How to Climate Proof Water & Sanitation Services in Informal & Peri-Urban Areas in Antananarivo

WSUP
Water & Sanitation for the Urban Poor

Cranfield UNIVERSITY

How to Climate Proof Water and Sanitation Services in Informal and Peri-Urban Areas in Antananarivo

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Work based on field visit to Antananarivo undertaken in August – September 2010

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Reference
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Executive Summary

This report evaluates the impacts of climate change on water and sanitation technologies in the informal and peri-urban areas in Antananarivo and considers the potential adaptations required to mitigate the impacts. The vulnerabilities and adaptations were determined based upon a field visit, a vulnerability assessment and a literature review. Under current forecasts for Antananarivo mean temperatures, rainfall and rainfall intensity are predicted to increase. There will be more frequent storms and cyclones will decrease in frequency but increase in intensity. This is likely to increase the volume of runoff, raise river levels and increase the speed of flood onset; resulting in an increase in flooding from both the river and the drains. The impacts of this scenario are the following:

- **Informal Areas:** there will be an increase in the frequency and severity of flooding from the drains. This presents major health risks and disrupts the live of communities. Water will get into houses, employment will decrease, it will be more difficult to travel, food costs will increase and the environment becomes dirty, odorous and very unpleasant. The infrastructure installed by CARE, WSUP and WaterAid is resilient to flooding, but the water supplied by JIRAMA is contaminated during floods as the catchment isn't protected, increased run-off leads to soil erosion giving the water a high sediment load and there is high non revenue water. In addition, household latrines overflow, their superstructures collapse, flying toilets increase (as latrines are flooded), there are long queues at kiosks, taps are submerged and the water pressure is lower.

- **Peri-Urban:** In the uplands there may be an increase in surface runoff. In the lowlands and paddies will flood from drains. Areas near the river will also flood. The impacts are similar to the informal areas but there will also be damage to crops and livestock, whilst opportunities for alternative employment will decrease. However there is typically more space for local coping mechanisms. When the paddies flood the water will take longer to drain due to higher groundwater.

In Antananarivo there have been a number of studies on the impacts of the river and drains flooding. This study focuses upon how climate will exacerbate these risks. However, as there is already an awareness of the environmental risks, there is a good understanding of the required adaptations, detailed in the WSUP SOMEAH Sanitation Master Plan. In this report this plan has been climate proofed highlighting the need to prioritise Sewage and Stormwater management. As flooding is the primary issue in the peri-urban and informal areas and it will exacerbate other problems. In addition, recommendations were produced for the 40 areas vulnerable to flooding. For these areas potential short, medium and long term adaptations are identified for WSUP (and the local providers), JIRAMA and the Communes. The key recommendations are as follows:

WSUP

- Monitor water from kiosks during floods
- Ensure septic tanks are flood proof
- Educate on risks of flooding

JIRAMA

- Commence programme of leak detection and pipe maintenance
- Reduce illegal connections and improve the hydrostatic pressure
- Introduce a new water treatment stage to deal with high sediment load in floods (extra settling tank or more flocculent)

COMMUNE

- Clear and maintain drains and enforce dumping legislation
- Improve solid waste collection and sanitary options
- Minimise occupation of areas not designed for habitation on the city plan

Contents

Introduction

"Observational evidence from all continents and most oceans shows that many natural systems are being affected by climate change, particularly temperature increases" (IPCC, 2007). This report outlines the impacts (both direct and indirect) associated with the climate changes predicted for Antananarivo. It focuses on the informal parts of the central urban area (Urban Commune of Antananarivo – CUA) and the peri-urban areas (OPCI FIFTAMA).

The report starts by reviewing the water resources in Antananarivo and the causes of flooding from rivers and drains. It then summarises the predicted changes to temperature, precipitation and cyclones in Antananarivo and reviews the indirect impacts of climate change. It then synthesises how the climate scenarios will affect water resources and the existing vulnerabilities, problems and technologies in the informal and peri-urban areas of Antananarivo and outlines which activities of the Sanitation Strategic Plan (Phase II) will be affected by climate change and how they should be adapted. It then presents the main adaptations required in areas affected by flooding for WSUP, JIRAMA, and the commune, dividing them between short, medium and long-term adaptations. Key climate studies for Antananarivo are also listed.

The report aims to provide pragmatic recommendations for adaptation; focusing upon what is known rather than the uncertainties. The environmental problems affecting Antananarivo (principally flooding) are well documented and the reports should be read alongside this study, which frames the environmental risks within the context of climate change. It should be noted that there is currently a political and economic crisis in Madagascar and because of this there is very limited funding from the government, donors are reluctant to invest and NGOs work with governments is restricted to government technicians.

Method

The research started by identifying literature on the impacts of climate change on water and sanitation technologies. The key document was a review completed by the WHO and DFID in 2010 (Charles *et al.*, 2010). This describes the vulnerabilities of various water and sanitation technologies to climate change, and proposes adaptations. This was followed by a field visit which identified the technologies being used in Antananarivo and hence identifying the vulnerabilities of the whole water and sanitation system to climate change. The adaptations required to mitigate these vulnerabilities were selected from Charles et al (2010) and are listed in the appendix.

The field visit to Antananarivo was completed in August 2010 and entailed 22 semi-structured interviews with representatives from the local service provider, water utility, local Council, regional government, scientific community and NGOs (Table 3 in the appendix lists the interviewees). The interviews and observations assessed the impact of flooding and cyclones on the existing environmental, social and economic vulnerabilities and on technologies. The interviews also assessed the institutional awareness of climate risks. Further climate vulnerabilities were identified from the literature review. Eight focus groups were undertaken with the community, completing a cause and effect analysis (i.e. what are the problems, what causes them and what impacts do they have).

The information gathered from the interviews was used to prepare a vulnerability assessment. This involved listing the problems identified in the peri-urban and informal areas and identifying the linkages between them in a flow chart (e.g. floods lead to latrines overflowing). Once the linkages between all of the problems had been identified, the expected changes in climate were added (e.g. increasing rainfall) and the factors they impacted (directly and indirectly) were identified. In addition, the indirect impacts of climate change (e.g. food insecurity) were incorporated assessing which factors they affected. This made it possible to assess how climate change will affect the existing vulnerabilities in the peri-urban and informal areas. This diagram was then used to determine the adaptations required to mitigate the problems. The adaptations from both the fieldwork and the literature review were then amalgamated and assigned to the WSUP, JIRAMA and the local Council, dividing them into short, medium and long term adaptations.

Water Resources and Flooding

This section overviews the water resources in the city and the causes of flooding from the river and the drainage canals. The city is supplied from the Ikopa River, whose flow is controlled by the Tsiazompaniry dam (50 km upstream). The river is diverted to a lake within the city, where the water supply is abstracted by JIRAMA, the water utility. The lake is silting up and though a protection area with a radius of 2.5 km has been designated by ANDEA (2010), it is not enforced. The river has more than sufficient water for drinking (estimated 20 year low flow is 18.1 m^3/s but demand is only 3.1 m^3/s (JIRAMA, 2002)) but during low flows there can be insufficient water for irrigation by downstream users.

Despite the adequate supply there are still water shortages in the city; the shortages are due to:

- The complexity of the system- the city consists of multiple hills and relies on a series of booster stations)
- The age of the system - it was designed 30 years ago
- the 38% non-revenue water (JIRAMA, 2002) - during the rainy season there are many pipes bursts, allowing ingress of contaminates

Leakage is one of the main challenges facing JIRAMA and there are plans to replace all of the old pipes and connections. To compensate for the water shortages, JIRAMA plan to develop groundwater sources. The EIB (European Investment Bank) were funding a new borehole to supply 60,000m^3/day (one third of current production) but this has been suspended due to the political crisis.

The causes of river flooding in Antananarivo were assessed by GTZ (2008), who evaluated the geomorphology, hydrology, climatology, vegetation, and hydrogeology of the plain; the following is a brief summary. Antananarivo is in the highlands of Madagascar, which consist of a raised zone, lateric hills (rich in iron and aluminum) and low lying alluvium areas. The upper basin receives 1250 mm/year of rainfall, slightly higher in the south and south east, where the Ikopa and Sisaony have their sources. The River Ikopa's catchment is predominately bare soil (due to deforestation), heavily exposed to weathering with high rates of erosion of the clay soil and runoff due to low infiltration rates. This leads to a high sediment load, which raises the river bed and causes it to migrate, increasing the levee maintenance requirements. The flood protection is designed so that the peri-urban areas have protection from floods with a 10 year frequency, while the central area has protection against floods that occur once every 100 years (1% chance in any year). However, the reality is there is flooding if rain falls in the catchment at a rate of 30 mm for one hour, which is often exceeded if there are cyclones. The factors contributing to flooding in the CUA and Peri-urban areas are:

CUA:

- The drainage channels are ineffective (Box 1)
- High groundwater tables in the low lying peri urban areas during rainy season
- The drains have to be pumped when the river is high after rains when their full
- Many of the informal areas are lower than the drains. These areas were not designed for habitation; here the flood waters should drain into the clay soil
- The renovation of the roads in 2000, as prior to this the roads drained the areas, but now they have been raised so now they trap the flood water

Peri-Urban Area:

- The river is constrained (rocky for about 7km) at the confluence with three other rivers (**Error! eference source not found.**). This limits river flow and reduces the speed the river levels drop after rain events (SOMEAH, 2010c)
- Clay soils cause high rates of runoff from the hills
- The flood protection levee is too low or has not been maintained

The extent of the flooding was modelled by SOMEAH (2010c) using a digital elevation model with a horizontal resolution of 30 m (Figure 2). The modelling was undertaken using CARIMA a model developed by SOGREAH, which models the flow in the river and links it to the flood plain (Details in SOMEAH, 2010c). They have also modelled the 20 year and 50 year flood and will be modelling the 1 in 100 and 1 in 10. Based on this work they identified 5 areas with critical drainage covering 40 fokontanys (local administrative districts) (Figure 6).

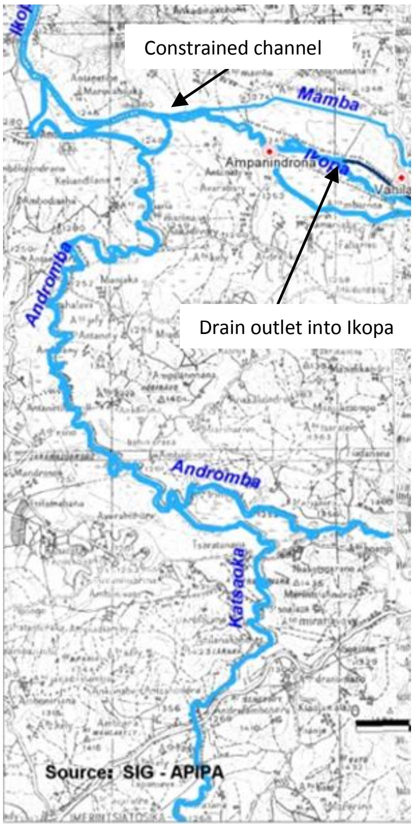
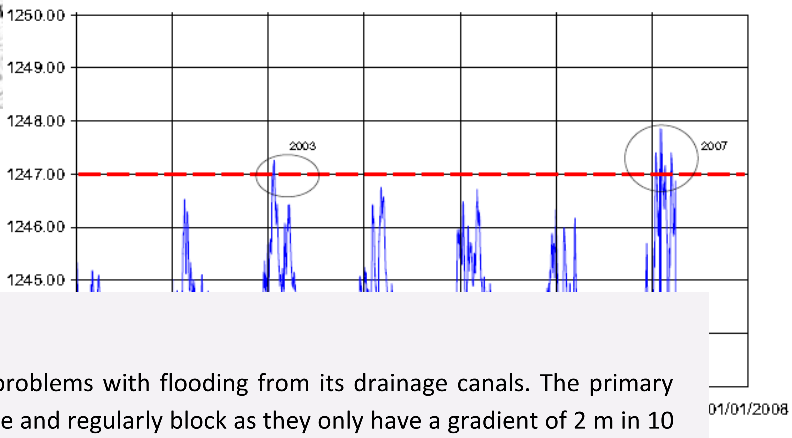


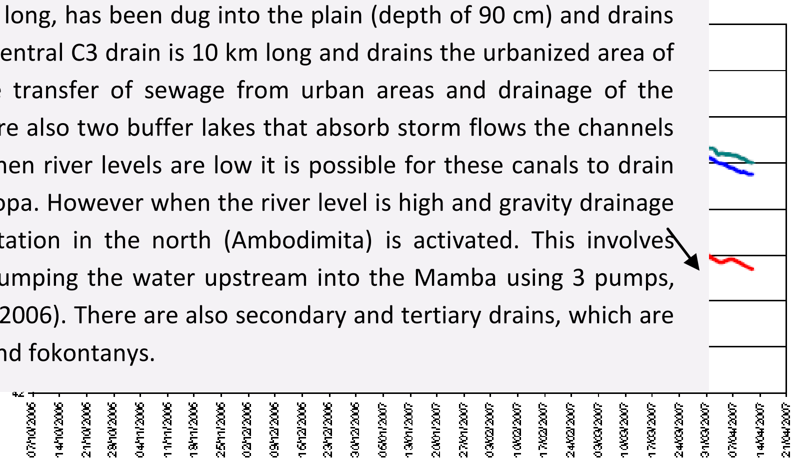
Figure 1 The rivers and drains of the Antananarivo plain (APIPA cited in Drecher *et al.,* 2008)

Pump outlet into Mamba



Box 1: Drains of Antanarivo

Antananarivo has significant problems with flooding from its drainage canals. The primary drains in the city are ineffective and regularly block as they only have a gradient of 2 m in 10 km (0.002), are filled with garbage and sewage and are not properly maintained. The main channel (Andirantay) is 25 km long, has been dug into the plain (depth of 90 cm) and drains the hilly part of the city. The central C3 drain is 10 km long and drains the urbanized area of the plain, providing both the transfer of sewage from urban areas and drainage of the upstream rice plots. There are also two buffer lakes that absorb storm flows the channels cannot absorb immediacy. When river levels are low it is possible for these canals to drain under gravity into the river Ikopa. However when the river level is high and gravity drainage is not possible, a pumping station in the north (Ambodimita) is activated. This involves closing the storm flaps and pumping the water upstream into the Mamba using 3 pumps, each pumping 3 m^3s^{-1} (APIPA, 2006). There are also secondary and tertiary drains, which are managed by the community and fokontanys.



APIPA have monitored the river and rainfall since 2000. Figure 3 displays the record for Bevomange station, which is located at the outlet of the plain where the drains discharge. If the water level is above 1247 NGN the drains must be pumped to the Mamba. During this time the storm water cannot drain from the city. **Error! Reference source not found.** isplays the river level for three gauging stations on the Ikopa between 2006 and 2007. If the water levels is

Figure 2 Green line is Mamba, Blue the main canal and red the Ikopa (same station as above). Y axis is height (mAOD – 1200m) above 1248.6 NGN in the Mamba the pumps cannot be used, to avoid rupture of the right bank of Mamba appafarm dam. The 2007 event is the largest on record and corresponds to a 1 in 5 year floods (Drescher *et al.,* 2008). The flooding was caused by the largest rainfall event on record which had a return period between 10 and 25 years (Drescher *et al.,* 2008). During this period the level of the River Mamba prevented pumping for 38 days (between 16/01/07 and 26/02/07) during

which time the drainage in the city would have been limited.

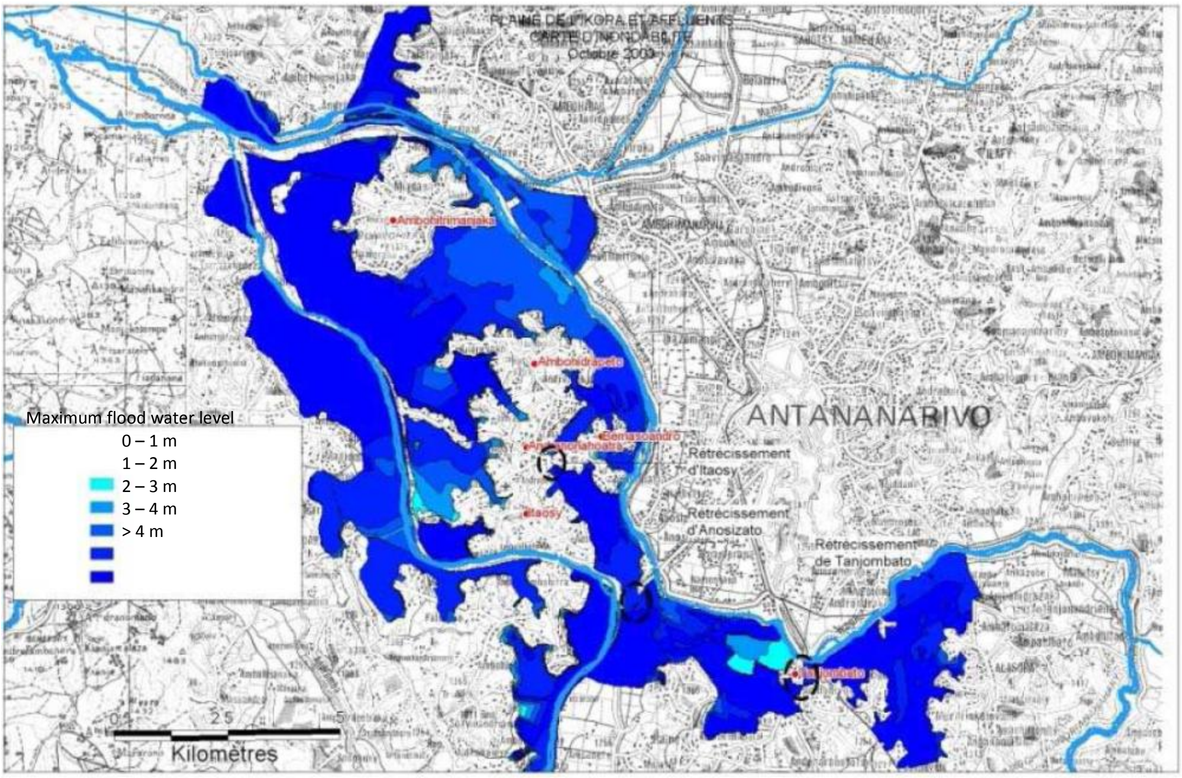


Figure 4 Maximum flood water levels (SOMEAH 2004 in Dresher *et al., 2008)*

Impacts of Climate Change on Antananarivo

Madagascar has severe problems with soil erosion and deforestation, which reduces habitats, soil fertility and productivity, increasing the vulnerability of agriculture and fishing-based livelihoods. Climate change will exacerbate soil erosion and deforestation and ultimately lead to a reduction in food security, income and water quality. Livelihood options will be reduced, leading to livelihood conversion or migrations, which will be compounded by population pressures (increased demand on resources). The changes to climate expected are as follows (refer to the Madagascar Climate Briefing (Heath, 2010) for a more in depth overview):

CLIMATE CHANGES

The latest assessment of the changes to climate are from a WWF and Conservation International Workshop in 2000, which based its predictions on multiple global climate models (13 for temperature, 6 for precipitation and 4 for cyclones); however, there has been no specific modelling of Antananarivo.

- Temperature: the mean temperature is predicted to increase in Madagascar. The greatest warming is projected in the South (2.6°C by 2055), while less warming is predicted in the coastal areas and the North (1.1°C). In Antananarivo the temperature increase is between 1.3 and 2°C by 2055. Figure 5 displays the maximum and minimum temperature changes predicted for Madagascar
- Rainfall: median rainfall will increase throughout the summer months (November to April). During the winter (May – October) the tropical regions are predicted to be wetter, and have more frequent storms, while the Southern half of the East coast is projected to be drier by 2050. Rainfall intensity is predicted to increase during the rainy season but decrease in the dry season. Antananarivo is expected to be wetter in the rainy season and during summer[1]
- Cyclones: the frequency is predicted to decrease in the early part of the main season, but their intensity and destructive power are expected to increase towards the end of the century

[1] The projections for rainfall are opposite to the observed trend of decreasing rainfall over the last 30-40 years

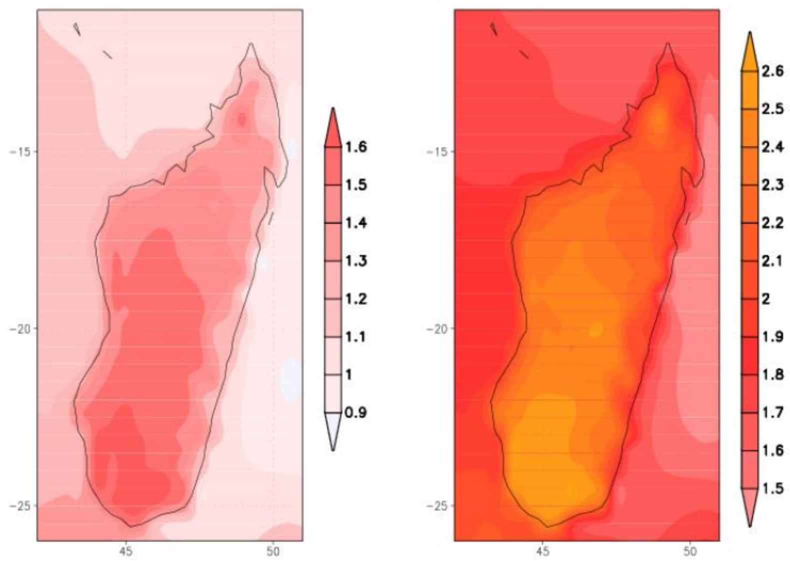


Figure 5 Minimum (left) and maximum (right) projected change in annual temperature by 2055

UNCERTAINTY

"One thing is certain; under climate change uncertainty will increase" (UNWATER, 2009). When making climate change impact assessments, a 'cascade' of uncertainty arises (e.g. uncertainty with modelling, scenarios and data) making it difficult to make reliable predictions. The impacts predicted need to be considered alongside current population pressures and existing vulnerabilities - even without anthropogenic climate change, climate variability undermines food security, negatively affects the environment and significantly affects livelihoods. Therefore the most pragmatic approach is to develop the resilience of water and sanitation systems– managing risks, building their capacity to deal with unpredictable events and prioritising no-regret measures (UNWATER, 2009).

CLIMATE SCENARIO

The changes to temperature and rainfall in Antananarivo have been identified, the magnitude of the changes is less certain but the direction is known. Therefore assessing the impacts can be completed using one scenario, evaluating the impact of increasing rainfall and increasing rainfall intensity. Presently the floodwater sources are runoff from the upper catchment and rising groundwater levels. The increase in rainfall is likely to increase the volume of runoff and raise river levels, while increases in rainfall intensity will increase the speed of the floods. This will lead to an increase in flooding from both the river and the drains. Even if the frequency of flooding does not change, the potential increase in river levels will increase the number of days when the drains can't empty and must be pumped, decreasing the speed water is removed from the city. The increase in rainfall may remediate the shortages for irrigation; however, this may be offset by increased demand associated with higher temperatures. As the extent of the variation in rainfall patterns and volume is uncertain, this report outlines the impacts associated with more significant changes to rainfall and highlights adaptations to increase resilience. Even if this "worse case scenario" is not realised imminently, the changes are likely in the coming decades.

IMPACTS OF CLIMATE CHANGE NOT DIRECTLY RELATED TO WATER AND SANITATION

The following summarises the impacts of climate change on Madagascar not directly related to water and sanitation; refer to the climate change briefing (Heath, 2010) and the second National Communication to the UNFCCC (2010) for a more comprehensive overview. WWF and UNDP are both undertaking analyses of the impacts of climate change but presently no results are available.

Food Insecurity: The increases in temperature and decreases in rainfall predicted in the south will make the climate more arid, reducing crop yields and increasing livestock diseases and death. The increase in temperatures will increase irrigation demands (in particular for sugar cane), decrease yields (by increasing moisture deficits) and may alter the growing season of cereal crops. The increase in rainfall may offset these impacts, but may result in crop failure through flooding or changes to the seasonality of the rains making it more difficult to plan. In addition, more intense cyclones will increase the damage to crops, reducing yields.

Migration: There are a ranges of vulnerabilities associated with climate change, which will threaten livelihoods and are likely to increase migrations, in particular to urban areas. These include crop failures, an increase in desertification in the south, loss of beaches and habitats and sea level rise (7 or 8 cm a year) which may engulf the mangroves making life more difficult for fisherman and shrimp farmers.

Air Pollution: Antananarivo has severe problems with air pollution and an increase in temperature will exacerbate the smog and respiratory diseases.

Impact of climate change on the informal and Peri-urban areas

The following summarises the impact of climate change on water and sanitation in the informal and peri-urban areas in Antananarivo based on the focus groups and interviews.

CUA

In the informal areas there is likely to be an increase in flooding from the drains. Currently the drains flood throughout the rainy season after 1 hour of heavy rain (APIPA found 60 mm/hour results in inundation). In the communities visited flood water comes to a depth of ½ - 1 m and takes around 2 hours to drain, although some areas have standing water throughout the rainy season. During cyclones, the impacts are more severe as there is more intense rainfall. The increase in rainfall intensity and volume will exacerbate these effects, potentially increasing the severity and frequency of floods. Sewage and garbage is dumped in the drains therefore when they flood they present major health risks (fever, diarrhoea, dysentery respiratory diseases, skin infections and malaria) and disruption to the lives of the communities. The impacts of the floods are as follows:

- Contaminated water enters up to 60% of the houses, causing health problems, unpleasant living conditions and house collapse
- Employment decreases. The main incomes are from laundry and selling goods and these are less viable during floods as it is too wet to dry clothes and people have less money. In addition people can't work as they have to stay at home to care for children and protect their homes
- It is more dangerous to travel, as manholes and culverts hidden and roads are damaged, limiting business, access to school and work
- Food costs increase, charcoal is very hard to find and markets reduce
- Rubbish is washed from other areas
- It is very dirty and odorous, children play in the mud, wooden houses absorb foul water and many of the paths turn to mud, harbouring diseases and making the area unpleasant (this may be exacerbated by temperature rises)

Water and Sanitation Technology

The flooding of the drains has severe impacts on water and sanitation technologies. The main issue is collapse of latrine super structure and latrines overflowing, filling houses with sludge and further contaminating the water. When the areas are flooded many latrines are not useable, and the only options are the sanitation blocks or sanitary pails. The latrine blocks installed by CARE, Water Aid and WSUP were designed accounting for flooding risks and are raised above the flood level making them resilient to the floods, but they are too expensive for some households and some have not been effectively maintained and no longer function. The

CARE, Water Aid and WSUP kiosks were designed to account for floods and are resilient as they are built on higher ground; however, the water supplied from JIRAMA is not safe during floods. This is due to the following:

- The catchment for the lake supplying the city is not protected;
- During floods the river has a very high sediment load (the maximum turbidity increases from 80 NTU, to 110 NTU, and remains high 10-15 days after rainstorms) and treatment does not effectively remove suspended sediments which carry bacteria and makes the water yellow
- High non-revenue water (illegal connections and leaks) make ingress of flood water likely, which contaminates supply

In addition, during floods the kiosks have long queues, some taps are submerged and the water pressure is lower so it takes longer to fill containers. The other major problems are people travel through the flood water to reach kiosks, exposing them to disease and water is contaminated when its transported and in the home.

Peri-urban areas

The impacts on the peri-urban areas need to be considered as three separate zones: the uplands, lowlands and rice paddies. Climate change will have limited impact on the uplands, the only change maybe an increase in the surface runoff and need for attention to drainage paths when locating latrines and pipes. The lowlands and paddies are affected by three sources of flooding, from the river, from the drains and from ground water. Flooding from the main river only effects a small part of the peri-urban areas highlighted on Figure 6, however as the flood bund only provides protection from the current 10 year flood (which is likely to become more regular) the area will flood more frequently. However, this area may be protected as the government plans to establish sacrificial land upstream to remediate the flooding. In addition the tributaries may become more flashy, rising faster and flooding more land. The drains in the lowlands are lower than in the city and flood when there is heavy rain, or problems with the city drains. There is also flooding due to collapse of irrigation dams. The paddies flood when the ground water rise or drains overflow and many of the areas that flood can take up to 3 months to drain.

The impacts on the lowlands are similar to those in the informal areas but there is the additional burden of the damage to crops and livestock. If roads are damaged it is hard to sell crops, food supply is reduced and there is little employment outside farming. In addition, masons can't work as it's too wet, people don't have money for drivers if they get sick and water is expensive. The impacts on water and sanitation are similar to those in the informal areas but as there is more space simple, coping strategies can be applied. One area of concern is the new latrine block built on the riverside of the flood plain in Alosora. There has been no flood since its construction and it has been designed to be resilient (based on WWF recommendation in EIA, 2008) but if floods become more frequent it may not function.

The impacts on the paddies are similar, except ground water has a more significant influence as the paddies are low and ground water is often above the surface, so drain slowly. In the paddies water can rise after 3 to 4 days of rain flooding the area and take up to 3 months to drain, in addition the area can flood if the drains overflow or the bund fails. The impacts of flooding are the same as above but there is also damage to the rice crop, which fails to grow effectively if the water is 1m deep. Also the rice crop can be destroyed if the flooding is combined with high winds (like during a cyclone) as the floodwater weakens the soil and roots and the high winds then flatten the crop.

CLIMATE CHANGE AWARENESS

As well as increasing the resilience of water supply and sanitation systems, working with other organizations to build capacity and share knowledge is key for successful adaptation to climate change. Therefore an understanding of the current climate awareness and actions of the different stakeholders is needed. Table 1 gives an assessment of this information based on stakeholder interviews.

Table 1: Climate change awareness and actions of organizations in Naivasha

Stakeholder	Awareness	Plans/Actions	No. Interviews
Community	Low	None	9
WSUP	Medium	This report	2
JIRAMA	Medium	Aware need to adapt system	1
Consultants	Medium	N/A	2
Commune/ Council	Low	None	2
Local Organisations	High	Aware of need to do incorporate	2
Government	High	- UNDP platform of exchange and information established - Second communication to UNFCCC just published - Summary of climate change prepared by Meteorological Department - Meteorological Department are mainstreaming climate change with support from presidential level - Climate change department - REDD programme	4
NGOs	2 organisation limited, 1 aware, 4 high and involved with advocacy	- Not incorporated into programmes - Have climate change project officer providing technical support - Focus on disaster preparedness - UNDP comprehensive study of impact of climate change on environment and agriculture	7

Recommendations

Adapting to climate change requires a combination of technological and structural measures, risk sharing and capacity building to increase the robustness of systems. Coping with climate change does not involve many entirely new processes or techniques. It should, however, be made clear that this is not an argument for 'business as usual'. Existing instruments, methods and measures may need to be introduced at a faster pace, and applied in different locations, at different scales, within different socio-economic contexts and in new combinations (CAPNET, 2009). Developing water safety plans should be a priority, to reduce the risks to water supply by establishing a framework for managing the risks to drinking water from catchment to consumer (Bartram 2009).

This section reviews how climate change affects the activities proposed in the Sanitation Strategic Plan phase II (SOMEAH 2010b), highlighting what needs to be prioritised and potential modifications. The purpose is to climate proof the strategy; however, it's important to clarify the activities not discussed are relevant for addressing sanitation, but they are not affected by climate change. It then presents a list of the proposed adaptations for areas affected by floods, principally the vulnerable areas identified by SOMEAH (2010a) in the Sanitation Master Plan (Figure 6), but the adaptations are also relevant to other areas affected by floods.

Impact of climate change on sanitation strategic plan

The Sanitation Strategic Plan vision is to ensure the Malagasy population as a whole has access to adequate, effective, and sustainable sanitation by 2015, while by 2030 the CUA and FIFTAMA communes will be equipped with excreta, sewerage, storm water and waste disposal accessible to the total population, including the poor. The strategy presents specific objectives for achieving the 2015 vision (contributing to achieving the overall 2030 vision) which are divided into 6 components (prerequisites, capacity building, hygiene promotion, solid waste, management of excreta and stormwater management) and 39 actions and activities. The following assesses how climate change affects the 6 components of the strategy identifying the activities which will increase the city's resilience to climate change.

Prerequisites and Crosscutting Issues

Climate change does not need to be considered in these activities.

Capacity Building

If the frequency of flooding increases, the need to address the associated risks will be greater, therefore capacity building and educating the communities will be key, in particular educating organisations on the importance of drain maintenance and solid waste disposal. Key activities for achieving this are as follows:

- campaign for sensitizing and informing the population on the rights, roles and responsibilities of the different actors
- capacity building of heads of fokontany on control (land use, sanitation installations, environmental pollutions: unlawful discharge or deposits of sludge, wastes, and sewerage water)
- Training trainers and disseminating information

Promotion of Hygiene

As with capacity building an increase in the frequency of flooding will increase the exposure of communities to flood water. Hygiene promotion is key to educate the communities of how to best cope with floods to maintain their health. Key activities for achieving this are as follows:Definition of appropriate approaches to develop demand for infrastructures and en sure their good use and maintenance.

- Implementation of information, sensitization, and training campaigns on sanitation and hygiene
- Capacity building of local actors for hygiene promotion

DOMESTIC WASTE

Poor domestic waste management exacerbates the impacts of flooding as it blocks drains and increases the health risks associated with the floodwater. Therefore dumping of rubbish in drains needs to be addressed; by ensuring communities have adequate disposal options. Key activities include the following:

- Improving the service rate of collective dumpsters
- Developing precollection in the 15 fokontanys of the CUA
- Stopping temporary dumping and replacing them with permanent dumping grounds
- Removing unlawful dumping within neighbourhoods

Management of excreta

The main risk from an increase in flooding is the increased exposure to excreta. To reduce the impacts it is crucial that better sanitation technologies are made available, emptying options are improved and funds are made available to try and reduce the amount of sewage onsite. The key activities are as follows:

- Supporting private operators in terms of tank drainage and drainage matters collection
- Studying and starting-up the process of drainage sludge disposal and treatment
- Piloting various means of support to households in funding or acquiring standalone sanitary installations (microcredit, revolving funds etc)

SEWERAGE AND STORM WATER

This is the component of the plan most affected by climate change as the severity of flooding will increase. It is essential the stormwater actions are addressed as the flooding is the main environmental problem in the city and by reducing flooding other problems will be less significant (for example poor excreta and domestic waste management). All of the activities need to undertaken

FLOOD ADAPTATIONS

This section reviews the key adaptations in areas affected by floods for WSUP (and local service providers) JIRAMA and the Communes; Figure 6 displays the areas most affected by floods. The adaptations were determined based on a field visit, a vulnerability assessment and a literature review. Some recommendations will be part of existing maintenance programmes; however, the priority of these actions may need increasing. WSUP Kiosks, laundry blocks and latrines are presently built to high standards and are resilient to floods, the following provides an overview of potential adaptations to design.

The adaptations have been divided into three timescales (based on Venton, 2010). References in brackets provide further information about each recommendation:

- **Short term:** contingency adaptation for extreme events – e.g. Drought management/ flood forecasting, focussed on disaster management experience;
- **Medium term:** tactical adaptations regarding climate variability, linked with disaster risk reduction;
- **Long term:** adaptations necessary to respond to a predicted different climate.

The adaptations categories (based on Charles *et al*., 2010):

- **Capital expenditure**, which includes new investments and projects;
- **Operational expenditure**, which includes adaptations that can be made to existing systems;
- **Monitoring**, which includes programmes that can be implemented immediately to support planning decisions, or implemented in the long term to support continuing decisions;
- **Socioeconomic,** tools such as community education, training and public awareness.

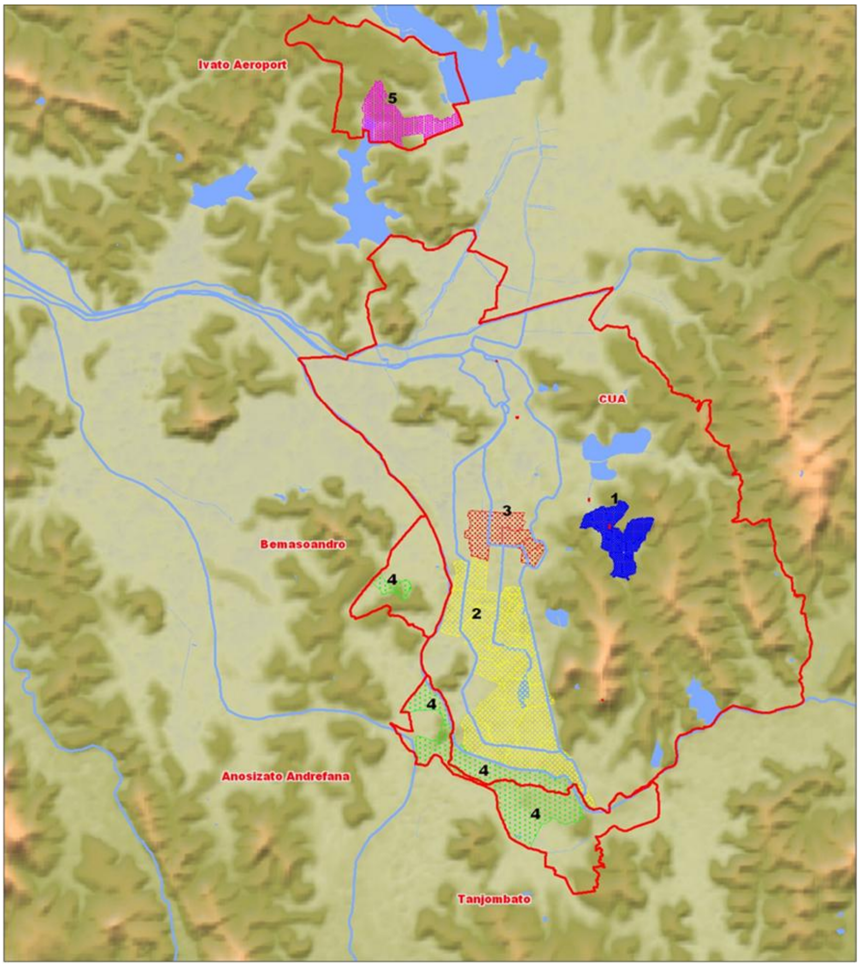


Figure 6 Areas most vulnerable to flooding (refer to SMP for list of full of Fokontanys (SOMEAH, 2010a))

WSUP (CARE or Water Aid)

The main impacts of climate change in the informal and peri-urban areas in Antananarivo are flooding and the associated health impacts. The local service provider infrastructure is built to a high standard and is resilient to floods, the main issue is the contamination of water supply and overflowing of septic tanks and latrines. The main adaptations to each of these issues are outlined below:

- **Monitor water from kiosks during floods:** to ensure it is safe to drink and adheres to WHO or national drinking water standards. If the water quality deteriorates the water should be chlorinated at distribution and boil water notices should be issued. Once the flooding has ended continue to monitor the water and flush the pipes with a high dose of chlorine
- **Ensure septic tanks are flood proof:** when constructing septic tanks ensure flooding is taken into account. Build them higher than the floodwaters, make sure tanks are attached firmly to ground and it is not possible for water to get underneath, install a flap valve which can be closed during floods, plant trees were possible to stabilise the soil. Build communal infrastructure to high standards but also educate communities on simple methods for making latrines more resilient (raising the platform, having a seal which can block the latrine in floods, building small latrines which are emptied regularly and properly compacting soil around hole
- **Education on risks of flooding:** the health issues associated with floods are exacerbated by the poor management of solid waste and excreta; community education on this will reduce the impacts. Trying to stop communities using the drains as a dumping ground is central to this and education on latrines (as above) will lower the impact. There should also be information on flood adaptations – how to avoid contamination of water in the home and during collection, the need to boil or chlorinate and how stop latrines flooding.

Immediate/ Short term (0 – 6 months)

Capital Expenditure

- Compaction of soil and planting above pipes, sewers, under paved roads etc
- Install non-return valves on septic tanks that can be shut in event of a flood; do not use the septic tank again until waters have receded (refer to WHO, 1996 3.9)
- Repair erosion damage around septic tanks and reseed areas as necessary to provide turf grass cover

Operation Expenditure

- Plan after-flooding response to assess and address infrastructure damage
- During floods increase chlorination
- Flush out flooded pipe network after waters have receded to remove sediments (refer to WHO, 1996 2.7)
- Reduce the use of buckets for collecting water by finding supplier of 15L Jerry cans (for children 20 l too heavy and 5l too small)

Monitoring

- Sanitary inspection of standpipes during floods (refer to WHO, 1996 2.1)
- Intensify monitoring of water quality after flooding event and before going back on line, chlorinate if necessary
- Flush out pipes and clean standpipes after floods
- Maintain conditions which mitigate erosion, e.g. compaction of soils and plants in buffer strips
- Regular emptying of septic tank services to minimize faecal sludge build-up
- Septic tanks and pump chambers can fill with silt and debris, and must be pumped out and cleaned after a flood (refer to WHO, 1996 3.9)
- Check the vegetation over the septic tank and soil absorption field after flooding

Social Economic

- Disseminate health advisory notices to the public with advice about dealing with the risks of flooding (Refer to Reed, 2006)
- Issue boil water notices where appropriate. Develop communication procedures for when water is safe

- Education about hygiene and cleaning up after flooding (refer to Reed, 2006)
- Hygiene promotion and education on regular maintenance requirements (refer to Appleton and Sijbensema, 2005 & Curtis 2005)
- Raise awareness about the dangers of unstable pit latrines, and under what conditions these occur

MEDIUM TERM (6 MONTHS – 1 YEAR)

CAPITAL EXPENDITURE

- Place kiosks on elevated platform or higher ground to allow access during floods
- Construct standpipes from durable materials to reduce damage during floods
- Land management – minimize erosion with planting schemes, buffer strips and storm water management.
- Use durable materials in construction (refer to ITDF, 2007)
- Where possible, site septic tank away from water supply and design to prevent ingress of silt
- Use durable materials in construction of tanks (refer to EASRWAG, 2008)
- Planting of grasses and shrubs on the absorption area, and around septic tanks, to reduce erosion
- Build bunds (banks, dykes or levees) to divert flow away from system

OPERATION EXPENDITURE

- Adopt a standpipe maintenance programme to reduce potential for ingress (e.g. chambers are sealed)
- Develop response plan after flooding to assess damage to standpipes and to inform future improvement
- Ensure adequate access to septic tanks so that they can be cleaned
- If groundwater rises above the bottom of the septic tanks, the tank will need to be secured to prevent floating during pump out (refer to WHO, 2003)

MONITORING

- Monitor water quality and groundwater levels during flood
- Education to increase awareness of the risks of sewage upwelling if soak ways are waterlogged
- Ensure that septic tanks are emptied regularly
- Increase water quality monitoring after floods have receded
- Monitor water quality and adapt treatment processes to ensure that water quality is not compromised, such as by increasing sedimentation time and improving filtration systems

SOCIAL ECONOMIC

- Raise awareness among the public of contamination issues during floods and extreme rainfall events, this may be done by posting leaflets, door-to-door visits, and radio and television announcements to inform people to boil water
- Ensure septic tanks are full of water during a flood to prevent damage to the infrastructure; however, lids need to be properly fitted and secured to prevent sewage overflow (refer to WHO, 1996 2.1)
- Raise awareness among the community about potential health issues associated with sewage and the damage that erosion can cause to infrastructure, and the potential effect on the water supply system(refer to Appleton and Sijbensema, 2005 & Curtis 2005)
- Raise awareness about potential contamination of drinking-water supply, health issues with sewage and the need for regular emptying of pit latrines

LONG TERM (1 YEAR+)

- Review the risks and benefits of removing the standpipe if it is located in an area at high risk of flooding
- Where possible, site system away from water supply
- Introduce trees and other plants around septic tanks to improve drainage and increase water loss by transpiration
- Promote infiltration of floodwaters (BGR, 2009)

Other Stakeholders

Adaptation to climate change requires an integrated approach from all stakeholders. Alongside WSUP, JIRAMA and the Communes are central for providing water and sanitation in the peri-urban areas. JIRAMA's main priorities should be increasing the resilience of their distribution systems and improving their water treatment. They need to undertake a programme of leak detection, pipe maintenance and reduce illegal connections to minimise contamination of the water supply and improve the hydrostatic pressure; Parker (2010) provides detailed recommendations for reducing NRW. The treatment needs additional treatment stages to deal with the high sediment load during floods, either an additional settling tank which can be used during floods or higher dosage of flocculent. The Communes need to focus on clearing the drains they are responsible for, assisting APIPA in monitoring drains, ensuring the communities don't dump material in the drains and improving waste collection and sanitation options. It is also important they minimise the occupation of areas not designed for habitation on the city plan. The following identifies focused recommendations for JIRAMA and the communes on how they can reduce the impacts of floods in the informal and peri-urban areas. The adaptations for both are split into short, medium and long term adaptations.

JIRAMA

Immediate/ Short term (0 – 6 months)

Capital Expenditure

- Adapt water treatment for flood conditions depending on water source and contamination, introduce additional, more robust barriers and treatment stages (refer to WHO, 2003)
- Protect electrical installations from flooding
- Compaction of soil and planting above pipes, sewers, under paved roads etc

Operation Expenditure

- Plan after-flooding response to assess and address infrastructure damage
- During flood increase chlorination (refer to WHO, 1996 2.27)
- Select appropriate water treatment stages to suit water quality (refer to WHO 2003)
- Dig out buried intakes after flood waters recede
- Flush out flooded pipe network after waters have receded to remove sediments (refer to WHO, 1996 2.27)
- Clean sewers regularly
- Clean drains regularly especially just before wet season

Monitoring

- Intensify monitoring of water quality after flooding event and before going back on line
- Regular inspection of network, including periodic integrity testing and tracer tests

Social Economic

- Disseminate health advisory notices to the public with advice about dealing with the risks of flooding
- Education about hygiene and cleaning up after flooding

Medium Term (6 Months – 1 year)

Capital Expenditure

- Design flood storage areas on rivers to mitigate the impacts of floods, this may include implementing land management activities to increase infiltration of water and reduce severity of floods, e.g. terracing, adequate urban drainage, reforestation, retention basins (refer to BGR, 2009)
- Where possible, aim to site pipes in areas of low risk of flooding; in areas where flooding is likely aim to keep water and sewage pipes separate in case of cross contamination through fractures (refer to Reed, 2006)
- Relocate water pipes away from open sewers and drainage channels
- Land management – minimize erosion with planting schemes, compaction of soils above pipes, buffer strips and storm water management (BGR, 2009)

- Use sustainable urban drainage systems and separate sewers
- Build shallow sewers with flap valves and ensure sewers are gravity flow wherever possible as (lower pumping requirements

Operation Expenditure

- Implement pipe maintenance programme to reduce leakage and the potential for ingress, include cut-off walls in high-risk areas
- Implement rehabilitation programmes to improve hydrostatic pressure (Parker, 2010)
- Implement leak detection and repair procedures (refer to DOH, 2008; EPD, 2007 & WHO, 2001)
- Zoning of water supplies for monitoring and management of distribution system

Monitoring

- Design and implement a monitoring programme for silt build-up in reservoirs and flooding of the pipe network
- Test water quality during major works
- Monitor water quality and adapt treatment processes to ensure that water quality is not compromised, such as by increasing sedimentation time and improving filtration systems.
- Monitor silt levels, blockages, cross connections and so on, in drains and sewers

Social Economic

- Manage communication of early warning of event to the public
- Develop communication procedures for notifying the public when the water is safe
- Raise awareness among the public of contamination issues during floods and extreme rainfall events, this may be done by posting leaflets, door-to-door visits, and radio and television announcements to inform people to boil water
- Raise awareness among water engineers of risks from water quality changes during extreme rainfall events and flooding, how to manage the risks and how treatment can be adapted
- Stop illegal connections to foul sewers

Long Term (1 year+)

- Adopt higher design standards for infrastructure to account for more frequent floods and extreme rainfall, particularly in terms of return periods for significant events (the more expensive option), or have systems that can be quickly and cheaply replaced (refer to WHO, 2003)
- Site water treatment works and other major infrastructure away from flood zones, or build appropriate flood defences
- Smaller more localized treatment systems may help to spread risk of widespread water shortages (refer to Gate, 2001)
- Develop back-up sources, such as linkages to other sources or emergency tank supplies, to mitigate risk of water shortages
- Decentralize and diversify water systems to mitigate the number of people affected in shortages
- Maintain vegetation in buffer strips next to rivers (refer to Gate, 2001
- Install low-cost sewers (easily maintained or replaced when damaged) with spare parts available (refer to EAWAG, 2008)

Commune

Capital Expenditure

- Maintain drains (dredge, clear rubbish)
- Education of pit latrines: installing proper cover to prevent material flowing out in a flood, Investigate overflow mechanisms to filter water to reduce pressure build-up; site latrine away from water supply, areas prone to flooding and drainage channel; Install robust upper foundations, collar and footing to protect from erosion and flooding damage; Small pits to minimize risk of collapse (refer to EAWEG, 2008)
- Advocate making latrine more durable, especially the bottom 30cm, or choosing a cheaper temporary option that can be reinstalled rapidly
- Build bunds (banks, dykes or levees) to divert flow away from latrines

Operation Expenditure

- Enforce regular emptying of latrines (encourage shallow latrines for regular emptying and post-flood rehabilitation to remove silt (refer to Scott and Reed, 2006)
- Regular maintenance essential to limit vulnerability to collapse
- Capacity build fuktontany strengthening the link between levels of management and establish specific tasks and procedures for environmental and sanitation issues
- Need legal standard for Communes on resolving environmental issues

Monitoring

- Monitoring and regulation systems should focus on emptying and faecal sludge management as well as construction of latrines

Social Economic

- Enforce no dumping of garbage or material in drains
- Education/requirements for use of durable materials in construction to protect pit cover, ensure proper compaction of soil around the latrine and presence of adequate base and earth filling to protect pits, pit covers and slabs (refer to ITDG, 2007)

Further Information

Climate modelling and climate change adaptation are both areas of continuing research. It is important to be aware of the ongoing work being undertaken which will inform future investments and adaptations. Table 1 illustrates that although climate change is recognised at the policy level, there is little application by organisations and utilities. As policy filters down it will have a greater impact on resource management and it is important to stay aware of changes to policy.

Current Research and key resources

- UNDP are undertaking a very comprehensive field surveys with the Meteorological Organisation reviewing of the impacts of climate change on agriculture and water resources in preparation of a Water Master Plan for Madagascar. They have just completed an assessment of the South and expect an assessment of the central region to be complete in 6 months
- UNFCCC have just submitted their second national communication to the UNFCCC, which overviews the national circumstances, indexes green house emissions, overviews the vulnerabilities and adaptations; and options for mitigating emissions and vulnerabilities
- WWF are completing various assessments of the impact of climate change on ecosystem services across Madagascar

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Appendix

STAKEHOLDER INTERVIEWS

Table 2 Overview of interviews undertaken in Naivasha (interviews can be with multiple staff)

Organisation	Number of Interviews
Community	**9**
• Peri-urban	5
• Informal	4
WSUP	**2**
Utility	**1**
• JIRAMA	1
Consultants	**2**
Commune/ Council	**2**
• Water Users Association	1
• Health Municipality	1
Local Organisations	**2**
• APIPA	1
• SAMVA	1
Government	**4**
• ANDEA	1
• Department of Climate Change	1
• Meteorological Department	1
• Department of Town Planning	1
NGO	**7**
• CARE	1
• Catholic Relief Services	1
• Water Aid	2
• UNDP	1
• UN volunteers	1
• WWF	1

Literature Review

In addition to identifying the impacts of climate change on the existing vulnerabilities and problems in the peri-urban areas in Lake Naivasha the literature was reviewed to assess the impact of climate change on water and sanitation technologies. The following tables overview how the technologies (current and planned) are vulnerable to the key issues and the resulting impacts. The tables are based on observations during the field visit and literature, which assesses the impact of climate change on technology – principally a review completed by the WHO and DFID in 2010 (Charles *et al*., 2010).

Impact of Climate Change on Technology in Peri-Urban and Informal Areas

Utility-managed drinking water systems (direct connections)

Issue	Vulnerability	Impacts	Adaptations			
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Flooding increases	Increased flooding reduces the availability of safe water resources	Flooding events increase the level of chemical and microbiological contamination in water sources, increasing the risk to public health. Increased suspended sediment load carried by flood waters exceeds the treatment capacity of water treatment facilities	Design flood storage areas on rivers to mitigate the impacts of floods. This may include implementing land management activities to increase infiltration of water and reduce severity of floods, e.g. terracing, adequate urban drainage, reforestation, retention basins. Adopt higher design standards for infrastructure to take higher and more frequent floods into consideration, particularly in terms of return periods for significant events.	Seasonal forecasting. Flood forecasting.	Hydrological monitoring stations. Rain gauging. Earth observation data. Enhanced inspection of infrastructure.	Raise awareness among the public of the risk of contamination during floods and the reduction in drinking-water availability. Dissemination of public health advisory notices with advice about dealing with the issues.
	Flooding of treatment system	Floods may lead to structural damage of the treatment works, or to the failure of pumping stations. Water supplies fail.	Site water treatment works and other major infrastructure away from flood zones, or build appropriate flood defences. Protect electrical installations. Smaller more localized treatment systems may help to spread risk of widespread water shortages.	Plan after-flooding response to assess and address infrastructure damage. Take treatment unit offline and apply corrective action. Increase chlorination. Plan for emergency supplies	Intensify monitoring of water quality after event and before going back on line.	Manage communication of early warning of event to the public. Develop communication procedures for notifying the public when the water is safe. Raise awareness among water engineers of risks
	Surface water quality deterioration during flood	Floodwater carries increased sediment load that may exceed the treatment capacity of the water treatment works. Run-off water from upstream may carry higher concentrations of chemical and microbial contaminants.	Adapt water treatment for flood conditions depending on water source and contamination. Introduce additional, more robust barriers and treatment stages. Relocate abstraction points	Select appropriate water treatment stages to suit water quality. Dig out buried intakes after flood waters recede	Design and implement a monitoring programme of flooding in water sources. Monitor silt build-up in Reservoirs Monitor raw water quality.	Raise awareness among water engineers of risks from water quality changes during flooding and how water treatment can be adapted to manage the risks.
	Entry of contaminated flood water into water supply pipes.	Localized or widespread contamination of the water distribution system.	Where possible, aim to site pipes in area of low risk of flooding. In areas where flooding is likely, aim to keep water and sewage pipes separate in case of cross contamination through fractures. Relocate water pipes away from open sewers and drainage channels.	Implement pipe maintenance programme to reduce leakage and the potential for ingress. Include cut-off walls in high-risk areas. Implement rehabilitation programmes to improve hydrostatic pressure. Flush out flooded pipe network after waters have receded to remove sediments.	Design and implement a monitoring programme for flooding of the pipe network. Review risks and need for refurbishment or replacement.	Raise awareness amongst the public of contamination issues during floods and reduction in drinking water availability. This may be done by posting leaflets, door-to-door visits; radio and TV announcements to inform people to boil water.

	Entry of contaminated water at service reservoir	Localized or widespread contamination of the water distribution system.	Re-line reservoirs. Re-point concrete reservoirs. Replace or repair damaged access points to the service reservoi	Clear drainage channels. Take tanks offline for repairs. Flush tank and distribution before re-commissioning. Repair leaks, drains and valve box. Repair valve if showing signs of wear	Validation by water quality monitoring at times of major works. Regular inspection. Periodic integrity testing. Tracer tests.	Raise awareness among the public of contamination issues during floods and reduction in drinkingwater availability. This may be done by posting leaflets, door-to-door visits, and radio and television announcements to inform people to boil water.
	Contamination of drinking-water in supply affecting large populations.	Major public health ris	Decentralize and diversify water systems to mitigate the number of people affected. Develop back-up sources, such as linkages to other sources or emergency tank supplies, to mitigate risk.	Zoning of water supplies for monitoring and management of distribution system. Implement leak detection and repair procedures	Intensification of water quality monitoring above minimum level specified in WHO guidelines.	Raise awareness among the public of contamination issues during floods and reduction in drinkingwater availability.
Increase in extreme rainfall	Damage to infrastructure.	Potential failure of the drinking-water supply system and loss of service. Public health risk from contaminants entering the water distribution system through damaged pipes	Design or adapt reservoir overflows and spillways to cope with larger flows. Adopt higher design standards for infrastructure to take more frequent extreme weather events into consideration.	Response plan after flooding to assess and address infrastructure damage..	Hydrological monitoring stations. Rain gauging. Earth observation data. Enhanced inspection of infrastructure	Disseminate health advisory notices to the public with advice about dealing with the risks.
	Increased erosion leading to more polluted run-off, with silt and nutrients.	Increase in suspended sediment loads may exceed the treatment capacity of the water treatment facilities. Public health risk from contaminants entering the water distribution system.	Land management – minimize erosion with planting schemes, buffer strips and storm water management.	Maintain vegetation in buffer strips next to rivers.	Monitor water quality and adapt treatment processes to ensure that water quality is not compromised, such as by increasing sedimentation time and improving filtration systems.	Raise awareness among the public of the risk of contamination during and after extreme rainfall events. Raise awareness among water engineers of risks from water quality changes during extreme rainfall events, and how to manage the risk.
Run-off increases	Erosion exposing and damaging pipe work.	Potential failure of the drinking-water supply system and loss of service. Public health risk from contaminants entering the water distribution system through damaged pipes.	Land management – compaction of soils and planting above pipes, under paved roads etc.	Implement leakage reduction plan, as leakage can contribute to landslides.	Hydrological monitoring stations. Rain gauging. Enhanced inspection of infrastructure.	Raise awareness among water engineers of risks from water quality changes from run-off and how to manage the risk..
	Increased erosion leading to more polluted run-off, with silt and nutrients.	Increased suspended sediment loads may exceed the treatment capacity of the water treatment facilities. Public health risk from contaminants entering the water distribution system.	Land management – minimize erosion with planting schemes, buffer strips and storm water management.	Maintain vegetation in buffer strips next to rivers.	Monitor water quality and adapt treatment processes to ensure that water quality is not compromised, such as by increasing sedimentation time and improving filtration systems.	Raise awareness among water engineers of risks from water quality changes from run-off and how to manage the risk. Disseminate health advisory notices to the public with advice about dealing with the risks.

KIOSK/ STANDPIPE

Issue	Vulnerability	Impacts	Adaptations			
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Flooding increases	Standpipes inundated with contaminated floodwater.	Standpipes become inaccessible or are damaged by the floodwater. Quality of the water at the standpipe deteriorates and there is potential for more widespread contamination of the distribution system.	Place on elevated platform to allow access during floods. Construct standpipes from durable materials to reduce damage during floods. Review the risks and benefits of removing the standpipe if it is located in an area at high risk of flooding.	Adopt a standpipe maintenance programme to reduce potential for ingress (e.g. chambers are sealed). Develop response plan after flooding to assess damage to standpipes and to inform future improvement. Flush out pipes and clean standpipes after floods.	Sanitary inspection of standpipe. Increase water quality monitoring after floods have receded.	Issue boil water notices where appropriate. Develop communication procedures for when water is safe.
Increase in extreme rainfall	See utility managed piped supply					
Run-off increases	Erosion damaging standpipe.	Destruction of the standpipe and loss of service. Public health risk from contaminants entering the standpipe.	Land management – minimize erosion with planting schemes, buffer strips and storm water management. Use durable materials in construction	Maintain conditions which mitigate erosion, e.g. compaction of soils and plants in buffer strips.	Sanitary survey.	Raise awareness among the community about the damage that erosion can cause to infrastructure, and the potential effect on the water supply system.

IMPROVED PIT LATRINES

Issue	Vulnerability	Impacts	Adaptations			
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Flooding increases; Increase in extreme rainfall events; run-off increases	Pit overflowing or inundated; very mobile contamination	Faeces leaving pit and causing pollution downstream. Silt and solids entering pit and filling it	Design pit to allow regular emptying and post-flood rehabilitation to remove silt. Proper pit covers to prevent material flowing out in a flood. Investigate overflow mechanisms to filter water to reduce pressure build-up. Where possible, site latrine away from water supply, and away from areas prone to flooding. Build pit latrine superstructure at the same level as the houses, as these usually are above normal flood level. In urban areas, consider small pits which need regular (monthly or less) emptying to minimize the amount of faecal matter exposed to flooding. Consider if dry or composting latrines or sewerage is appropriate	Regular pumping or emptying of pit latrine (particularly in urban setting)	Monitoring and regulation systems should focus on emptying and faecal sludge management as well as construction of latrines – to ensure that systems are in place	Raise awareness about potential contamination of drinking-water supply and need for regular emptying
	Increased intentional emptying of pits during floods	Widespread contamination with faeces		Regular pumping or emptying of pit latrine (particularly in urban setting)	Monitoring and enforcement systems should focus on emptying and faecal sludge management, as well as construction of latrines – to ensure that systems are in place	Raise awareness about potential health issues associated with sewage. Raise awareness about potential contamination of drinking-water supply
	Inundation or erosion	Collapse of latrine	Site latrine away from drainage channel. Use durable materials in construction to protect pit covers. Proper compaction of soil around the latrine and presence of adequate base and earth	Regular maintenance essential to limit vulnerability to		Hygiene promotion. Education on regular maintenance requirements

			filling to protect pits, pit covers and slabs. Install robust upper foundations, collar and footing to protect from erosion and flooding damage. Small pits in urban areas to minimize risk of collapse. Build bunds (banks, dykes or levees) to divert flow away from latrine. Planting of shrubs around the pit to reduce erosion damage. Adopt more conservative design standards for infrastructure to take higher and more frequent events into consideration (more expensive), or have systems that can be quickly and cheaply replaced	collapse		
	Damage to the superstructure		Make more durable, especially the bottom 30cm, or choose a cheaper temporary option that can be reinstalled rapidly			
	Latrine not accessible		Find a new site, not subject to such frequent flooding, or construct temporary latrines in refuges			
	Erosion	Collapse of latrine	Site latrine away from drainage channel. Use durable materials in construction to protect pit covers. Proper compaction of soil around the latrine and presence of adequate base and earth filling to protect pits, pit covers and slabs. Install robust upper foundations, collar and footing to protect from erosion and flooding	Regular maintenance essential to limit vulnerability to collapse		Hygiene promotion. Education on regular maintenance requirements
Groundwater tables rising	Inundation of the pit from below	Contamination of groundwater and soil, potentially reaching drinking-water resource	Provide protected water supply. Consider options: shallower pits and more frequent emptying; dry composting latrines; sewerage.	Regular pumping or emptying of pit latrine (particularly in urban setting) – link to smaller pit sizing	Monitor drinking-water quality	Education to increase marketing and user education of alternatives
	Inundation of pit	Pit collapse.	Build round pits instead of square to increase stability. Use durable materials in construction to protect pit covers. Proper compaction of soil around the latrine and presence of adequate base and earth filling to protect pits, pit covers and slabs. Install robust upper foundations, collar and footing to prevent collapse. Small pits in urban areas to minimize risk of collapse. Introduce trees and other plants to improve drainage and increase water loss by transpiration			Raise awareness about the dangers of unstable pit latrines, and under what conditions these might occur

SEPTIC TANKS

Issue	Vulnerability	Impacts	Adaptations			
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Flooding increases; Increase in extreme rainfall events; run-off	Back flow of sewage into the house		Install non-return valve that can be shut in event of a flood; do not use the septic tank again until waters have receded	Regular emptying services to minimize faecal sludge build-up		Raise awareness about potential health issues associated with sewage
	Inundation of the system, resulting in contamination of surrounding area		Where possible, site tank away from water supply			Raise awareness about potential health issues associated with sewage

increases	with sewage					
	Flooding of septic tank resulting in accumulation of silt		Design to prevent ingress of silt	Septic tanks and pump chambers can fill with silt and debris, and must be pumped out and cleaned after a flood. Ensure adequate access to tanks so that they can be cleaned		
	Flotation	Structural damage to tank, for example from movement	Use durable materials in construction of tanks			It is important that tanks are full of water during a flood to prevent damage to the infrastructure. However, lids need to be properly fitted and secured to prevent sewage overflow. Education and increased awareness of issues surrounding damage and when to replace
	Flooding of the absorption field with sewage sludge		Install non-return valve that can prevent flow to the field in event of a flood			
	Inundation of the soakaway		Delay using septic tank until flood waters and groundwaters have receded			Raise awareness of signs of failure of an absorption field, and how to fix it or construct a new one
	Erosion of soil around the tank and absorption field	Damage to infrastructure. Reduced efficacy of the absorption field	Planting of grasses and shrubs on the absorption area, and around the tank, to reduce erosion. Repair erosion damage and sod or reseed areas as necessary to provide turf grass cover. Build bunds (banks, dykes or levees) to divert flow away from system	Check the vegetation over the septic tank and soil absorption field after flooding		
Groundwater tables rising	Flotation of septic tank	Damage to infrastructure		If groundwater rises above the bottom of the tank, the tank will need to be secured to prevent floating during pump out		Education and increased awareness of issues surrounding damage and when to replace
	Inundation of soakaway	Increased potential for contamination of groundwater. Treatment of sewage by soil in soakaways may be reduced Septic tank fills and backs up	Use shallower infiltration trenches or introduce artificial wetlands or reedbed systems to improve effluent treatment. Where possible, site system away from water supply. Design septic tank systems in conjunction with drainage to lower the groundwater table. Introduce trees and other plants to improve drainage and increase water loss by transpiration		Monitor water quality and groundwater levels	Education to increase awareness of the risks of sewage upwelling if soakaways are waterlogged. Ensure that septic tanks are emptied regularly

Sewers

Issue	Vulnerability	Impacts	Adaptations			
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Flooding increases; Increase in extreme rainfall events; run-off increases	Erosion	Same as improved Pit Latrines				
	Infiltration of flood water into sewer, leading to plug flow of pollutants and resuspension	Overloading of treatment works. Pollution of water resources downstream. Ingress of silt	Use sustainable urban drainage systems and separate sewers. Encourage decentralized systems	Clean sewers regularly. Clean drains regularly especially just before wet season	Monitor silt levels, blockages, crossconnections and so on, in drains and sewers	Stop illegal connections to foul sewers
	Rising receiving water levels.	Overloading of sewers, leading to backing-up.	Shallow sewers. Flap valves.			
	High flows cause sewers to flood into environment and houses	Decrease diameter of pipes to attenuate and store water. Separate sewage and stormwater systems. Consider use of small bore or other low-cost sewerage options at local level to reduce costs of separate systems. Design decentralized systems to minimize impact of local flooding				Education about hygiene and cleaning up after flooding
	Treatment and pumping systems cannot work if electricity is affected		Ensure that sewers are gravity flow wherever possible. Low-cost and shallow sewers have much lower pumping requirements	Local decentralized treatment will reduce pumping costs and enable local responsive management when system is vulnerable to damage		
	Erosion exposing and damaging pipe work, especially simplified sewerage		Site pipe away from drainage channel. Compaction of soil and planting above sewers, under paved roads etc. Adopt more conservative design standards for infrastructure to take more severe and more frequent extreme weather events into consideration (the more expensive option), or have systems that can be quickly and cheaply replaced	Low-cost sewers can be more easily maintained or replaced when damaged, but are more vulnerable to erosion. Have spare parts available		
Groundwater tables rising	Sewer surrounded by water	Overloading. Damage to sewer (scouring or washout of bedding, and flotation leading to cracking of the sewer pipes)	Do not locate sewers in soils which are regularly waterlogged. Low-cost and shallow sewers may be less susceptible and above groundwater levels			