CRIDF

Final CCRA Pilot - Makonde

6 November 2015

Disclaimer

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List of Acronyms

Acronym	Long-Form
CCRA	Climate change risk assessment
COWSO	Community Water and Sanitation Organisation
CRIDF	Climate Resilient Infrastructure Development Facility
DFID	Department for International Development
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
CVT	Climate Vulnerability Tool
ENSO	El Niño-Southern Oscillation
GEF	Global Environment Facility
GHG	Greenhouse Gas
LCLIP	Local Climate Impacts Profile
MWSSA	Makonde Water Supply and Sanitation Authority
NDC	Newala District Council
O&M	Operation and Maintenance
SADC	Southern African Development Community
UNDP	United Nations Development Programme
VIP	Ventilated-Improved Pit
WASH	Water, Sanitation and Hygiene

Executive Summary

The Climate Resilient Infrastructure Development Facility (CRIDF) is DFID's innovative water infrastructure programme for southern Africa. CRIDF prepares water infrastructure projects and facilitates access to finance for the implementation of these projects. Activities are selected according to a set of CRIDF principles to ensure that investments align with strategic objectives that have been developed specifically for each SADC river basin.

According to the CRIDF Climate Resilience Strategy, climate resilience should be practically integrated into all CRIDF Projects, at programme, project and activity levels. A protocol was developed that provides guidance on what activities should be undertaken to manage climate risk as part of a climate risk review process for CRIDF projects. The climate risk assessment process was rolled out and tested on three pilot studies, one of which is the Makonde project.

The key questions that this report aims to answer are:

- How and where will climate change impact on the project infrastructure?
- How can we optimize existing technologies and systems to maximize their resilience to climate change?
- What needs to be done differently, so that the project and the services it provides to beneficiaries (water supply and sanitation and hygiene) and the beneficiaries/ area vulnerabilities can cope with the climate changes we can anticipate?
- What do we need to understand better to respond effectively?

The key findings and recommendations for the Makonde project are as follows:

Livelihoods

The project needs to be carefully considered against the communities' water demand elasticity and willingness to pay particularly in the context of future climate risks to livelihoods and associated impacts to disposable income. This is an issue that has also been flagged in the project's cost benefit analysis study. It is suggested that action is taken to ensure:

- Policies that make financial credit, loans, and crop and livestock insurance are available to farmers, increasing their ability to cope with natural disasters and pay for water.
- Strong legal enforcement of water pricing policies can support monitoring water use and associated fees, thereby increasing revenues for maintenance and upgrades.

Groundwater resources

The project yield to recharge ratio increases to 33% (when worse case climate scenarios are accounted for) from approximately 10% (the value concluded in the GIZ WRA study[1] assuming historical precipitation values). A 33% overall annual average recharge to yield ratio is still below to what is considered an average sustainable

[1] Unpublished technical study previously prepared for the study area which was made available to CRIDF

yield of 40%; however the 33% ratio does not account for increases in temperature which can result in significant evapotranspiration losses and lower further recharge rates increasing this ratio. It is not possible to determine the relationship between temperature changes and changes in recharge from the GIZ report. To properly understand recharge impacts from temperature increase the hydrogeological model would need to be run again using the temperature projections presented in **Appendix B** of this report. Setting up and running the hydrological model is beyond the scope and purposes of this risk assessment and it is recommended that CRIDF look into this issue further. Finally, it is recommended that a sensor is installed at the unused borehole at at Mitema wellfields to monitor groundwater levels.

Surface water bodies

It is expected that a yield beyond 10% of recharge will bring effects to surface water bodies like wetlands, springs and streams that have a direct connection with the aquifer such as Lake Kitere and nearby wetlands. The river Mambi that flows to Kiswa is also a source for Lake Kitere. A robust monitoring programme should be put in place not only for Mitema wellfields but also covering downstream surface water bodies such as Lake Kitere, adjacent wetlands and Mambi river.

Water Quality

Livestock watering and farming activities in the Mitema Well field area constitute a pollution risk. Growing of vegetables, for instance might cause high nitrate in the groundwater due to uncontrolled application of fertilizers. This in combination with more precipitation both in quantity and intensity that is projected in the area, by most climate models, could impact the quality of the water resources. It is essential to protect the project's water sources, by banning or limiting activities that might contaminate the groundwater. The same applies to Mkunya Springs. To enhance environmental protection of the Mkunya springs and Mitema Wellfields, education of local communities and clear demarcation of the protected areas is recommended.

Flooding

The area does not experience frequent flooding and as such not considered a major risk for the project; however a number of precautionary no/low regret measures are proposed such as:

- Install cut-off drains to intercept water runoff from up slope for pumps 1, 2 and 3 in Mitema Wellfields.
- Raise plinths around pumps in Mitema boreholes to at least 200mm to protect from flooding.
- Install cut-off drain to intercept surface water in areas where VIP latrines are to be constructed.
- Training to be given to artisans for appropriate construction and siting of VIP latrines to avoid groundwater horizons
- Community education on risks using water from shallow wells e.g. health risks due to contaminated water through local teachers, e.g. school health club.
- Provisions in the immediate measures programme of works to look into the power interruptions issue and investigate 2 options: 1) The possibility of a dedicated supply from power supplier or 2) develop standby generator capacity either through diesel or solar power.

Drought

The baseline drought risk for the area has been characterised as mild and future climate trends indicate that the area is likely to receive on average more rainfall than it does at the moment so drought is not considered a major risk. However, projected temperature increases along with increased rainfall variability are likely to increase evapotranspiration which could cancel the possible benefits of increased precipitation.

The single source project will provide resilience to drought events due to reliability of supply. Also, Mkunya springs project will improve water supply, sanitation and hygiene conditions in the nearby villages that at the moment receive no water and enhance resilience.

The following supplementary actions are suggested:

- Drought conditions monitoring to be included in the project's monitoring plan
- Education and water purification supplies to treat water on rainwater harvesting pits to be considered.
- It is expected that in the event of increases drought more and more people will build rainwater harvesting pits particularly in the absence of project. Investigate possibility of rainwater harvestings pits presenting increased malaria hazards (due to possible breeding ground of mosquitos). If this is the case the project itself can serve as a risk mitigating measure against increase in malaria.
- Education programmes run by community development officers and delivered through schools and local committees are proposed to raise importance of WASH issues.

Erosion

The area faces significant erosion issues. Unearthed and exposed pipelines of the existing water network is a common sighting. This presents serious risk of damage of network due to natural phenomena or vandalism. It is recommended that project pipelines are buried in sufficient depth (>800mm) to protect from erosion related hazards. In areas where topography requires pipes to be over ground then steel pipes to be used to protect also from wildfires. For Mkunya springs it is proposed that a fence is installed in sufficient distance from the springs to allow for vegetation to protect weir from erosion.

Institutional issues

In addition to the physical risks there is a set of softer, institutional and governance risks to the project that were identified. The weak institutional capacity of managing agencies and authorities for implementation and management, can become a bottleneck for the long term sustainability of the project. This can inappropriately limit funds available for operations, maintenance and repairs. On the other hand, having the capacity and systems in place to identify and respond to disruptions can lessen their duration and severity. The establishment of well managed water users' associations to govern local water systems such as the proposed COWSOs for rural areas and associations for community engagement for urban areas can help in the right direction. Clear systems and plans in place on how they will operate and will be governed are also required.

Introduction

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An overview of the process followed is presented in **Figure 1** below.

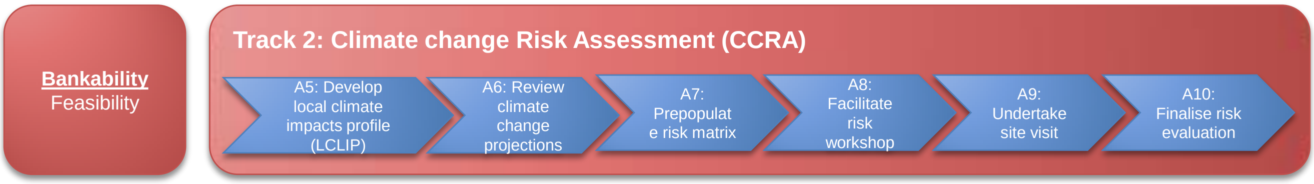

Figure 1 **Overview of climate change risk assessment process activities**

The report is structured as follows:

Sections 1 and 2 present an overview of the project, the local context and historical climate and impact information that help the reader understand the existing risk situation in the area.

Section 3 summarises an overview of projections of the estimated change in the regional and local climate for climate parameters of interest.

Section 4 provides the risk results from the climate risk screening workshop exercise and the site visit. The section includes a summary of the risks with their potential consequences for the project and local community. It also includes adaptation measures for 'high' and 'extreme' risks along with a summary of recommendations.

1. Project and area background

This section presents an overview of the project, the local context and historical climate and impact information that help the reader with understanding the existing risk situation in the area.

Project Background

The Project can be best characterised as an institutional capacity support intervention with a strong infrastructure development component. The MWSSA currently serves approximately 56,000 households, which will benefit greatly from reliable access to water supply infrastructure. At the moment, less than half of the total population is served by the system, and operation and maintenance (O&M) is not adequate in terms of procedures, coordination and qualification. Only around 40 % of the total population on Makonde Plateau are served by the current water supply system. Water supply takes place on an intermittent and unreliable basis with insufficient quantities.

The service area of the Makonde water supply scheme (MWSS) is located on the Makonde Plateau – situated at an altitude ranging from 120 to 930 meter above sea level (masl). MWSSA serves 8 towns (Kitangara, Newala, Mahuta, Nanyanga, Namikupa, Tandahimba, Kitama and Nanyamba) and approximately 350 villages distributed as follows:

- 157 in Tandahimba District.
- 150 in Newala District.
- 40-50 in Mtwara Rural District.

Nanyamba town in Mtwara Rural District has no regular service. Water supply in Nanyanga, Namikupa and Kitama is problematic due to an infrequent power supply. Only 297 of the villages within the service area are covered by network with intermittent supply. 50-60 villages scattered all over the area have no supply at all.

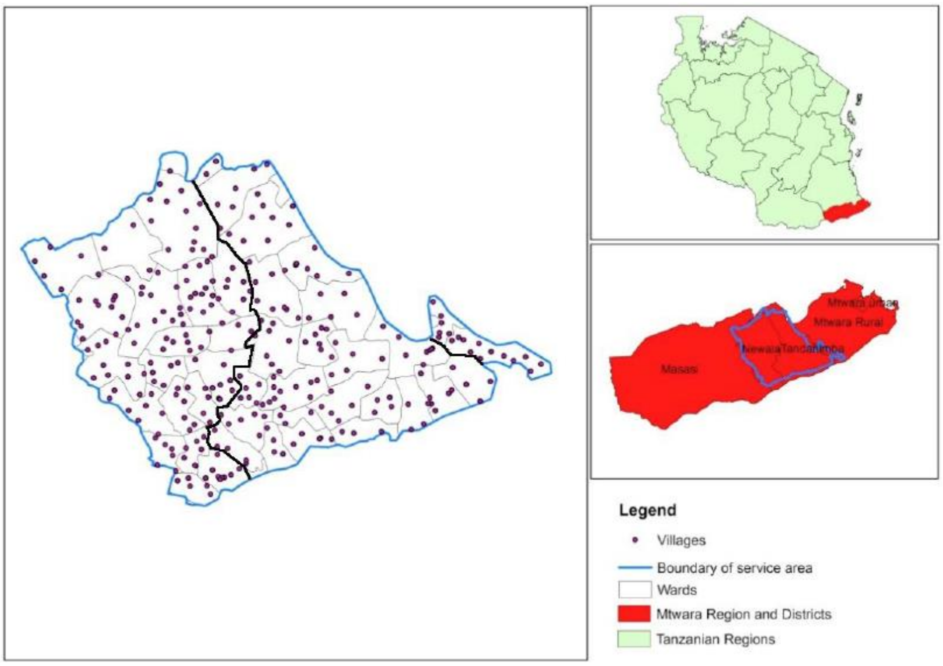

Figure 2 **Makonde WS Service Area and Administrative Boundaries**

Latest figures estimate that only around 40% of the current population in the area is connected to the network, with some 350,000 people served by the Makonde Water Supply and Sanitation Authority (MWSSA), albeit on an intermittent and unreliable base. The population, forecasted to increase to up to 597,000 by 2030, is dependent on regular operation of five pumping schemes supplied by five separate sources:

1) Mitema Boreholes (6);
2) Mkunya Springs;
3) Mahuta Springs;
4) Tandahimba Boreholes;
5) Mnyawi Borehole.

It is noted that the overall performance of the water sources is low and the available water sources and water production are inadequate to meet the current demand from the population in the area.

The objective of the project is to expand the water supply system in the Makonde area by drawing on these water sources. It aims to do this by increasing water production, growing water distribution networks and building capacity of both the local water authority and the target population to better manage water resources. The entire project will have a large impact on the population, specifically benefiting those who are not currently connected in any way to the water supply in the area. The project is comprised of two phases:

- The “Immediate Measures” mainly aim to address immediate O&M needs
- The “Longer-term Measures” are aimed to changing the existing water supply system from multi-source to a single-source

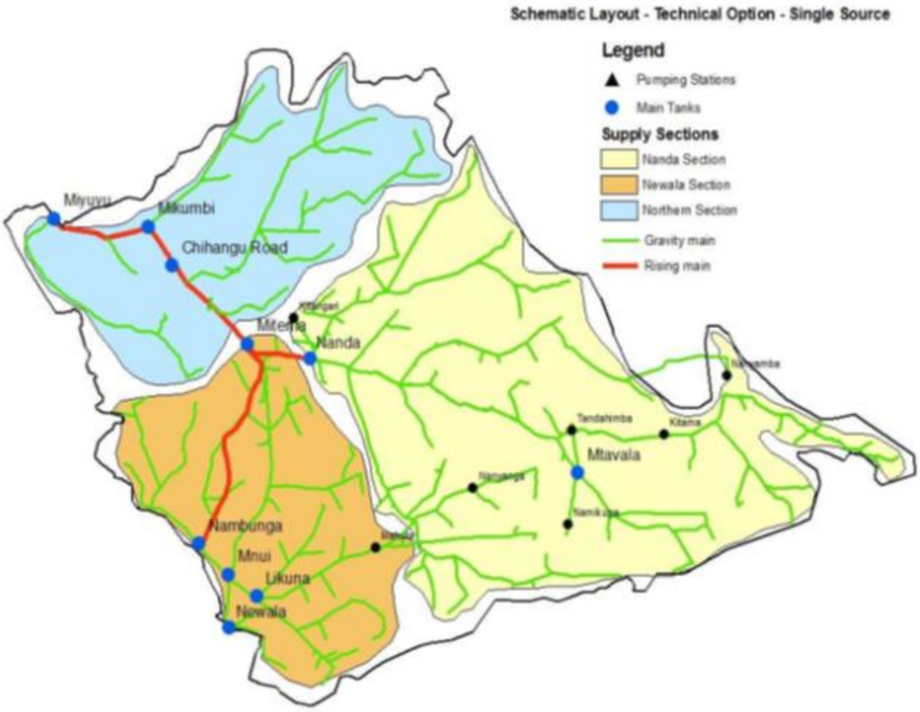

Figure 3 **Schematic layout of the MWSS**

The "Immediate Measures" mainly comprise of activities such as rehabilitation of water extraction and treatment facilities at Mitema, as necessary; upgrading of treatment plants and associated mains; replacement of old pipes; other O&M; and capacity building for the MWSSA's staff. The total cost of the "Immediate Measures" is estimated at about GBP1.7 million, while the total cost of "Phase 1" measures (divided into three sub-phases: A, B and C) of the rehabilitation is estimated at GBP59.17 million, bringing the total Project cost at GBP61.4 million.

The "Longer-term Measures" (Phase 1) are aimed to changing the existing water supply system from multi-source (six: Mitema, Mkunya, Mahuta, Chiwambo, Tandahimba, and Mnyawi) to a single-source (Mitema-Kitangari), reducing unaccounted for water (UfW) and improving the operational efficiency of the Authority. This single-source option is a significant change in the system.

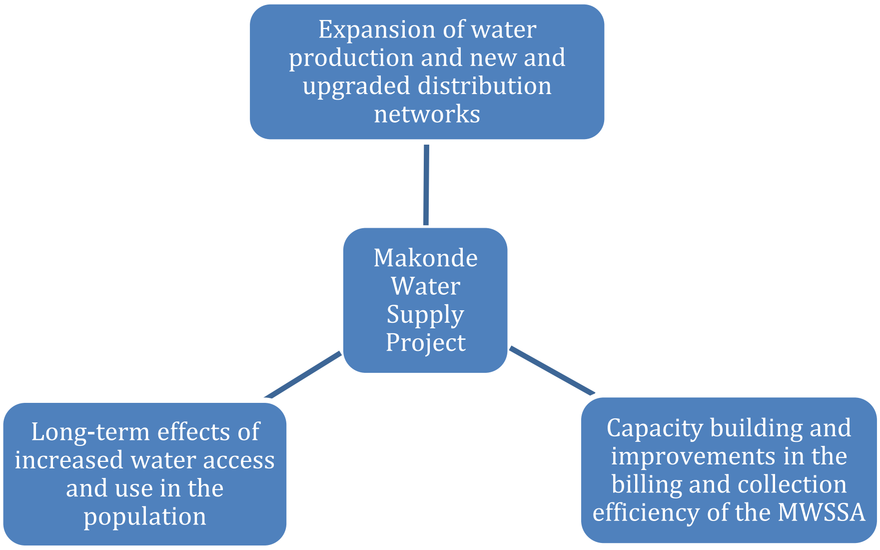

Figure 4 **Key outcomes of the project**

Scope of CCRA

The scope of this CCRA includes the following activities:

1) Deliver the "Immediate Measures" component that consists of the following:

a) Rehabilitation and upgrading of pumping stations (borehole pumps, main PS and booster PS);

b) Replacement of pipelines (risers, transmission and distribution pipes);

c) Replacement/rehabilitation of water tanks (BPTs, balancing, pump sumps etc.);

d) Procurement of water meters (bulk and customer meters) to be installed by MWSSA; and

e) Consultancy services (Computerised billing, capacity strengthening, GIS etc.).

2) Improve WSS for communities in the lower flood plain once implementation of Phase 1 is underway i.e. increased use of the Mitema ground water source to supply the Plateau frees up the Mkunya source. The

intervention in the lower flood plain thus aims to use this source to supply domestic water to 5 local villages that are currently not connected to the network.

3) Improve sanitation facilities in the villages and catchment protection - including the protection of the Mkunya spring.

4) At a high level evaluate longer-term climate resilient opportunities of the broader Phase 1 work i.e. upgrading the MWSSA's system based on the single-source plan.

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2. Local Climate Impacts Profile

Tanzania lies just south of the equator, at 1-11˚S and has a tropical climate with regional variations due to topography. With the exception of a narrow coastal strip, most of Tanzania is highland. The greater part of Tanzania is a central plateau of around 900-1800m, punctuated with mountain ranges (including Kilimanjaro, 5895m). The coastal regions of Tanzania are warm and humid, with temperatures 25 to 17˚C through most of the year, dipping just below 25˚C in the coolest months: June, July, August and September (JJAS). The highland regions are more temperate, with temperatures around 20-23˚C throughout the year, dropping by only a degree or so in JJAS.

The Makonde plateau is a high-lying, water-scarce area found in south-eastern Tanzania. There are no perennial rivers and the only accessible water source lies deep below the surface in the form of groundwater. The area is home to approximately 450,000 people; according to the local water authority, the existing water scheme in the area supplies around 350,000, but both the population and the demand for water are expected to rise in the future.[2]

Geographic Setting

The Makonde plateau is an uplifted plateau of marine deposition. It is flat lying and tilts very gently to the East towards the costal line. In the western part the edge of the Makonde plateau is a sharply dropping escarpment which incidentally forms the administrative boundary between the districts of Newala and Masasi.

The vegetation cover is limited to scattered woodlands (Miombo trees), shrubs and grasses (elephant grass in the valleys), which thrive during the rainy season and dry up after the rains are gone. Most of the villages are sited along the roads. The economy of the area is mainly agriculture, where maize, sweet potatoes and cassava are the main subsistence crops, while cashew nuts and coconuts are planted for cash. Small scale fishing activities take place in the rainy season and along the Ruvuma River.

Rainfall

Seasonal rainfall in Tanzania is driven mainly by the migration of the Inter-Tropical Convergence Zone (ITCZ), relatively narrow belt of very low pressure and heavy precipitation that forms near the earth's equator. The exact position of the ITCZ changes over the course of the year, migrating southwards through Tanzania in October to December, reaching the south of the country in January and February, and returning northwards in March, April and May. This causes the north and east of Tanzania to experience two distinct wet periods – the 'short' rains in October to December and the 'long' rains in March to May, whilst the southern, western and central parts of the country experience one wet season that continues October through to April or May. The amount of rainfall falling in these seasons is usually 50-200mm per month but varies greatly between regions, and can be as much as 300mm per month in the wettest regions and seasons. The movements of the ITCZ are sensitive to variations in Indian Ocean sea-surface temperatures and vary from year to year, hence the onset,

[2] GIZ Feasibility Study: Volume 1, in a copy of the ToR from Government of Tanzania for the commissioning of the Feasibility Study, Pg. 7

duration and intensity of these rainfalls vary considerably inter-annually. One of the most well documented ocean influences on rainfall in this region is the El Niño Southern Oscillation (ENSO). El Niño episodes usually cause greater than average rainfalls in the short rainfall season (OND), whilst cold phases (La Niña) bring a drier than average season. Most of the country receives less than 1,000mm, except the highlands and parts of the extreme south and west where 1,400 to 2,000mm can be expected.

Spatial distribution of mean annual rainfall in the project area is presented in **0**.

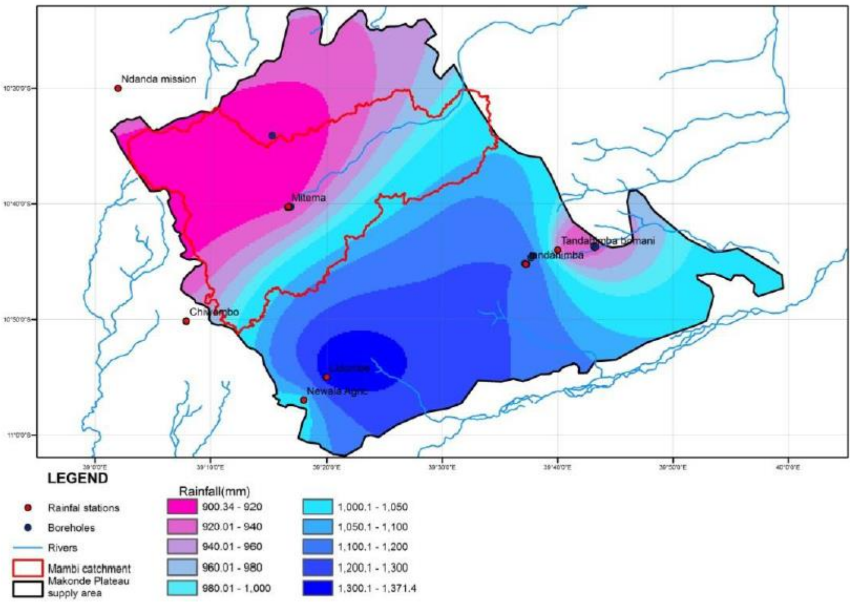

Figure 5 **Annual Rainfall Distribution in Makonde Plateau, (GIZ WRA Report, 2011)**

- Observations of rainfall over Tanzania show statistically significant decreasing trends in annual, and June-July-August-September (JJAS) and March-April-May (MAM) rainfall. Annual rainfall has decreased at an average rate of 2.8mm per month (3.3%) per decade. The greatest annual decreases have occurred in the southern most parts of Tanzania. MAM and JJAS rainfalls have decreased by 4.0 and 0.8 mm per month per decade, respectively (3.0% and 6.0%).
- Trends in the extreme indices based on daily rainfall data are mixed. There is no statistically significant trend in the proportion of rainfall occurring in heavy events. 1-day and 5-day rainfall maxima show small, non-statistically significant decreasing trends. 5-day events show a significant increasing trend of +11.03mm per decade in MAM. (McSweeney, 2010)

An overview of rainy season historical deviation from the mean is presented in **Figure 6** below where a slight downward trend can be noticed.

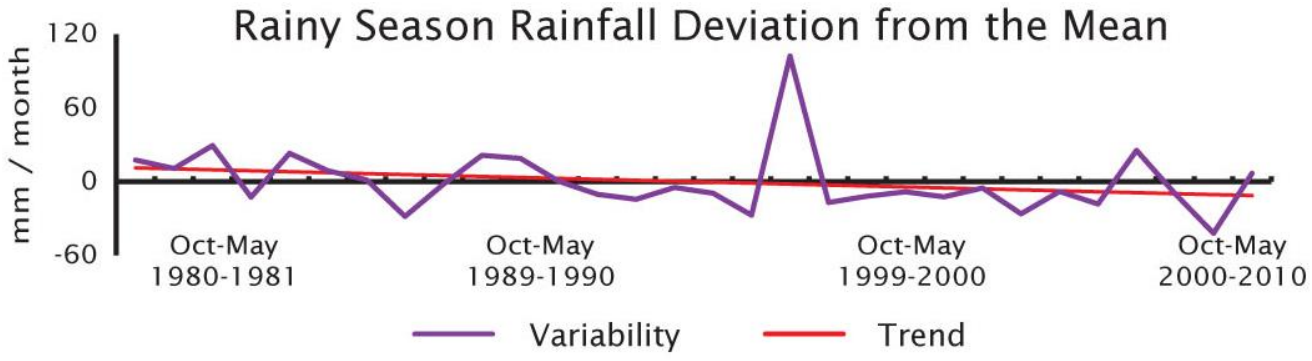

Figure 6 **Rainy Season Historical Deviation from the Mean**

Temperature.

So far the following impacts have been observed:

- Mean annual temperature has increased by 1.0˚C since 1960, an average rate of 0.23˚C per decade. This increase in temperature has been most rapid in JF and slowest in JJAS.
- Daily temperature observations show only small increasing trends in the frequency hot days, but much larger increasing trends in the frequency of hot nights with likely increasing malaria risks.
- The frequency of cold days has not changed discernibly, despite the observed increases in mean temperature. The frequency of cold nights has, however, decreased significantly in all seasons. (McSweeney, 2010)

Increases in average and extreme temperatures can affect water resources, treatment, and demand. For example:

- Water flows can be altered by increased evapotranspiration.
- Reduced recharge of ground water due to increased evapotranspiration.
- Demand for water can increase due to high temperatures

Changing temperature and precipitation patterns can also likely cause certain diseases to increase in occurrence as well as change their spatiotemporal distribution. For example, in Tanzania, malaria has already expanded into regions that have historically been unaffected (e.g. Tanga, Kilimanjaro, and Arusha Highlands).

Variability

East Africa's climate is naturally dynamic with high temporal and spatial rainfall variability. Some variability can be explained by large scale oscillations in atmospheric and ocean circulation - in particular the El-Nino Southern Oscillation (ENSO) and less well known events such as the Indian Ocean Dipole reversal. Research linking rainfall variability in East Africa to ENSO and sea surface temperature variations in the Indian and Atlantic oceans suggests that extreme events occur regularly at cycles of approximately 2.3, 3.5, 5 and 8 years.

Flooding

Extreme precipitation and flooding can affect the quality and continuity of water, wastewater, and sanitation services. For example:

- Increased runoff can introduce new contaminants into the water supply, increasing the pollutant load.
- Erosion and sedimentation can occur in waterways, reducing reservoir capacity.
- Extreme precipitation can increase erosion and sedimentation in waterways, reducing reservoir capacity.
- Extreme precipitation can inundate latrines and cause overflow. Flooding during wet season rains is already associated with annual cholera outbreaks in both urban and rural settings because pit latrines, the sanitation option for most Tanzanians, are washed out.
- Heavy rainfall events can reduce the effectiveness of erosion control measures in the watershed.

Floods are a natural hazard that Tanzania experiences on a regular basis. Heavy rainfall and sea level rise are contributing factors to floods within the country affect many people, like the floods of 2002, 2009 and 2010 and have devastating impacts on agriculture, food security, health, groundwater supplies, hydropower generation, and the economy. However flooding has not been a major issue in the Makonde project area mainly due to topography. An overview of flood frequencies in the project area is presented in **Figure 7** below. As it can be noted the flood areas are outside the areas of the Makonde project and mainly run through surface water bodies such as the Ruvuma River.

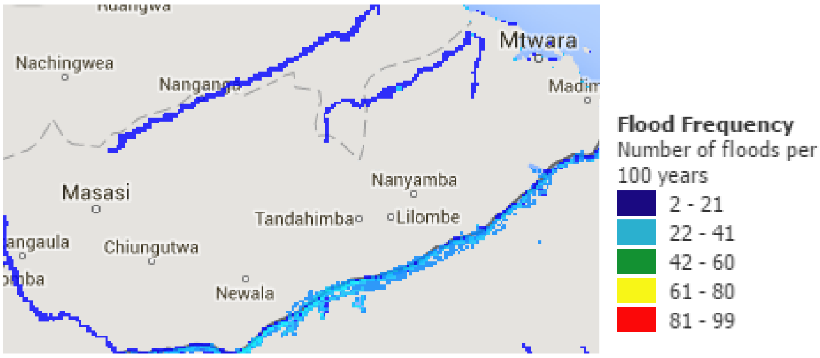

Figure 7 **The expected average number of flood events per 100 years based upon observed flood data from 1999-2007 (UNEP, GRID)[3]**

[3] This dataset includes an estimate of flood frequency. It is based on three sources: 1) A GIS modeling using a statistical estimation of peak-flow magnitude and a hydrological model using HydroSHEDS dataset and the Manning equation to estimate river stage for the calculated discharge value. 2) Observed flood from 1999 to 2007, obtained from the Dartmouth Flood Observatory (DFO). 3) The frequency was set using the frequency from UNEP/GRID-Europe PREVIEW flood dataset. In area where no information was available, it was set to 50 years returning period. Unit is expected average number of event per 100 years. This product was designed by UNEP/GRID-Europe for the Global Assessment Report on Risk Reduction (GAR). It was modeled using global data. Credit: GIS processing UNEP/GRID-Europe, with key support from USGS EROS Data Center, Dartmouth Flood Observatory 2008.

Landslides

An overview of the landslide risks caused by precipitation events is presented in **Figure 8**. It appears that the valley of the Mambi River where Mitema is located is in a medium landside risk zone.

Figure 8 **Physical exposure to landslides triggered by precipitations (UNEP GRID)**[4]

Drought and Wildfires

In the last 40 years Tanzania has experienced severe and recurring droughts with devastating effects to agricultural, water and energy sectors. Drought events recorded for 1967–2013 in the EM-DAT database include the following years: 1967, 1977, 1984, 1988, 1990, 1996, 2003, 2004, 2006, and 2011.[5] Currently more than 70% of all natural disasters in Tanzania are hydro-meteorological, and are linked to droughts (and floods). The droughts that occurred during 2000-2002 affected several million Tanzanians, and in 2004/2005 and 2009 droughts caused poor crop yields, which undermined efforts to alleviate poverty and food insecurity. The environmental and ecological impacts of these droughts were alarming. Agriculture in the affected areas was crippled, a lot of livestock and wildlife perished due to starvation and lack of water. Following these droughts, Tanzania suffered a serious energy crisis which had severe social and economic implications.

Local community impacts

In the Ruvuma River Basin, where the population is very poor and with few coping mechanisms, drought can have an immediate impact on food security. Drought produces a complex web of impacts that span many sectors of the economy and reaches well beyond the area experiencing physical society's ability to produce goods and provide services. Impacts are commonly referred to as direct and indirect. Direct impacts include

[4] This dataset includes an estimate of the annual frequency of landslide triggered by precipitation. It depends on the combination of trigger and susceptibility defined by six parameters: slope factor, lithological (or geological) conditions, soil moisture condition, vegetation cover, precipitation and seismic conditions. Unit is expected annual probability and percentage of pixel of occurrence of a potentially destructive landslide event x 1000000. This product was designed by International Centre for Geohazards /NGI for the Global Assessment Report on Risk Reduction (GAR). It was modelled using global data. Credit: GIS processing International Centre for Geohazards /NGI.

[5] http://www.emdat.be/database

reduced crop, rangeland, and forest productivity, increased fire hazard, reduced water levels, increased livestock and wildlife mortality rates, and damage to wildlife and fish habitat. The consequences of these direct impacts illustrate indirect impacts. For example, a reduction in crop, rangeland, and forest productivity may result in reduced income for farmers and agribusiness, increased prices for food and timber, unemployment, reduced tax revenues because of reduced expenditures, foreclosures on bank loans to farmers and businesses, migration, and disaster relief programs.

Project impacts

More specifically for the Makonde project itself drought can affect the quantity and quality of water supply. For example:

- Droughts can reduce recharge to surface and ground water supplies, thereby impacting water pumping needs.
- Low water levels as a result of drought can lead to higher concentrations of contaminants.
- Drought can increase demand for irrigation water and other uses.

While drought is not considered a major or recurrent risk as in other parts of Tanzania the project area has experienced dry conditions**.** An overview of exposure to droughts from UNEP GRID is presented in **Figure 9** below. As it can be noted most of the area experiences mild exposure to drought. The Makonde Water Supply will help to alleviate any water supply pressures to local population.

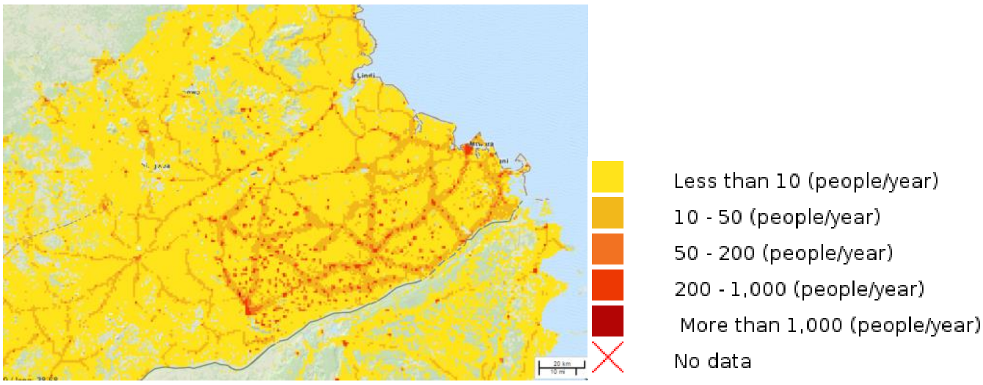

Figure 9 **Physical exposure to droughts events 1980-2001 (UNEP GRID)[6]**

[6] This dataset includes an estimation of the annual physical exposition to drought based on Standardized Precipitation Index. It is based on three sources: 1) A global monthly gridded precipitation dataset obtained from the Climatic Research Unit (University of East Anglia). 2) A GIS modelling of global Standardized Precipitation Index based on Brad Lyon (IRI, Columbia University) methodology. 3) A population grid for the year 2010, provided by LandScanTM Global Population Database (Oak Ridge, TN: Oak Ridge National Laboratory). Unit is expected average annual population (2010 as the year of reference) exposed (inhabitants). This product was designed by UNEP/GRID-Europe for the Global Assessment Report on Risk Reduction (GAR). It was modelled using global data. Credit: GIS processing UNEP/GRID-Europe.

Furthermore drought in combination with higher temperatures can cause wildfires. This can result in damaging the project's infrastructure, pose safety issues for the local population and potentially damage cashew trees. An overview of the expected number of fire events is presented in **Figure 10** below.

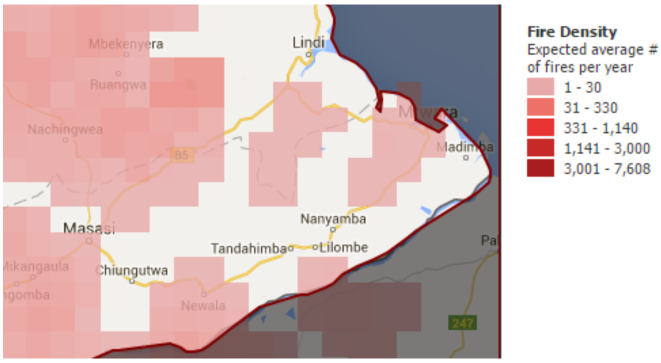

Figure 10 **The expected average number of fire events (per 0.1 decimal degree pixel, per year) based upon fire densities from 1997-2010 (UNEP, GRID)[7]**

Deforestation, Erosion and Water Protection

The issue of environmental degradation was mentioned in villages as one of the areas problems during site visits in the area. There are indications that in the 1970s there was no or limited soil erosion, no extreme tree cutting and no destruction of water sources. The problem has over time escalated after expanded agricultural activities and population increase. Trees are cleared for opening new farms, for timber, charcoal burning and building activities. Another reason mentioned for environmental degradation was bushfires which are used for drying cashew crops and as a way of clearing farms.

Deforestation is considered as a main reason of losing productive water sources. As an example, most of the water sources in the south-eastern part of Masasi and Tandahimba districts originate from the Newala Plateau. Several springs along the Newala Plateau have been used as water sources for large gravity fed schemes, but due to destruction of the spring catchment areas the projects are either unserviceable or performing with a much reduced capacity. The use of agrochemicals is not yet a significant issue due to little commercial faming in the area.

Health

The population is mainly affected by waterborne diseases, malaria, and malnutrition. Approximately 7.7% people were found to be infected with the HIV/AIDS between 2000 - 2003 in Mtwara (Mtwara, 2007). For the

[7] This dataset includes an average of fire density over the period 1997-2010. It is based on the World Fire atlas (WFA, ESA-ESRIN) dataset. UNEP/GRID-Europe compiled the monthly data and processed the global fire density. Unit is *'expected average number of event per 0.1 decimal degree pixel per year multiplied by 100'* (e.g. 64 value means 0.64 events per year) and slightly smoothed. This product was designed by UNEP/GRID-Europe using global data. Credit: World Fire atlas (ESA-ESRIN), Fire density UNEP/GRID-Europe.

period covering 2000 - 2003 Mtwara region reported a total of over 175,000 cases of waterborne diseases, including an outbreak of around 4,600 cases of cholera and 168,000 cases of diarrhea (Mtwara, 2007). In 2006, cholera cases were reported from 16 regions (out of 21) in Tanzania including Mtwara. The region with the highest fatality rate was Mtwara (33%) (WHO, 2008).. Mtwara is one of the poorest areas in Tanzania. The under-five mortality rate there is twice the national average. This situation may also explain the higher rates of death.

Malaria prevalence is also high with an incidence of 34% among tested children under 5 years old in Mtwara region. The Percentage of stunted children in Mtwara, Ruvuma and Lindi was over 40% in 2004 according to the Demographic and Health Survey 2004-05 Preliminary Report.

In Mtwara major providers of health services are government, and private institutions i.e. religious institutions. There are government run regional hospitals for Mtwara as well as district hospitals. The health sector in the region is faced by a variety of basic problems, which work against the development of a healthy and productive population. Poor communications, poor water supply, poverty, poor rural health services and malnutrition are only some of the factors contributing towards ill health. Health infrastructure for the Mtwara Region is presented in **Table 1** below. It should be noted though that the distribution of hospitals, health centers and the dispensaries is not even.

Table 1 **Health Infrastructure in Mtwara Province**

Country	Province	Dispensaries		Health Centres		Hospitals		Total
		Units	Beds	Units	Beds	Units	Beds	Units
Tanzania	Mtwara	139	85	14	1105	4	1190	157

Source: Mtwara Region 2007;URT,(2002),Health Statistics Abstract,2002.Inventory Statistics, Report prepared by the ministry of health, Dar es salaam and ERB-Survey 2004

Most of the top 10 diseases and cause of deaths are water-and sanitation related in the project area. Part of the existing environmental hazards is the general lack of improved sanitation facilities and lack of knowledge of the relationship between water, hygiene and excreta disposal. Vulnerability to waterborne pollution is generally related to the main urban areas and growth centres located in the basin.

The problem of water related diseases is however not limited to urban areas. It is equally relevant in the irrigation schemes e.g. Namatuhi in Tanzania, which has seen an increase in the prevalence of number of cases of bilharzias and malaria.

Climate Vulnerability Tool Indicators

Table 2 below shows the level of the climate indicators for the Makonde plateau area. Based on the CRIDF Climate Vulnerability tool, the Makonde Plateau Water Supply project faces a number of current climate vulnerability stresses (Seasonal variability – High; Inter-annual variability – Medium to high. One of the main factors affecting people’s lives will be the water risk, due to the high seasonal and inter-annual variability. It is likely that CRIDF interventions at the Makonde plateau will address some of these climate change vulnerabilities in the project area.

Table 2 **Climate resilience indicators**

Indicator	Outcome
Baseline Water Stress	Low (<10%)
Inter-annual variability	Medium to high
Seasonal variability	High
Flood Occurrence	No Data
Drought Severity	Low
Upstream Storage	No major reservoirs
Groundwater Stress	Low
Household and community resilience	Moderately less resilient
Population density	21.0 (people per km^2)
Resilient Population	High
Baseline Risk to People	Medium
Climate Change Pressure	High
Water Risks Under Climate Change	Medium
Future Risks to People	Moderate

3. Climate trends and projections

This section presents on overview of the latest climate trends and projections that were used to inform the climate change scenarios developed for the project area.

Changes to the following key climatic parameters can impact the Makonde Water supply project.

- Rises in average temperatures that increase the loss of water through evapotranspiration as well as increased demand for clean water.
- Changes in precipitation that affect the quantity of water available
- More frequent or severe extreme weather events, such as floods and droughts that can damage water supply infrastructure.

The climate science community sources a suite of models to inform decision makers on future climate. Among the most widely used are GCMs (Global Climate Models or Earth System models) that capture the non-linear complexity of the Earth to represent changes across the climate system for key processes and contexts. The collection of models presented here represents the best-presently-available-data to outline likely future changes in the climatologies of temperature and precipitation across the globe. The collection presented here includes results from 16 available global circulation models (GCMs) used by the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report and is a representative subset of the full CMIP5 (Coupled Model Inter-comparison Project Phase 5) distribution. Results are presented for 2 Representative Concentration Pathways (RCPs), RCP 4.5 and RCP 8.5.

Representative Concentration Pathways

Representative Concentration Pathways are greenhouse gas concentration trajectories adopted by the IPCC for its fifth Assessment Report (AR5). They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively). RCP 2.6 assumes that global annual GHG emissions (measured in CO2-equivalents) peak between 2010 - 2020, with emissions declining substantially thereafter. Emissions in RCP 4.5 peak around 2040, then decline. In RCP 6, emissions peak around 2080, then decline. In RCP 8.5, emissions continue to rise throughout the 21st century.

Looking at the future climate projections give some indication of whether we can expect a largely drier or largely wetter future in the project area. Climate futures are indicative of a range of possibilities that are supported by the best current climate science from the Intergovernmental Panel on Climate Change. The climate futures therefore provide an initially plausible space for thinking about the range of possible climate impacts and the range of climate futures that can be considered in future adaptation planning and design. In addition, it is important to note that “drier” in water resource planning is a combination of temperature and precipitation, as higher temperatures lead to higher evaporation from surface waters, higher evapotranspiration from plants, and as a result, lower runoff, all else being equal.

However, figuring out how exactly the project’s infrastructure development should be modified to take climate change into account is difficult, because of the high degree of uncertainty in climate projections. For this reason most of the measures proposed in this report are ‘no or low regret’.

Climate Trends Overview

- In spite of the declining rainfall trend observed, global projections suggest that by the end of the 21st century, the climate in eastern Africa will be wetter, with more intense wet seasons and less severe droughts in October-November-December and March-April-May, a reversal of recent historical trends. (IPCC, 2014)
- Projections indicate shorter spring rains in the mid-21st century and longer autumn rains in Tanzania.
- Increases in heavy precipitation and the number of extreme wet days by the mid-20th century over the region have been reported with high certainty in IPCC’s Special Report on Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC, 2012).
- ‘Heat wave duration’ is projected to increase over Tanzania by the end of the 21st century and Western Tanzania is projected to experience the largest change.
- Observed increase in climate variability in most East African countries and particularly in Tanzania has increased the uncertainty in seasonal rainfall prediction. Projections indicate truncated boreal spring rains in the mid-21st Century while the boreal fall season is lengthened in Tanzania.
- While unpredictable rainfall and prolonged dry spells (which are indicative of climate volatility), have been recognised as key threats in the National Adaptation Programme of Action (NAPA) of Tanzania these are applicable mostly for the North and Central parts of the country.

Changes in Temperature

The first chart (**Figure 11**) shows projected change in monthly temperature for the project location for the period 2040-2059 according to a range of models for RCP4.5 and the second (**Figure 12**) according to RCP8.5. All models predict an increase in temperature. RCP4.5 GCMs project a 1.0 - 1.6°C increase whereas RCP8.5 project an increase 1.16 – 2.22°C in 2040. Projected changes are calculated from a 20 year historical control period covering the years 1986-2005. Detailed projections are presented in **Appendix B**.

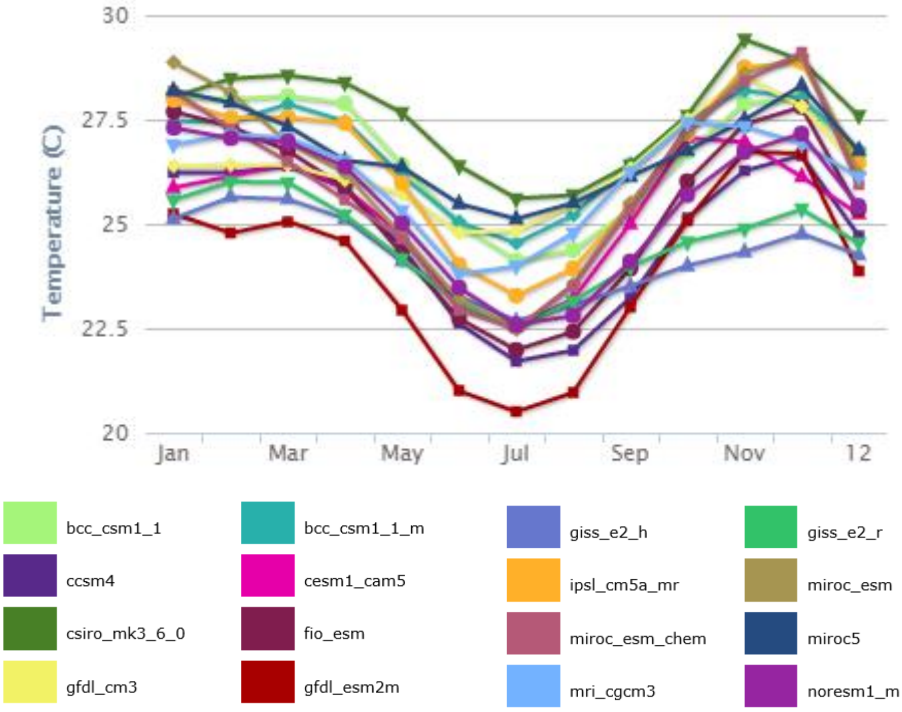

Figure 11 **Mean Projected Temperature for Project Location from 2040 to 2059 for RCP4.5, Source: World Bank Climate Change Knowledge Portal**

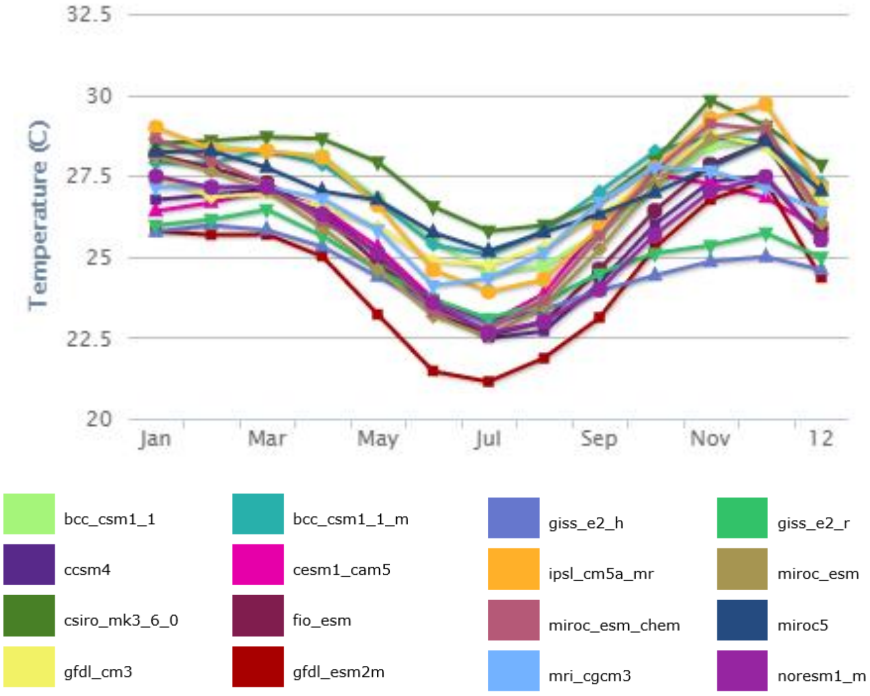

Figure 12 **Mean Projected Temperature for Project Location from 2040 to 2059 for RCP8.5, Source: World Bank Climate Change Knowledge Portal**

Impacts

The likely impacts due to increased temperatures are presented below:

Human Health: Shifts in disease vector habitats / incidence of malaria; respiratory problems; an increase in rainfall will increase the number of cholera cases

Agriculture & food Security: Shifts in the viable area for coffee and cash crops; reduced agricultural outputs; higher evapotranspiration losses

Infrastructure & settlements: Increased evaporative losses; damage to roads; cooling costs

Environment & Biodiversity: Biodiversity loss as niches are closed out; changing ecosystem dynamics and production

Changes in precipitation

Precipitation projections are more uncertain than temperature projections and exhibit higher spatial and seasonal dependence than temperature projections. CMIP5 projects likely increases in mean annual precipitation over areas of eastern Africa beginning the mid-21st-century.

More specifically for RCP8.5:

- 9 out of a total 16 GCMs indicate an increase of 8% - 165% in average yearly precipitation in the area
- 2 models show no or minimal change; and
- 5 models indicate a decrease of 2% - 27%.

For RCP4.5 the results are not dissimilar:

- 10 models show an increase of 1% to 170%
- 1 model shows no change; and
- 5 models show a decrease of 2 – 27%.

The first chart (**Figure 13**) shows projected change in monthly rainfall for the project location for the period 2040-2059 according to a range of models for RCP4.5 and the second (**Figure 14**) according to RCP8.5. The majority of models predict an increase in precipitation in the area. Projected changes are calculated from a 20 year historical control period covering the years 1986-2005.

Detailed climate projections are presented in **Appendix B**.

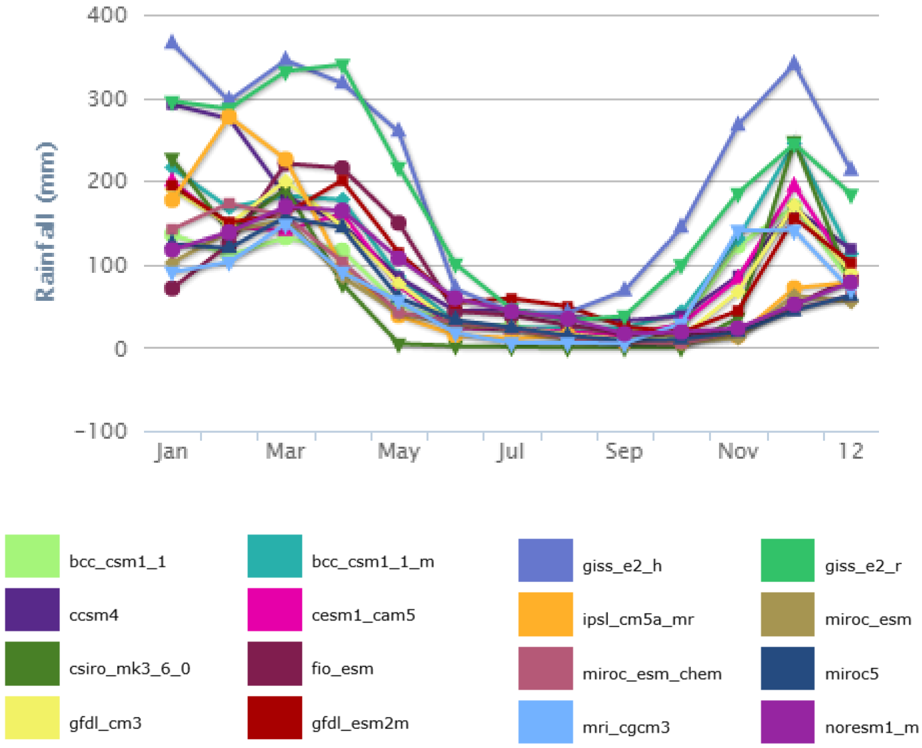

Figure 13 **Mean Projected Rainfall for Project Location from 2040 to 2059 for RCP4.5, Source: World Bank Climate Change Knowledge Portal**

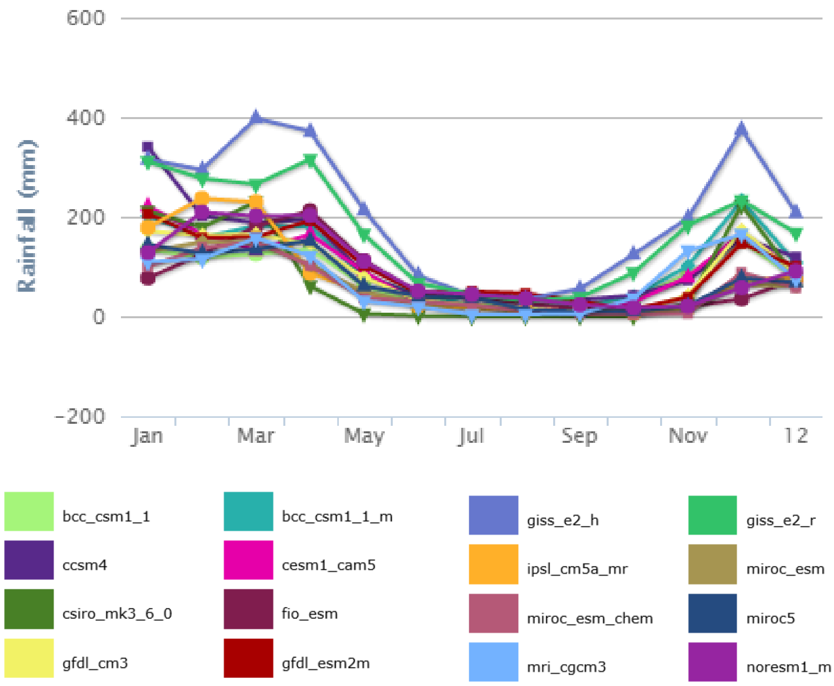

Figure 14 **Mean Projected Precipitation for Project Location from 2040 to 2059 for RCP8.5, Source: World Bank Climate Change Knowledge Portal**

Impacts

The likely impacts due to increased rainfall and seasonality are presented below:

- **Human Health:** Shifts in disease vector habitats / incidence of malaria; respiratory problems; an increase in rainfall will increase the number of cholera cases
- **Agriculture & food Security:** Elevated erosion, land degradation crop loss; change in crop yields/ disease
- **Infrastructure & settlements:** Flood damage to infrastructure, transport, communications and settlements. Only 3% of roads are sealed in the area.
- **Environment & Biodiversity:** Shift in habitats and growing seasons

4. Climate Risk Assessment

Following the development of the local climate impact profile and the climate trends, the key events that could pose a hazard for the area were identified and a series of scenarios were developed to describe possible impacts to the infrastructure and local community. The impact scenarios were scored for their likelihood and associated consequences in collaboration with project engineers and local stakeholders (MWSSA). Scores were further refined after the site visit and further discussions with local stakeholders and the local community.

Some more details are provided in the assumptions and rationale columns in **Table 3** in the risk scoring section below and in the completed climate risk assessment tool for Makonde that accompanies this report.

Livelihoods risk

The majority, if not all of the adult community members are not in full employment.[8] According to the project's social survey, 80% of the household head interviewed were self-employed as farmers, and about 14% were not involved in any income generating activity, whilst only 8% were employed. It is safe to assume that livelihoods of local population are heavily dependent on agriculture activities that include primarily cultivation of cashew nuts that constitutes the main source of income for the majority of the locals and to a lesser extent cassava and mango. From a climate perspective it is worth considering the following:

- Although the cashew tree can withstand high temperatures, a monthly mean of 25 °C is regarded as optimal. Projected temperature increases in the area could negatively influence future yields. Further work is needed to quality this statement.
- Yearly rainfall of 1,000 mm is sufficient for production but 1,500 to 2,000 mm can be regarded as optimal. Projected average rainfall increases in the area could positively influence yields. Further work is needed to quality this statement.
- The cashew tree has a well-developed root system and can tolerate drought conditions; however rain during the flowering season causes flower abortion due to anthracnose and mildew. Furthermore, during harvesting, while nuts are on the ground, rain and overcast weather causes the nuts to rot or start germinating. Projected increased rainfall variability and unseasonal rains could impact crop quality and quantity.

The above trends could have a knock-on-effect on the local population's willingness to pay for water perhaps jeopardising the commercial viability of the project, depending how heavily the economic model depends on tariffs. In addition to this the overall risk to willingness to pay is exacerbated by the fact that there are cost-free water supply alternatives such as:

- Rainwater harvesting and run-off collection in large water pits for domestic and agriculture use is widely practiced in the area (**Figure 15**). It was also mentioned during meetings with district officials and MWSSA that constructing a water pit will be a requirement for planning permission for new build homes in the area (**Figure 16**). This could potentially provide a cost-free, albeit less safe, water source to villagers.

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- The availability of the Mkunya springs and overflow from the Mitema wellfields (**Figure 17** and **Figure 18**) provide an alternative unprotected cost-free source of water to villagers.

Figure 15 **Water pit for rainwater and run-off collection**

Figure 16 **Water collection pit to be constructed in new build home**

Figure 17 **Overflow used for water collection**

Figure 18 **Water collection from Mitema Wellfield site overflow**

Recommendations:

- The project economic model needs to be carefully considered against future communities' water demand elasticity and willingness to pay. This is an issue that has also been flagged in the project's cost benefit analysis study.

- Policies are needed that make financial credit, loans, and crop and livestock insurance available to farmers, increasing their ability to cope with natural disasters and pay for water.
- Strong legal enforcement of water pricing policies that can support monitoring water use and associated fees, thereby increasing revenues for maintenance and upgrades.

Risk to groundwater resources

A range of climate projections relating to changes in precipitation were presented in the previous section. For the purposes of this assessment, a worst case scenario of an average 29% reduction in annual rainfall [9] was assumed in order to 'stress test' the project. This reduction in rainfall will increase the yield to recharge ratio of the project to 33%, a significant increase from the current figure of approximately 10% (the value concluded in the GIZ WRA study assuming historical precipitation values). A 33% overall annual average recharge to yield ratio is still below to what is considered an average sustainable yield of 40%; It is worth noting, that the 33% ratio does not account for increases in temperature which can result in significant evapotranspiration losses and lower recharge rates.

Recommendations:

- A sensor should be installed at unused borehole at Mitema to monitor groundwater levels.
- It is not possible to determine the relationship between temperature changes and changes in recharge from the GIZ report. To properly understand impacts from temperature increase the hydrogeological model would need to be run again. Since this is beyond the scope and purposes of this risk assessment, it is recommended that CRIDF look into this issue further.

[9] MIROC ESM Global Circulation Model results for RPC 4.5 for 2040 – 2059 for the area.

Risks to surface water resources

A functional ecosystem is critical for maintaining groundwater quantity and quality. Wetlands intercept precipitation and overland flowing water. These natural systems act as filtering agents, removing pollutants and sediment from water as it infiltrates to the groundwater. Recharge can occur as a steadier pace, minimizing variability in groundwater availability. Over-extraction of the Mitema aquifer can directly affect the water supply downstream.

A yield beyond 10% of recharge will bring effects to surface water bodies like wetlands, springs and streams which have a direct connection with the aquifer such as Lake Kitere and nearby wetlands. The river Mambi that flows to Kiswa is also a source for Lake Kitere. (**Figure 19**).

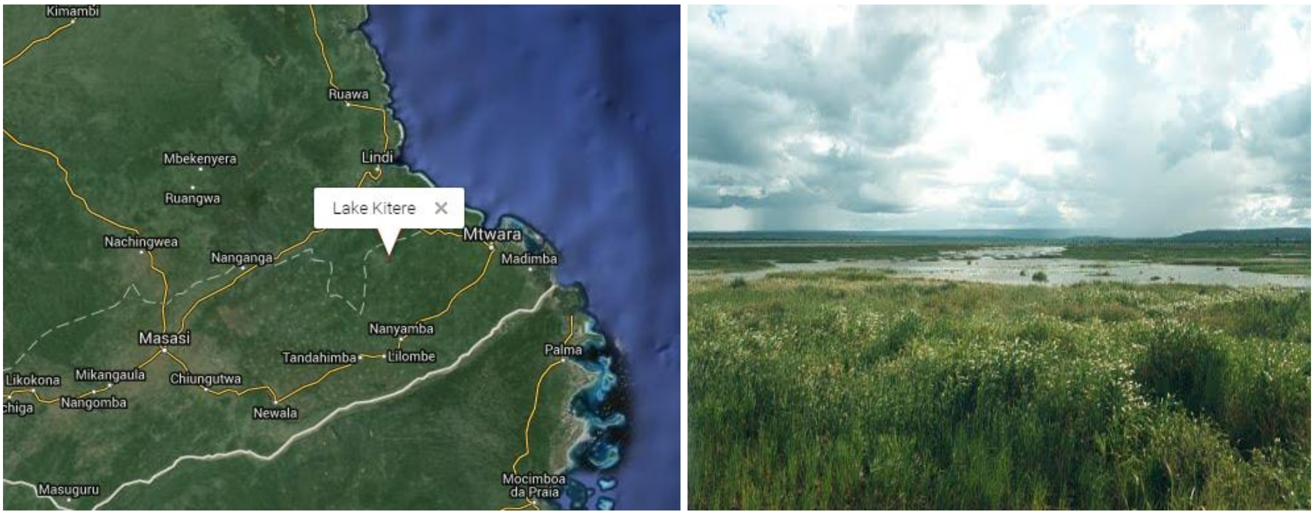

Figure 19 **Lake Kitere map and photo showing lake with Makonde Plateau in the background**

The lake and wetlands are mostly utilized for crop production, mainly rice, and grazing (E.M. Kafiriti et al, 2003). There is also a rice irrigation scheme in place in the area which depends on an artesian well drilled in the 1950s (**Figure 20**).

Figure 20 **Rice Irrigation Scheme in Lake Kitere (Source: Photographed by S Dondeyne, 2009 and published in Panoramio)**

Recommendations:

- An appropriate monitoring programme should be put in place not only for Mitema wellfields but also covering downstream surface water bodies such as Lake Kitere, adjacent wetlands and Mambi river.

Water pollution risk

Livestock watering and farming activities in the Mitema Well field area constitute a pollution risk. Growing of vegetables, for instance might cause high nitrate in the groundwater due to uncontrolled application of fertilizers. This in combination with more precipitation both in quantity and intensity that is projected in the area, by most climate models, could impact the quality of the water resources either through greater dilution or an increased spread depending on the extent of the change in precipitation and the local environment. It is essential to protect the project’s water sources, by banning or limiting activities that might contaminate the groundwater. The same applies to Mkunya Springs.

Recommendations:

- Enhance environmental protection of the Mkunya springs and Mitema Wellfields through education and clear demarcation of the protected areas.

Flooding risk

The area does not experience frequent flooding and as such it does not present major risks for the project; however the following no/low regret risk mitigating measures are proposed:

Recommendations:

- Install cut-off drains to intercept water runoff from up slope for pumps 1, 2 and 3 in Mitema Wellfields.

- Raise plinths around pumps in Mitema boreholes to at least 200mm to protect from flooding.
- Install cut-off drain to intercept surface water in areas where VIP latrines are to be constructed.
- Training to be given to artisans for appropriate construction and siting of VIP latrines to avoid groundwater horizons
- Community education on risks using water from shallow wells e.g. health risks due to contaminated water through local teachers, e.g. school health club.
- Provisions in the immediate measures programme of works to look into the power interruptions issue and investigate 2 options: 1) The possibility of a dedicated supply from power supplier or 2) develop standby generator capacity either through diesel or solar power.

Drought risk to local services

The baseline drought risk for the area has been characterised as mild and future climate trends indicate that the area is likely to receive on average more rainfall than it does at the moment so drought is not considered a major risk. However, projected temperature increases along with increased rainfall variability are likely to increase evapotranspiration which could cancel the possible benefits of increased precipitation.

The single source project will provide resilience to drought events due to reliability of supply particularly in terms of ease of maintenance and concertation of resources on resilience issues. Also, and the Mkunya springs project will improve water supply, sanitation and hygiene conditions and enhance resilience in the nearby villages that at the moment receive no water.

The following no/low regret measures are proposed:

Recommendations:

- Drought conditions monitoring to be included in the project's monitoring plan
- Education and water purification supplies to treat water on rainwater harvesting pits to be considered.
- It is expected that in the event of increases drought more and more people will build rainwater harvesting pits particularly in the absence of project. Investigate possibility of rainwater harvestings pits presenting increased malaria hazards (due to possible breeding ground of mosquitos). If this is the case the project itself can serve as a risk mitigating measure against increase in malaria.
- Education programmes run by community development officers and delivered through schools and local committees are proposed to raise importance of WASH issues.

Erosion risk

The area faces significant erosion issues. Unearthed and exposed pipelines of the existing water network is a common sighting. This presents serious risk of damage of network due to natural phenomena or vandalism. (**Figure 21**)

Figure 21 **Erosion in the project area**

Recommendations:

- Project pipelines to be buried in sufficient depth (>800mm) to protect from erosion related hazards. In areas where topography requires pipes to be over ground, steel pipes to be used to protect from erosion and wildfires.
- For Mkunya springs it is proposed that a fence is installed in sufficient distance from the springs to allow for vegetation to protect the weir from erosion.

Institutional risks

In addition to the physical risks there is a set of softer, institutional and governance risks to the project that were identified. Climate change is likely to increase pressures more widely on society and government, thereby increasing institutional risk. The weak institutional capacity of managing agencies and authorities for implementation and management, can become a bottleneck for the long term sustainability of the project. This can inappropriately limit funds available for operations, maintenance and repairs. On the other hand, having the capacity and systems in place to identify and respond to disruptions can lessen their duration and severity.

Recommendations:

- Establishment of well managed water users' associations to govern local water systems such as the proposed COWSOs.
- Clear systems and plans in place on how COSWOs will operate and will be governed.

Risk Scoring

The results from the risk assessment along with the risk scenarios for the project and local community and adaptation measures for ‘high’ and ‘extreme’ risks and estimated residual risk for each is presented in **Table 3.** The likelihood and consequence for each identified risk was scored both for existing risk (i.e. now) using historical information and the LCLIP and for future risk (project lifecycle horizon) by taking into account the climate trends that were described in the previous section. Combinations of different levels of likelihood and consequences have resulted in varying levels of risk. For definitions and examples of levels of likelihoods and consequences along with the full risk methodology and matrix please refer to the CCRA protocol. The assumptions and rationale for risk scoring the Makonde project and the full results of the process can be found in the CCRA tool completed for Makonde that accompanies this report.

Table 3 **Events, hazards and impact scenarios for Makonde project and area**

No.	Event	Hazard and impact scenario	Current risk	Future risk	Adaptation measures	Residual risk
1	Flooding	Heavy flooding causes damage to Mitema well field pumps and system is down for 2 weeks	Low	Moderate	Install cut-off drains to intercept water runoff from up slope for pumps 1, 2 and 3 in Mitema Wellfields. Raise plinths around pumps in Mitema boreholes to at least 200mm to protect from flooding.	Moderate (however measures reduce consequence of future risk from moderate to minor)
2	Changes in rainfall patterns	Rainfall is increasingly variable resulting in difficulties in collecting rainwater for home uses	Low	Moderate	Makonde project will ensure reliable water supplies and reduce reliance and need on rain harvesting	Moderate (however measures reduce consequence of future risk from moderate to minor)
3	Soil	Heavy rainfall and flooding causes	High	Extreme	Pipes to be buried in sufficient depth (>800mm) to	Moderate

	erosion	erosion, unearths and damages PVC pipe infrastructure			protect from hazard and be careful where pipe crosses to provide erosion protection. Where that is not practical steel pipes to be used	
4	Fires	Drought and increased temperatures cause fires in the project area and result in damaging PVC water pipe infrastructure and/or spring source	Moderate	Moderate	Pipes to be buried in sufficient depth (>800mm) to protect from hazard and where they need to be overground to use steel pipes	Moderate
5	Flooding	Heavy rainfall / flooding damages water supply sources Mkunya and results in water supply interruptions in the area	High	High	Moving from multi-source to single-source will partially mitigate system risks. For Mkunya springs it is proposed that a fence is installed in sufficient distance from the springs to allow for vegetation to protect weir from erosion.	Moderate
6	Drought	Recurrent drought and unreliability of rainfall in the area increases use of water from contaminated sources e.g. rivers and rainwater harvesting pits. This results in 50% more incidents of water related diseases in local population such as malaria, diarrhoea, bilharzia, hookworms and dysentery	Moderate	High	Single source project will provide resilience to drought events due to reliability of supply and Mkunya springs project will improve health situation at the nearby villages that at the moment receive no water. It is also proposed that education and water purification supplies to treat water on rainwater harvesting pits are considered. Also education programmes run by community development officers and delivered through schools and local committees are proposed to raise importance of WASH issues.	Moderate
7	Heavy	Heavy rain causes damages of basic	Moderate	High	Install cut-off drain to intercept surface water Training	Moderate

	rain	latrines. Flooding also distributes human excreta and poses health risk to the community. Contamination of groundwater source and soil, potentially reaching drinking-water sources like shallow wells.			to be given to artisans for construction of proper sited VIP latrines. Community sensitisation - education on risks using water from shallow wells eg. health risks due to contaminated water through local teachers - school health club.	
8	Flooding	Intense rainfall causes drinking-water supply from shallow wells to flood and be out of commission for a few months until repair.	Low	Low	Project will provide resilience and help to move away people from relying on shallow wells	Low
9	Drought	Drought due to reduced precipitation and increased temperatures result in reduced surface water flows and falling groundwater tables and lead to an unsustainable use of the Mitema wellfields	Moderate	High	Put in place robust monitoring programme in place for Mitema wellfields and downstream water bodies as lake Kitere, adjacent wetlands and Mambi river. Install sensor in unused borehole to monitor water levels at Mitema. Look further at temperature impacts to groundwater recharge	Moderate
10	Heavy rain	Increased rainfall causes groundwater levels to rise and reaching pit latrines once every 10 years. Contamination of groundwater and soil, potentially reaching drinking-water sources.	Low	Moderate	Appropriate siting for future VIP latrines to avoid groundwater horizons. Training to be given to artisans for construction of latrines. Education on risks using water from shallow wells eg. health risks due to contaminated water through local teachers. Also project will reduce dependency of people for water supply from local wells	Moderate
11	Heavy	Damages to energy infrastructure -	Moderate	High	Provisions in the immediate measures programme of	Moderate

	rain	especially falling power cables - cause power interruptions to electric pumps and increasing the unreliability of system and results in 2 days downtime			works to look into the power interruptions issue and investigate 2 options: 1) The possibility of a dedicated supply from power supplier or 2) develop standby generator capacity either through diesel or solar power.	
12	Changes in rainfall patterns	Changes in rainfall patterns cause frequent failure of rainfed agriculture in the area and local farmers break into pipelines to access water for irrigation resulting in system losses of 20%	Moderate	Moderate	Bury pipelines in adequate depth to make them hard to reach and create teams to patrol and police the pipelines	Moderate
13	Changes in rainfall patterns	Changes in rainfall patterns cause frequent failure of rainfed agriculture in the area and local subsistence farmers deforest the area for timber or charcoal with biodiversity and environmental impacts as well as impacting the water sources.	Moderate	Moderate	Education on the value of forests in the area and the damage they are doing when deforestation occurs and encourage sustainable forest management practices and replanting.	Moderate
14	Changes in rainfall patterns	Changes in rainfall patterns, overall rainfall and temperature increases cause decrease in cashew nut tree yields and reduction of local income. This in turn influences locals' willingness to pay for water services and creates commercial risks to the project	Moderate	High	• Establishment of well managed water users' associations to govern local water systems such as the proposed COWSOs. Clear systems and plans in place on how COSWOs will operate and will be governed. • Policies that make financial credit, loans, and crop and livestock insurance available to farmers, increasing their ability to cope with natural disasters	Moderate

					and pay for water. • Strong legal enforcement of water pricing policies can support monitoring water use and associated fees, thereby increasing revenues for maintenance and upgrades.	
15	Changes in rainfall patterns	Changes in rainfall patterns cause frequent failure of rainfed agriculture in the Mkunya springs area and local farmers move closer to the springs to use water for irrigation	Moderate	Moderate	Environmental protection of the Mkunya springs through education and clear demarcation will further mitigate this risk	Moderate
16	Drought	Drought due to reduced precipitation, increased temperature results in reduced surface water flow and falling groundwater tables and lead to an unsustainable use of the Mkunya springs	Moderate	Moderate	No action needed	Moderate
17	Changes in rainfall patterns	Changes in rainfall patterns cause frequent failure of rainfed agriculture and local farmers move in the Mitema wellfield area for irrigation	High	High	It is essential to protect the water sources, by banning activities that might contaminate the groundwater. Environmental protection of the Mitema wellfield through education and clear demarcation will further mitigate this risk	Moderate

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Appendix A: Groundwater recharge review

The following high level analysis was conducted by Jonathan Barnes for the purposes of this CCRA.

Current Situation with Future Demand Projections

The Water Resources Assessment (GFA, 2013) carried out pumping tests within the Mitema well field.

The results showed that at Mitema assuming an average annual precipitation of 922mm, the groundwater recharge was 120 mm/year which corresponds to on average 65,698,000 m3 groundwater recharge.

The Water Resources Assessment report (GFA, 2013) found that “Currently, the Mitema aquifer has the possibility to discharge up to 17,826 m3/d if all six wells are operated in 24 hours (chapter 5-1). This amount of 17,826 m3/d (6,506,000 m3/year) is approximately equal to 10% of the recharge and is within a reasonably conservative sustainable yield based on the concept of Ponce (2007). Therefore for the proposed water demand for the year 2030 in Makonde water supply system of 27,000 m3/d (i.e. 9,855,000 m3/year) there is about 15% of which is still below the average sustainable yield of 40%.”

Since in the future the abstractions will be greater than 10% of the reasonably conservative yield the report also states a monitoring programme should be setup as follows:

“However, it is important to note that the yield beyond 10% of recharge will bring some effects to surface water bodies like wetlands, springs and streams which have a direct connection with the aquifer. A functional ecosystem is critical for maintaining groundwater quantity and quality. Wetlands intercept precipitation and overland flowing water. These natural systems act as filtering agents, removing pollutants and sediment from water as it infiltrates to the groundwater. Recharge can occur as a steadier pace, minimizing variability in groundwater availability. Therefore, a monitoring programme for surface water and groundwater should be designed and operated in an integrated way for yield beyond 10% of recharge. The monitoring programme is very important in Mitema well field since hydrogeologically it is connected with the coastal aquifers. Hence, over-extraction of the Mitema aquifer will directly affect the water supply in the coast area.”

Future Projection with 29% Reduction in Rainfall

Assuming the scenario of climate change rainfall reductions in the future of 29%, this corresponds to an annual average groundwater recharge of 55mm (GFA, 2013) reference Figure 52. Therefore the average Mitema groundwater recharge would be 30,022,000 m3. Assuming the average demand of 27,000 m3/d (i.e. 9,855,000 m3/year) this corresponds to an abstraction of 33% of the overall annual average recharge which is still below the average sustainable yield of 40%.”

Again since the yield beyond 10% of recharge a monitoring programme will need to be included as explained above.

Approach to Sustainable Groundwater Yield

An important aspect is to determine how much water should be extracted per year to enable the long term sustainable yield at Mitema. The Water Resources Assessment (GFA, 2013), which references Ponce 2007, assumes the following:

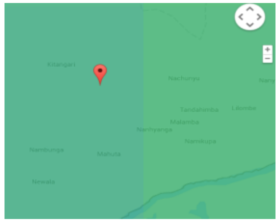
"Sustainable yield can also be expressed as a percentage of recharge. Globally, if recharge can be assumed to be approximately 20% of precipitation, then deep percolation would be about 10% of recharge. Thus, a reasonably conservative estimate of sustainable yield would be 10% of recharge. Limited experience indicates that average values of this percentage may be around 40%, while less conservative percentages may exceed 70% (Miles and Chambet, 1995; Hahn et al., 1997). The current concept of sustainable yield represents a compromise between theory and practice. In theory, a reasonably conservative estimate of sustainable yield would be about 10% of recharge. In practice, values higher than 10% may reflect the need to consider other factors besides conservation." (Ponce 2007).

Sustainable groundwater yield can also be defined as "The groundwater extraction regime, measured over a specified planning timeframe that allows acceptable levels of stress and protects dependent economic, social, and environmental values."

From Villier (2011) "The challenge that Hydrogeologists face in determining the sustainable yield for boreholes has led to the adoption of risk averse approaches in recommending borehole yields in fractured aquifers. A popular method to determine groundwater sustainability is the groundwater balance (also known as the groundwater budget) method. This method has come under scrutiny as it is proposed that capture is a more conservative and technically correct approach. Where the groundwater balance approach typically makes use of an assumed recharge rate over an aquifer surface area to determine a volume, the capture method relies on the aquifer parameters and boundaries as well as pumping time to determine a "sustainable" borehole yield. Two of the most important parameters in determining long-term borehole yield namely, recharge and storativity are unknown and unknowable at the time of well field development. At best, qualified guesses can be made with regard to these two parameters. In this paper, it was shown that the risk averse approach in determining borehole yield will result in the most expensive groundwater development option. The principle of sustainability requires that environmental, social and economic considerations be taken into account. By following a risk averse approach, which would be the most expensive, the principle of sustainability is violated and it cannot be claimed that the borehole yield is "sustainable". Due to the exponential relationship between risk and cost, a no risk approach would be infinitely expensive. It was shown that due to the uncertainties, it is actually impossible to determine the sustainable yield of a borehole. The objective should rather be to develop a sustainable groundwater management plan. This can be achieved by following a systems management approach based on the minimum groundwater balance approach."

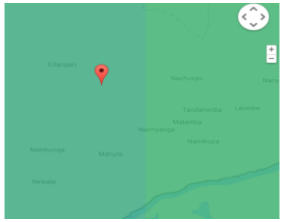
Appendix B: Climate Projections

Variable	**Rainfall (mm)**
Location	**(-10.7,39.4)**
Time Period	**2040 - 2059**
Statistic	**Mean**
Scenario	**RCP8.5**



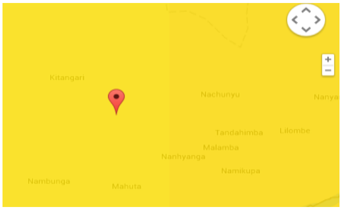
Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**	**Average**	**Difference**
bcc_csm1_1	135	119	125	135	62	26	21	18	18	35	86	151	930	77	-2%
bcc_csm1_1_m	203	158	181	181	79	45	24	20	23	40	102	232	1287	107	36%
ccsm4	340	202	188	195	85	40	48	38	33	42	72	157	1441	120	52%
cesm1_cam5	221	166	133	165	90	27	20	17	16	29	80	167	1130	94	19%
csiro_mk3_6_0	212	179	230	62	6	2	0	0	0	0	27	224	942	78	0%
fio_esm	77	125	181	212	112	47	36	26	15	16	20	36	904	75	-4%
gfdl_cm3	171	163	165	145	79	32	23	16	9	10	42	173	1029	86	9%
gfdl_esm2m	206	158	160	192	102	48	50	47	30	15	39	147	1194	100	26%
giss_e2_h	315	295	398	372	214	82	41	35	56	125	197	375	2505	209	165%
giss_e2_r	311	277	265	315	165	67	45	31	38	88	183	233	2019	168	113%
ipsl_cm5a_mr	179	237	230	87	49	21	19	11	10	7	17	73	941	78	0%
miroc_esm	130	150	148	105	50	26	23	11	8	7	15	63	737	61	-22%
miroc_esm_chem	100	138	150	102	37	30	23	11	5	5	6	88	695	58	-27%
miroc5	144	126	135	152	61	41	39	13	10	11	211	77	1021	85	8%
mri_cgcm3	110	115	157	122	31	20	4	4	5	37	132	165	902	75	-5%
noresm1_m	128	209	202	203	111	51	45	37	24	18	21	58	1105	92	17%

Variable	**Rainfall (mm)**
Location	**(-10.7,39.4)**
Time Period	**2040 - 2059**
Statistic	**Mean**
Scenario	**RCP4.5**



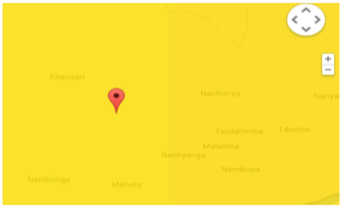
Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**	**Average**	**Change**
bcc_csm1_1	136	111	132	117	52	29	26	18	18	28	122	169	957	80	1%
bcc_csm1_1_m	216	168	182	177	85	31	24	24	23	43	131	245	1349	112	43%
ccsm4	292	275	182	148	85	44	45	37	32	38	86	167	1431	119	51%
cesm1_cam5	200	145	140	161	75	24	23	19	14	28	83	193	1105	92	17%
csiro_mk3_6_0	226	139	191	77	5	2	1	0	0	0	35	247	924	77	-2%
fio_esm	71	124	221	212	149	44	39	27	17	15	21	51	991	83	5%
gfdl_cm3	190	148	200	145	77	28	24	16	10	12	67	171	1087	91	15%
gfdl_esm2m	195	150	161	201	114	54	59	49	25	18	44	155	1226	102	30%
giss_e2_h	365	297	345	317	259	71	43	42	68	144	267	340	2558	213	170%
giss_e2_r	296	287	332	340	217	101	46	33	38	100	185	245	2218	185	134%
ipsl_cm5a_mr	177	277	226	96	38	15	11	15	7	7	14	72	955	80	1%
miroc_esm	102	139	153	85	42	27	24	9	6	6	12	63	669	56	-29%
miroc_esm_chem	142	173	158	103	42	31	22	12	7	5	20	46	759	63	-20%
miroc5	124	120	156	144	60	33	24	15	9	10	19	45	758	63	-20%
mri_cgcm3	91	103	148	91	56	18	5	6	5	29	140	141	832	69	-12%
noresm1_m	118	138	169	164	107	59	44	35	17	19	23	52	944	79	0%

Variable Temperature (C)
Location (-10.7,39.4)
Time Period 2040 - 2059
Statistic Mean
Scenario RCP8.5



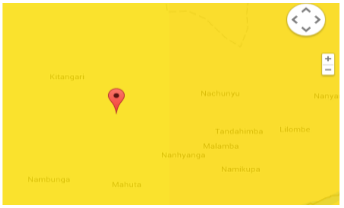
Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
bcc_csm1_1	28.3	28.4	28.3	28.1	26.8	25.5	24.5	24.7	25.8	27.1	28.4	28.6	27.0
bcc_csm1_1_m	27.9	27.9	28.3	27.9	26.7	25.4	25.1	25.8	27.0	28.3	28.7	28.6	27.3
ccsm4	26.8	26.9	27.1	26.5	25.1	23.4	22.5	22.7	24.2	26.0	27.3	27.5	25.5
cesm1_cam5	26.4	26.7	27.1	26.5	25.3	23.7	22.9	23.9	25.9	27.6	27.3	26.8	25.8
csiro_mk3_6_0	28.5	28.6	28.7	28.6	27.9	26.6	25.8	26.0	26.7	28.0	29.8	29.0	27.8
fio_esm	28.2	27.7	27.3	26.3	24.8	23.4	22.6	23.0	24.6	26.4	27.9	28.6	25.9
gfdl_cm3	27.5	26.9	26.9	26.5	25.9	24.9	24.8	25.3	26.3	27.4	28.8	28.4	26.6
gfdl_esm2m	25.8	25.7	25.7	25.0	23.2	21.5	21.1	21.9	23.1	25.3	26.8	27.3	24.4
giss_e2_h	25.8	26.0	25.8	25.3	24.4	23.5	23.0	23.4	24.0	24.4	24.9	25.0	24.6
giss_e2_r	26.0	26.2	26.5	25.6	24.6	23.7	23.1	23.6	24.5	25.1	25.4	25.7	25.0
ipsl_cm5a_mr	29.0	28.3	28.3	28.1	26.6	24.6	23.9	24.3	25.9	27.7	29.3	29.7	27.1
miroc_esm	28.1	27.6	27.0	25.9	24.6	23.2	22.5	23.5	25.2	27.2	28.6	29.0	26.0
miroc_esm_chem	28.6	28.0	27.3	26.1	25.1	23.3	22.8	23.7	25.6	27.6	29.1	28.9	26.3
miroc5	28.2	28.3	27.8	27.0	26.8	25.7	25.2	25.8	26.3	27.0	27.8	28.6	27.0
mri_cgcm3	27.2	27.2	27.2	26.8	25.8	24.1	24.3	25.1	26.7	27.8	27.7	27.1	26.4
noresm1_m	27.5	27.1	27.2	26.3	25.1	23.6	22.6	23.0	24.0	25.7	27.0	27.5	25.5

Variable	**Temperature (C)**
Location	**(-10.7,39.4)**
Time Period	**2040 - 2059**
Statistic	**Mean**
Scenario	**RCP4.5**



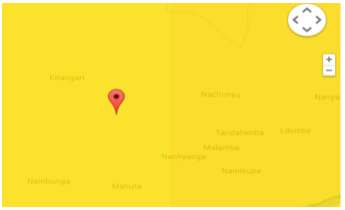
Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
bcc_csm1_1	28.1	28.0	28.1	27.9	26.4	25.0	24.1	24.4	25.3	26.7	27.9	28.0	26.7
bcc_csm1_1_m	27.5	27.5	27.9	27.5	26.2	25.0	24.5	25.2	26.5	27.6	28.2	28.0	26.8
ccsm4	26.2	26.2	26.4	25.9	24.4	22.6	21.7	22.0	23.2	25.1	26.3	26.6	24.7
cesm1_cam5	25.9	26.1	26.5	25.9	24.7	23.1	22.5	23.2	25.0	27.1	27.0	26.1	25.3
csiro_mk3_6_0	28.0	28.5	28.6	28.4	27.7	26.4	25.6	25.7	26.4	27.6	29.4	28.9	27.6
fio_esm	27.7	27.3	26.8	25.9	24.3	22.7	22.0	22.4	23.9	26.0	27.4	27.8	25.3
gfdl_cm3	26.4	26.4	26.4	26.1	25.7	24.8	24.8	25.5	26.3	27.5	28.5	27.8	26.4
gfdl_esm2m	25.2	24.8	25.1	24.6	22.9	21.0	20.5	21.0	23.0	25.1	26.7	26.7	23.9
giss_e2_h	25.1	25.6	25.6	25.1	24.1	23.3	22.7	23.1	23.5	24.0	24.3	24.8	24.3
giss_e2_r	25.6	26.0	26.0	25.2	24.2	23.1	22.6	23.2	24.0	24.6	24.9	25.4	24.5
ipsl_cm5a_mr	28.0	27.5	27.6	27.4	26.0	24.0	23.3	23.9	25.4	27.2	28.8	28.9	26.5
miroc_esm	28.9	28.1	26.9	26.2	24.7	23.2	22.5	23.6	25.5	27.2	28.6	29.0	26.2
miroc_esm_chem	28.2	27.3	26.5	25.6	24.6	22.9	22.5	23.5	25.4	27.3	28.4	29.1	25.9
miroc5	28.2	27.9	27.3	26.5	26.4	25.5	25.1	25.5	26.1	26.8	27.5	28.3	26.8
mri_cgcm3	26.9	27.2	27.1	26.5	25.3	23.8	24.0	24.8	26.3	27.4	27.3	26.9	26.1
noresm1_m	27.3	27.1	27.0	26.4	25.0	23.5	22.6	22.8	24.1	25.7	26.7	27.2	25.4

Variable	**Temperature (C)**
Location	**(-10.7,39.4)**
Time Period	**2040 - 2059**
Statistic	**Change (anomaly)**
Scenario	**RCP8.5**



Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
bcc_csm1_1	1.6	1.5	1.4	1.5	1.3	1.4	1.5	1.4	1.5	1.3	1.7	1.6	1.5
bcc_csm1_1_m	1.8	1.7	1.6	1.6	1.8	1.6	1.6	1.9	1.7	1.8	1.6	1.5	1.7
ccsm4	1.5	1.6	1.7	1.7	1.7	1.9	1.8	1.7	1.8	1.8	1.8	2.0	1.8
cesm1_cam5	1.7	1.8	1.8	1.8	1.8	2.1	1.9	1.9	2.0	2.2	1.7	1.6	1.9
csiro_mk3_6_0	2.0	1.9	1.9	1.8	1.9	2.0	1.8	1.7	1.8	1.9	2.3	1.8	1.9
fio_esm	1.6	1.6	1.5	1.5	1.4	1.7	1.6	1.7	1.8	1.6	1.7	1.6	1.6
gfdl_cm3	3.1	2.3	1.9	2.1	2.5	2.1	1.9	1.7	1.9	1.6	2.0	3.0	2.2
gfdl_esm2m	1.5	1.5	1.6	1.7	1.6	1.8	1.5	1.3	1.0	1.5	1.1	1.8	1.5
giss_e2_h	1.7	1.2	1.2	1.4	1.6	1.7	1.4	1.6	1.6	1.6	1.6	1.2	1.5
giss_e2_r	1.5	1.4	1.6	1.4	1.5	1.6	1.4	1.5	1.5	1.6	1.8	1.5	1.5
ipsl_cm5a_mr	2.6	2.2	2.2	2.3	2.3	2.3	2.2	1.8	2.1	2.1	2.1	2.6	2.2
miroc_esm	0.8	1.0	1.1	0.8	0.7	0.9	1.0	1.2	1.3	1.6	1.6	2.0	1.2
miroc_esm_chem	1.8	1.4	1.5	1.3	1.6	1.6	1.6	1.2	1.7	1.9	1.9	1.8	1.6
miroc5	1.3	1.6	1.4	1.6	1.7	1.4	1.3	1.5	1.4	1.4	1.6	1.7	1.5
mri_cgcm3	1.3	1.5	1.4	1.6	1.7	1.7	2.0	1.7	1.6	1.2	1.6	1.4	1.6
noresm1_m	1.4	1.3	1.3	1.0	1.3	1.3	1.2	1.4	1.3	1.3	1.3	1.4	1.3

Variable	**Temperature (C)**
Location	**(-10.7,39.4)**
Time Period	**2040 - 2059**
Statistic	**Change (anomaly)**
Scenario	**RCP4.5**



Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
bcc_csm1_1	1.3	1.0	1.2	1.3	0.9	0.9	1.2	1.1	1.1	0.9	1.2	1.1	1.1
bcc_csm1_1_m	1.3	1.2	1.2	1.2	1.3	1.2	1.1	1.3	1.1	1.1	1.1	1.0	1.2
ccsm4	1.0	0.9	1.0	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.8	1.2	1.0
cesm1_cam5	1.2	1.3	1.2	1.2	1.3	1.4	1.5	1.3	1.1	1.8	1.4	0.9	1.3
csiro_mk3_6_0	1.6	1.8	1.7	1.6	1.6	1.8	1.6	1.5	1.5	1.5	1.9	1.7	1.6
fio_esm	1.1	1.2	1.0	1.0	0.9	1.0	1.0	1.1	1.1	1.2	1.2	0.9	1.0
gfdl_cm3	2.1	1.9	1.4	1.6	2.3	2.1	2.0	1.8	1.9	1.7	1.7	2.5	1.9
gfdl_esm2m	0.9	0.7	0.9	1.3	1.3	1.3	0.9	0.4	0.9	1.3	1.1	1.1	1.0
giss_e2_h	1.0	0.9	1.0	1.2	1.3	1.5	1.1	1.3	1.1	1.2	1.1	1.0	1.1
giss_e2_r	1.1	1.3	1.1	1.0	1.1	1.0	0.8	1.0	1.0	1.1	1.3	1.2	1.1
ipsl_cm5a_mr	1.6	1.4	1.5	1.7	1.7	1.7	1.6	1.4	1.6	1.5	1.6	1.8	1.6
miroc_esm	1.5	1.5	1.0	1.1	0.8	0.9	0.9	1.4	1.6	1.5	1.6	2.0	1.3
miroc_esm_chem	1.3	0.7	0.8	0.8	1.1	1.2	1.4	1.1	1.4	1.6	1.2	2.0	1.2
miroc5	1.2	1.3	1.0	1.1	1.3	1.2	1.2	1.2	1.2	1.1	1.3	1.5	1.2

mri_cgcm3	1.0	1.5	1.3	1.3	1.2	1.4	1.7	1.3	1.2	0.9	1.3	1.2	1.3
noresm1_m	1.2	1.2	1.1	1.1	1.1	1.2	1.2	1.2	1.5	1.4	1.1	1.1	1.2

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