enforcement
- Private companies

A contact person should be identified per organization, so they can be easily contacted. **Table 19** provides an example of a contact information form.

Table 20. Example of contact information form for stakeholders

No.	Name of the person	Affiliation	Designation	Mobile number

Table 20 provides an overview of typical actions. Disaster Management Role Players are the persons identified as responsible for a certain disaster management activity.

Table 21. Actions for Disaster Management Role Players

N.	What must be done	Who must do it	Where it must be done	When it must be done	Why it must be done
1	Monitor weather information sources (Listen, see, notice)	Local Authority	24 Hour Call center	Immediately	To determine if action is required
2	Call a meeting and Prepare Action list - Make a list of actions to take (e.g.	Local Authority	24 Hour Call center	Immediately	To plan action to be taken and determine responsibilities

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	warn communities, clear drainage) and divide the responsibilities				
3	Identify areas vulnerable to a flood event	Local Disaster Management and Services Standby Teams	24 Hour Call center	Immediately	To determine the extent of potential flooding
4	Issue an early warning to areas vulnerable to flooding	Local Disaster Management Team, Weather Services, Media	24 Hour Call center, Vulnerable areas	Immediately	To minimize and/or prevent disruption / damage
5	Notify response teams (Municipal engineering, Police, Fire & Rescue, Medical, Dept. Water Affairs, Weather Services)	Local Authority	24 Hour Call center	Immediately	To activate response teams
6	Activate response teams	Local Disaster Management and Services Standby Teams	From locations/ standby positions	Immediately	Prepare for appropriate emergency intervention
7	Implement appropriate emergency intervention e.g. evacuation of areas vulnerable to flooding, road closures, etc.	Municipality / Prov Traffic/ First responders on the scene	At scene	On arrival	To protect life and property and neutralize any impacting hazard
8	Activate JOC	Head of DMC and senior management of all services/jurisdictions involved.	DMC or alternative	Immediately if a major flooding incident	To plan strategically and coordinate a multidisciplinary response, relief, and rehabilitation
9	Assess information	All services	JOC	Immediately	To plan actions
10	Design plan of action	DM Co-ordination Team / JOC Team	JOC	After assessment	To facilitate response and relief
11	Implement response actions	Local Disaster Management Team, Army, Police, Medical, Fire & rescue	Affected area	ASAP	To prevent injury/mortality and to provide basic needs/services
12	Provide relief	Relevant Stakeholders	At affected area/relief center	After assessment	To minimize impact
13	Mopping up	Relevant Stakeholders	Affected area	ASAP	To normalize community
14	Assess the possibility of further flooding	Local Disaster Management Team, Weather Services	Entire area	Immediately	To minimize and/or prevent further disruption/damage
15	Issue an early warning to areas vulnerable to further flooding	Local Disaster Management Team, Weather Services	Vulnerable areas	Immediately	To minimize and/or prevent further disruption/damage

16	Flood management	Department of Water Affairs	On-site and downstream	ASAP	To manage the effects of the flood
17	Organize medical search parties	EMS / Fire & Rescue	On-site	ASAP if people reported missing/unaccounted for	To treat medical cases
18	Arrange temporary accommodation	Municipality / Social services/ NGO's	Available venues	When needed	To provide temporary accommodation – emergency shelter
19	Institute recovery measures	DMC, Treasury, Relevant Departments	JOC	Once the situation is under control	To restore normal activities in the area
20	Rapid initial impact assessment	Municipal engineer and Provincial roads engineer	In affected area	Once flooding has subsided, if infrastructure damage suspected	To establish impact and immediate required repair to infrastructure as well as assistance required from province / national
21	Prioritize, plan and implement emergency repairs to infrastructure	Infrastructure owner	Areas with damaged infrastructure	ASAP – depending on prioritization and available resources	To restore critical and essential services
	Verification of impact assessment	NDMC / PDMC / DMC / Contracted impact assessment team	Areas with damaged infrastructure	ASAP after a rapid initial impact assessment	To quantify and verify infrastructure damage and repair/replacement cost in monetary terms

MONITORING AND EVALUATION

The list below provides a guideline for the frequency and schedule of data collection to be developed and agreed upon by all stakeholders. Plans also need to be developed for compiling and analyzing the collected information and data.

- Type of Data Collected
- Data Source
- Data Set
- Frequency
- Responsible Person

While the activities are being implemented, the Government must regularly check if they have been carried out properly or not. Later, the Government should evaluate the plan by using the Evaluation Form in **Table 21** and send it to the municipality.

Table 22. Evaluation form

Evaluation form - Disaster preparedness and response plan
Did the community receive an early warning about the flooding that happened? If yes, from who and what kind of information did you receive?
What actions did the community leaders take?
Did you receive any support from other stakeholders? If so, what kind of support?
What needs to be modified in terms of disaster evacuation and design to help the community with better preparedness and response during a flood?
Do you need any further support from the Government or the Disaster Management Role-players?

To execute the monitoring and evaluation program, the following steps need to be taken.

Table 23. Steps for monitoring and evaluate

Process	Definition	Role	Activities
Stakeholders Engagement Consultation	Involvement of person or organizations having an investment what will be learned from the evaluations This might be stakeholders or partners involved in program operations, those served or affected by the program. These will be our beneficiaries and recipients, and primary users of evaluation	Help increase the usefulness of evaluations through their inputs and buying	Conduct workshops with stakeholders Coordinate stakeholder input through the process of evaluation design Only relevant stakeholders to be engaged to avoid excessive stakeholder identification.
Describe the program	Describe the features of the program being evaluated. This should include purpose, background information on the intention of the program, what does the program address, expected changes/outcomes, the activities, and available resources	To help stakeholders and partners understand how program features fit together	List specific expectations as goals, objectives, and criteria for success, Analyze the context within which the program operates.
Identify the relevant indicators that will inform the evaluation program	Outcomes and impact indicators	To ensure that progress of indicators is tracked and informed by evaluation studies	Collection of relevant indicators, Review indicators and consolidate into indicator matrix, Population of indicators on the dashboard.
Evaluation Design	The direction and process of the evaluation must be focused	Provide investment in quality: increases the	Discuss the purpose of evaluation with stakeholders

	on assessing issues of greatest concern. An evaluation plan should anticipate intended uses and create an evaluation strategy with the potential for being useful, feasible, ethical, and accurate	chances that the evaluation will succeed by identifying procedures that are practical, politically viable, and cost-effective.	Write evaluation questions that should be answered by the study. Identify who will benefit from the evaluation findings Describe practical methods for sampling, data collection, data analysis and judgment
Gather credible evidence	Collect data with accurate and realistic information. Compiling information that stakeholders perceive as trustworthy and relevant for answering their questions. Such evidence can be experimental or observational, qualitative, or can include a mixture methods	Credible evidence will enhance the evaluation's utility and accuracy, guide the scope and selection of information and promote the collection of valid, reliable and systematic information, i.e. the foundation of effective evaluation	Choosing indicators that meaningfully address evaluation questions. Describe the information sources and the rationale for their selection. Monitor the quality of information obtained and taking practical steps to improve quality. Establish criteria for deciding when to stop collecting data. Safeguard the confidentially of information and information sources.
Justify conclusion Ensure use and share lessons learned	Evaluation conclusions will be justified they are linked to the evidence gathered and judged against agreed upon values for or standards set by stakeholders.	Reinforces conclusions central to the evaluation's utility and accuracy; involves values clarification, qualitative and quantitative data analysis and synthesis	Appropriate methods of analysis and synthesis to summarize findings should be used. Considered alternative ways to compare results. Recommending actions or decisions that are consistent with the conclusions Limiting conclusions to situations, time periods, persons, contexts, and purposes for which the findings are applicable.
Ensure use and share lessons learned	Deliberate effort to be considered in ensuring that the evaluation processes and findings are used and disseminated	Ensure that evaluation achieves its primary purposes	Design evaluation to achieve intended use by intended users. Preparing stakeholders for eventual use by rehearsing would affect program operations. Provide continuous feedback to stakeholders. Schedule follow-up meetings with intended users to

			facilitate the transfer of evaluation conclusions to appropriate actions or decisions. Disseminate both the procedures used and the lessons learned from the evaluation to stakeholders, using tailored communications strategies that meet their particular needs

Table 23 provides the format for the development of the action plan for monitoring and evaluation, which needs to be filled in by the Disaster Management Role Players.

Table 24. Format for the action plan for monitoring and evaluation

Activity	Performance Indicator	Responsibility	Time frame	What has been accomplished	How has it been accomplished

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