Mainstreaming Climate Adaptation in Mozambican Urban Water, Sanitation, and Drainage Sector

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Abstract

The Capacity Development Programme (CDP) is an agreement between the Government of Mozambique and the Nordic Development Fund, to tackle climate variability by planning and the sustainable operations and maintenance of sanitation and drainage infrastructure. The Mozambican Administration of

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Water and Sanitation Infrastructure (AIAS) is the agency responsible for this project. The international consortium in charge of developing the CDP provided consultancy services to AIAS and the vulnerable cities of Beira and Matola. The assignment included not only capacity building but also institutional strengthening activities, as well as specific studies, mainly based on climate modelling (dynamic downscaling) and mapping exercises. Important results and conclusions were achieved, and further adaptation strategies to increase the resilience of the Mozambican urban water, sanitation, and drainage sector were proposed.

Keywords

Adaptation · Urban water · Sanitation and drainage · Mozambique · Climate modelling · Adaptation options

Introduction

Mozambique is one of the top three among African countries most exposed to multiple weather-related hazards (GFDRR 2016). The country is located downstream of nine major international river basins, with extensive areas classified as arid or semiarid, and stretches of coastline on the path of tropical systems formed in the Indian Ocean. Vulnerable population, services, and assets are regularly exposed to floods and droughts, often severely. The devastating effects of Idai and Kenneth, the two intense tropical cyclones that in March and April 2019 struck central and northern provinces, will remain for a long time. According to the assessments published by the Government of Mozambique (GoM), a total of 2.8 million people were affected (GoM 2019a), with recovery and reconstruction works estimated at a total of US$ 3.2 billion (GoM 2019b). Before these events, the country was already facing high levels of food insecurity. Between September and December 2018, 1.78 million people suffered severe food insecurity in the country (GoM 2019b). Although the provinces most affected by these events tend to show higher levels of poverty compared to those least affected (Baez et al. 2018), natural disasters may challenge development of Mozambique as a whole.

Climate variability is already modifying the regional patterns of those extreme events. During the period 1960–2005, significant positive trends in temperature change were observed across most of the country and in all four seasons (INGC 2009). Rainy seasons commenced later, and dry spells lasted longer. As a result, over the past decades, the country has experienced increased droughts, flooding, and storms.

Climate scenarios vary across models depending on assumptions; however, most climate models suggest increases in mean annual temperatures, extended dry periods, more intense storms, and sea level rise (USAID 2012). As a result of climate change, the exposure to natural disaster risk in Mozambique will increase significantly over the coming 20 years and beyond (INGC 2009). Unless adaptations strategies are implemented, relative to baseline growth in 2003, gross domestic product could fall between 4% and 14% in the period 2040–2050 (WB 2010).

Moreover, given that Mozambique is such a poor country, under a "business as usual" scenario, climate change will impact even greater on the economy, driving the majority of the poor people into further poverty (Irish Aid 2018). There is a need to design effective mechanisms to address the risks and disasters associated with climate change by introducing inclusive and climate-resilient economic models that could increase income and generate social cohesion.

Climate change adaptation is being tackled by the GoM through different ongoing policies. As a "Least Developed Country" in the United Nations Framework Convention on Climate Change (UNFCCC), Mozambique published a National Adaptation Programme of Action (NAPA) in 2007. The NAPA outlined four specific actions, which aim to reduce the negative impacts of extreme hydrometeorological events through adaptation initiatives. Two of the program's prioritized strategies are reducing the impact on coastal zones and improving the management of water resources against climate change (MICOA 2007).

In 2012, the National Climate Change Strategy (NCCS) 2013–2025 was launched. Under the adaptation pillar of the strategy, several areas for intervention and consequent actions were identified. In terms of water resources, the strategy proposes, among other recommendations, improving rainwater drainage and sanitation systems (GoM 2012).

Mozambique ratified the Paris Agreement in 2017, and the country is defining the specific action for different goals proposed in the Intended Nationally Determined Contribution (INDC) submitted to UNFCCC in 2015 (MITADER 2015). The INDC reinforces NCCS objectives, to be implemented between 2020 and 2030. The first NDC is currently under development.

In addition, the National Disaster Risk Reduction Master Plan 2017–2030 is well-aligned with the adaptation priorities of the NCCS. The plan's main objective is to improve the resilience for population, livelihoods, health, and infrastructures, through an established culture of prevention, preparedness, response, and recovery (GoM 2017).

To carry out these climate policies, the GoM is drawing on both national resources and external aid. The country has attracted strong donor support for reconstruction and development over the last two decades and continues to obtain high volumes of international cooperation (Irish Aid 2018).

In this sense, the Cities and Climate Change Project (CCCP), developed in recent years with the aid of the World Bank, is one of the most important international cooperation initiatives undertaken in the country. The objectives of the CCCP include reducing disaster risks in urban areas and vulnerability associated with the impact of climate related. The project was approved in 2012 and finalized in 2019. Key analytical and infrastructure works to achieve the objectives were financed by the Bank. The CCCP had two components. Component 2, specifically aimed at increasing resilience in the cities of Maputo and Beira, was implemented by the Administration of Water and Sanitation Infrastructure (AIAS). AIAS was created in 2009, under the authority of the Ministry of Public Works and Housing, to manage urban water and sanitation investments, including drainage in small- and medium-sized cities.

In terms of the agreed priority actions and building on synergies within Component 2 of the CCCP, the Nordic Development Fund (NDF) approved parallel co-financing of this World Bank project. The Grant Agreement between NDF and the GoM was signed at the end of 2012 (NDF 2015). The NDF support, called "Capacity Development Programme (CDP)," was aimed at enabling AIAS (the national counterpart) and the municipal autonomous water and sanitation services of two selected cities (Beira and Matola), within their mandate, to act on climate variability.

The international consortium comprising of IDOM (leader), Nordic Consulting Group, Meteosim, and COBA was in charge of implementing the CDP. This 26-month technical assistance (September 2017–December 2019) project greatly benefited AIAS and other relevant stakeholders.

This paper summarizes the activities and results of the Capacity Development Programme (CDP).

Institutional Strengthening

Resilience must be understood at country level involving all institutions and agencies together, in which stakeholders, decision-makers, officials, and other relevant stakeholders should understand the concept and how to put it into practice along with their specific tasks. This is the case in Mozambique, where an articulated vision of adaptation, disaster risk management, and resilience is still a challenge for national institutions (UNDP 2019).

The CDP has contributed to narrowing these gaps, with the completion of important activities.

In the first stage, a complete stakeholder mapping exercise was carried out (summarized in Table 1), including an assessment of the existing institutional influence on the decision-making processes in relation to resilience. It should be noted that a number of national agencies participate in the management of water cycle.

To develop skills in relation to resilience in AIAS, the institution needed access to available data and information on climate variability as well as coordination and cooperation with key institutions involved in climate change adaptation. The CDP facilitated inter-institutional linkages. Collaboration agreements were signed with the Ministry of Environment (MITADER), INGC, INAM, and INAHINA.

The two components or products specifically developed to improve AIAS managerial activities were an institutional website (www.aias.gov.mz) and a decision support system (DSS) based on a geographic information system (GIS) (Fig. 1). The new website serves as a platform to effectively publish the activities of the institution. The website also features internal management utilities, such as the possibility of remote access to information networks (intranet) and projects or shared resources. In terms of the GIS-DSS application developed, as a first step, the geo-referenced infrastructure database managed by AIAS was included and adapted. Following this, an analysis module of the vulnerability of receptors (population and assets) sensitive

Table 1 Key actors involved in water, sanitation, and hygiene (WASH) sector resilience (acronyms in Portuguese)

Institution/agency	Role/duties	Influence
National Directorate for Water Resources Management (DNGRH)	Water resources policies, regulations, and infrastructures	Medium
National Directorate for Water Supply and Sanitation (DNAAS)	Water supply, sanitation and drainage policies, regulations, and infrastructures in rural settlements	High
Water-Supply Asset Holding and Investment Fund (FIPAG)	Management of public investments in water systems for major urban areas	Medium
Administration of Water and Sanitation Infrastructure (AIAS)	Development of water and sanitation and drainage infrastructure in attributed secondary towns outside the FIPAG remit	High
Water Regulatory Authority (AURA, former CRA)	Urban water regulatory agency (tariffs approval, quality of service compliance)	Medium
Regional Water Administrations (ARAs)	There are four of them covering the country area (South, North, Center, Zambezi), assuming decentralized duties	Medium
Private agents	Contractors in public infrastructures and water systems for some urban areas	Low
Ministry of Health	Water supply quality standards	Low
National Directorate of Environment	Climate change policies. Focal point to UNFCCC	Very high
Natural Institute of Disaster Management (INGC)	Coordination of DRM policies and activities. Promote development in arid zones	Very high
National Institute of Meteorology (INAM)	Weather forecasts and seasonal outlooks. Alerts. Meteorological data register and exploitation	Medium
National Institute of Hydrography and Navigation (INAHINA)	Oceanography (marine weather), coastal protection, and navigation support	Low
Cities	Urban sanitation. Rural and urban water and sanitation	Low

Source: Authors, based on WB (2018)

to floods and droughts was designed. This tool also integrates geographic information provided by other institutional sources and a historical record of extreme events. The vulnerability module allows the different factors that determine the sensitivity and adaptive capacity of considered receptors to be classified/categorized. The DSS was designed using open-source GIS software. The objective of this tool was to provide support to AIAS in prioritizing new water and sanitation projects as well as operational and maintenance tasks, taking into account the climate risk component. Both products (website and GIS-DSS) were backed up with manuals on operation procedures.

Beira and Matola were the subjects of specific institutional strengthening activities. Both cities have their own water and sanitation services, which required strategic support in terms of organization and finance. In Beira, the Autonomous

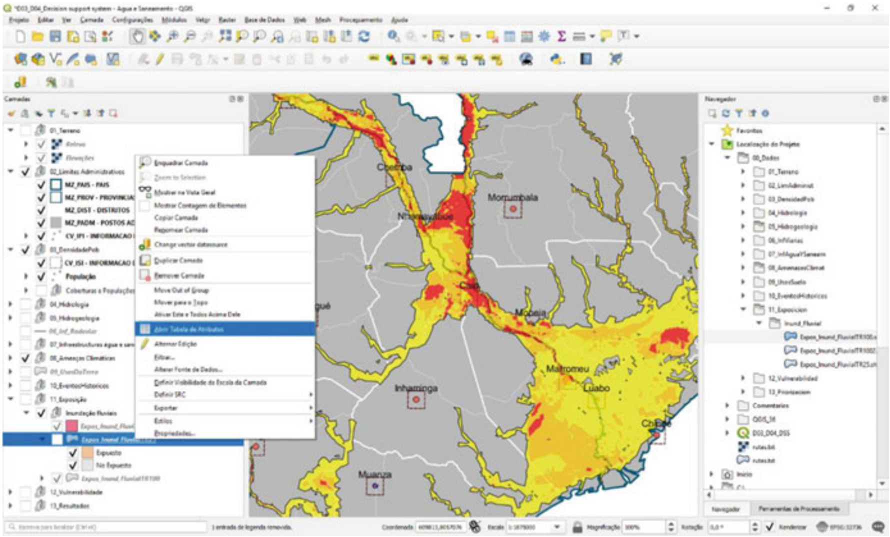


Fig. 1 GIS-based decision support system. (Source: Authors)

Sanitation Service (SASB) was established by the municipality in 2008 and currently has its own staff. The Municipal Water and Sanitation Entity (EMAS) of Matola was constituted in 2016 and is still under development with the objective of fully addressing its agreed responsibilities. An output of the CDP was adjusted business development plans for both SASB and EMAS, including resources and recommendations on diverse key items: rates, investments, resources, organizational chart, financial scenarios, accountability practices, additional sources of finance, or key performance indicators.

Institutional strengthening activities for AIAS, SASB, and EMAS followed a knowledge, attitude, and practice (KAP) approach. Under this methodology, the baseline study provided a good framework for defining capacity building activities and goals. One of the conclusions of the mapping exercise was that from the perspective of capacity development needs, there was limited knowledge among the Mozambican institutions interviewed about climate change phenomenon and its potential consequences. After defining the existing state of the intuitions, the technical needs identified set the basis for the design of a training program which was appropriate for each.

Capacity Building

One of the main targets of the CDP was to achieve the effective transfer of technical skills in relation to climate impact to the AIAS, municipalities, and other key stakeholders dealing with planning and management.

Water is the common denominator of the climate system (atmosphere, hydrosphere, cryosphere, land surface, and biosphere). Therefore, climate change affects

Table 2 Climate impacts on WASH systems

Driver	Associated threat	Potential impacts
Increased intensity of rainfall	Flash flooding	Direct damages/losses to facilities
		Ingress of groundwater into pipe networks, septic tanks, and pit latrines
		Peaks in diarrheal diseases
		Need of modifying design standards in sanitation and drainage infrastructures
	Greater peak runoff	Erosion (direct damages/losses)
		Transport of sediments and contaminants into water bodies and groundwater
Greater rainfall variability	Longer and/or more frequent meteorological droughts	Loss of quantity and quality of resources
		Low soil moisture (agricultural drought)
		Peaks in hygiene diseases
		Loss of efficiency of certain infrastructures (e.g., waste water treatment plants)
	Increased frequency of flooding	See "Flash flooding" above
Longer-term decline in rainfall	Reduction in river flows (hydrological drought)	Loss of capacity of surface water to dilute, attenuate, and remove pollution
		Increased algal growth in surface water and reservoirs
	Alteration of groundwater recharge rates	Loss of quantity and quality of resources
Sea level rise	Saline intrusion	Loss of quantity and quality of resources
	Coastal occupation	Direct damages/losses
	Erosion	Need of additional solutions on coastal protection

Source: Authors, based on Oates et al. (2014) and Charles et al. (2010)

water through a number of mechanisms (Bates et al. 2008) with a growing and significant impact on both the supply and demand of water, sanitation, and hygiene (WASH) delivery systems (Batchelor et al. 2011). These impacts as especially severe in African cities, with direct effects that affect people's health through waterborne diseases, damage to food, loss of income and the deterioration of sanitation, increased exposure to disease, and temporary reduction of access to health-care facilities (ActionAid 2006). Therefore, the WASH sector is highly vulnerable to potential climate effects.

Possible changes affecting WASH systems that could be expected in a changing climate can be grouped into four categories or drivers: (1) increased intensity of rainfall, (2) greater rainfall variability, (3) longer-term decline in rainfall, and (4) sea level rise. Table 2 presents the associated threats and potential impacts for each.

Most of these impacts are present in Mozambique. During the development of the CDP, workshops were held in in Maputo and Beira where these impacts were discussed (Table 5). It is worth noting that transboundary effects were repeatedly mentioned, as the country has to deal with the effects of practices carried out

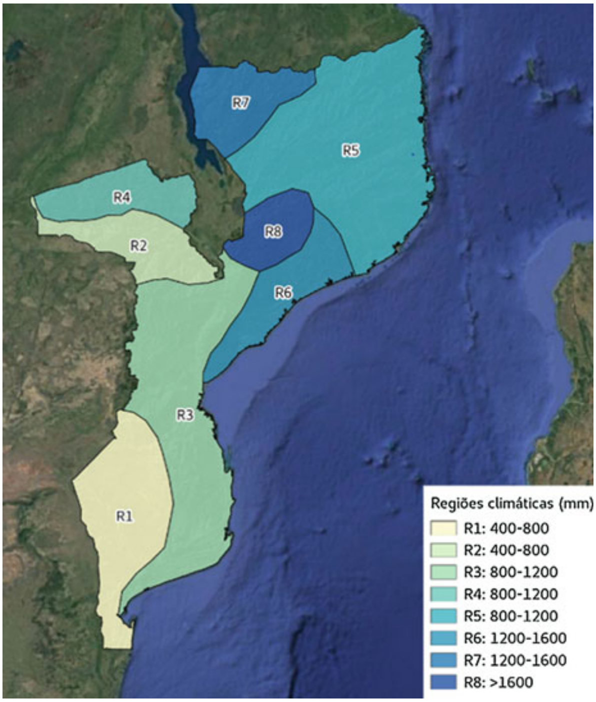


Fig. 2 Representation of climate regions in Mozambique. (Source: Authors)

upstream in the shared basins. When towns and cities experience flooding from major rivers overtopping their banks, flood protection is considered in the context of the entire river basin, and this may include more than one state (ActionAid 2006). On the contrary, some possible positive effects associated with climate variability were identified during the workshops, such as the increased availability of water in the country's dams or the opportunity to develop new technologies in the country (sea water desalination for consumption).

In order to get a clearer picture of the future climate conditions in Mozambique and their related potential impacts on WASH systems, a specific climate modelling exercise was developed within the scope of the CDP. A good assessment of past and future climate conditions serves as input for the subsequent vulnerability analysis and risk assessment.

The climate in Mozambique varies depending on the location and the time of the year. This variability is due to the interaction of different factors, namely, the atmospheric systems and the topography of the country (INAM 2019). For the analysis, eight different climate regions were defined for the development of the CDP (Fig. 2, Table 3), considering certain uniformity in the aforementioned factors.

In terms of variability over time, the annual cycle has two seasons: the rainy season starts, approximately, in November and finishes in April, while the dry season starts in May and finishes in October. This variability is due to the shift of the Intertropical Convergence Zone (ITCZ), which is located very close to the country

Table 3 Climate regions in Mozambique

Climate region	Description
R1	R1 comprises almost the whole provinces of Maputo and Gaza, in which topography is not complex and maximum altitude is around 500 m in the western part. The climatology is dry and hot and annual precipitation is normally below 600 mm/year
R2	R2 comprises the southern part of the Tete province, in which the topography is governed by the Zambezi river basin. The predominant climate is semiarid and hot and annual precipitation is normally below 800 mm/year
R3	R3 comprises Inhambane, Sofala, and Manica, whose topography is almost plain, except Manica with elevations between 600 and 1600 m. The climatology is close to tropical savanna and annual precipitation is around 1200 mm/year
R4	R4 comprises the northern part of the Tete province, in which the topography is mountainous, limited by the Cahora Bassa lake in the south. The elevations are over 2000 m at the northern boundary. The annual precipitation is over 1200 mm/year in spatial average and over 1600 mm/year in the higher areas
R5	R5 comprises Cabo Delgado, Nampula, the southeast of Nassa, and a coastal area of Zambézia. Orography is over 1000 m and annual precipitation is around 1200 mm/year
R6	R6 comprises the lower course of the Zambezi and Licungo rivers, which results in a plain topography. Precipitation is around 1200 mm/year in spatial average, although 1600 mm/year are reached in the north of the region
R7	R7 covers the northwest of Niassa and has a complex topography. The climatology is wet subtropical, and precipitations reach in average 1600 mm/year
R8	R8 is the wettest region and its topography is complex (Namuli mountains) whose highest points are the Mount Namuli (2700 m). The annual precipitation is 1600–1800 mm/year

Source: Authors

during the November-April period, and reaches the latitudes of Mozambique around January and February, when maximum precipitation is normal. Interannually, Mozambique is influenced by the El Niño–Southern Oscillation (ENSO), in which sea surface temperature (SST) positive anomalies in the Tropical Pacific Ocean are well correlated with dry conditions, especially in central and southern Mozambique. As concluded from the 5th IPCC report (Stocker et al. 2013), significant changes in ENSO are not conclusive, although there is a high confidence that ENSO will remain a dominant mode of natural variability in the twenty-first century.

Precipitation was selected as the meteorological variable most affected during flooding in the coastal cities of Mozambique. The intention of this study is to analyze the change of climatological patterns in this variable at national level and also at local level in Beira and Matola.

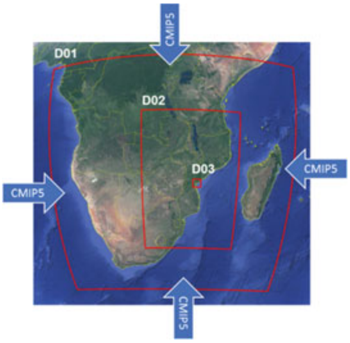
To assess historical changes in climate, consistent long-term meteorological observations were necessary. Since the weather station network in Mozambique is reduced (INGC 2009), with only one station per 29,000 km^2 and major geographical gaps in the provinces of Gaza and Tete, an alternative historical climatological database was necessary as a reference. Climate Forecast System Reanalysis (CFSR, Saha et al. 2010) was chosen as the most suitable gridded database without gaps in the historical climatology.

There are many climate scenarios as a result of running different models over long periods of time, developed by research institutes around the world, that can be used to assess the future climate. Global climate models (GCMs) are freely available through the Coupled Model Inter-comparison Project Phase 5 (CMIP5, Taylor et al. 2012), and regional climate models (RCMs) are available through the Coordinated Regional Climate Downscaling Experiment (CORDEX (http://www.cordex.org/)). However, due to their spatial resolution (around 100 km for CMIP5 models and 50 km for CORDEX models), they are still not capable of representing the local climate phenomena, potentially underestimating climate extremes, especially when topography is locally complex and land uses are varying depending on the location. Aligned with the data needs of the CDP, this study was focused on the generation and analysis of higher resolution climate change scenarios: 9 km resolution dataset for Mozambique in its entirety and 3 km resolution dataset for the city of Beira.

The new climate scenarios were generated based on a dynamic downscaling approach using the Weather Research and Forecast (WRF) model and its ARW solver (Advanced Research WRF), supported by the NCAR Mesoscale and Microscale Meteorology Laboratory. In contrast with other downscaling approaches, dynamic models like WRF solve the non-hydrostatic Euler equations governing atmospheric dynamics over a limited area at very high resolution. Indeed, the WRF model is able to solve atmospheric dynamics using multiple key parametrizations such as microphysics, radiation, cumulus, surface, and planetary boundary layer (PBL) and whose proper setup is of paramount importance to optimize the performance of the model. In this sense, several experiments were evaluated following a standardized methodology defined by Arasa et al. (2016), choosing the most convenient WRF options to minimize the error in the mean precipitation and the percentile 90th (P90) of daily precipitation, as proxy of extreme precipitation. The resultant optimized WRF configuration is shown in Table 4 (central and right columns).

The WRF model was used to downscale some GCMs from CMIP5 ensemble as well as CFSR. Due to computational limitations, the three most appropriate GCMs (among tens of models available) were chosen to be downscaled from CMIP5 ensemble, according to a comprehensive validation of GCM precipitation patterns over Mozambique area. As a result, MPI-ESM-MR (Giorgetta et al. 2013), IPSL-CM5A-MR (Dufresne et al. 2013), and CanESM2 (https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/modeling-projections-analysis/centre-modelling-analysis/models/second-generation-earth-system-model.html) were selected. The validation consisted of analyzing the performance of annual cycle bias as well as spatial correlation in Mozambique's annual precipitation cycle of each CMIP5 model against the GPCC precipitation dataset (Global Precipitation Climatology Center). (GPCC global dataset were used in order to keep the same grid scale between climate models and observations in the validation exercise.) The results of the GCM validation exercise are shown in Fig. 3, displaying the good performance of the selected models in the annual cycle as well as in the spatial distribution in the Mozambique area. All selected models show a Pearson correlation higher than 0.98 and a normalized root-mean-square error

Table 4 WRF running domains and options selected which optimize monthly mean precipitation

	Parametrization	WRF option
 D01: 27 km resolution (Austral Africa) D02: 9 km resolution (Mozambique) D03: 3 km resolution (Beira)	Radiation	CAM (Collins et al. 2004)
	Microphysics	WSM6 (Hong and Lim 2006)
	Cumulus	New-Tiedtke (Zhang et al. 2011)
	Surface	MM5 similarity (Monin and Obukhov 1954)
	PBL	YSU (Hong et al. 2006)

Source: Authors

(NRMSE) lower than 20% in the annual precipitation cycle. In the same vein, spatial distribution of precipitation climatology for the three selected models is performing correctly showing spatial correlation with GPCC higher than 0.7 for an area covering Austral Africa.

The WRF model was run considering the three previously mentioned GCMs as inputs for two different 20-year periods of time: a historical/reference period 1986–2005 using CFSR and a future period (2026–2045) using the three CMIP5 models. These periods were chosen according to the design of climate simulations within CMIP5 initiative, which define the historical period between 1850 and 2005 and future period from 2006 to 2100 under the Representative Concentration Pathway (RCP) 8.5. This RCP8.5 is considered as a "business as usual" scenario reaching a radiative forcing of 8.5 W/m^2 at 2100. RCP8.5 is the most conservative scenario, since it predicts the most extreme global warming according to an increasing fossil burning and increase of greenhouse gases (GHG).

As part of WRF configuration, an optimal grid architecture is defined through three nested domains to downscale gradually the CMIP5 models (available at more than 100 km resolution); as shown in the left column of Table 4, the CMPI5 and CFSR models are used as input to the first domain D01 covering Austral Africa at a 27-km resolution. D02 is covering Mozambique at 9-km resolution, while D03 is covering the city of Beira at 3-km resolution.

The analysis of the WRF datasets is framed through the definition of a set of climate indicators, which represent the relevant climate aspects for the WASH sector, which are mean annual precipitation, annual precipitation cycle, dry spell (consecutive number of days with daily precipitation <1 mm), and intensity-duration-frequency curves. (IDF curves explain the relation between rainfall intensity (mm/h), rainfall duration (time rained at certain intensity), and rainfall frequency or

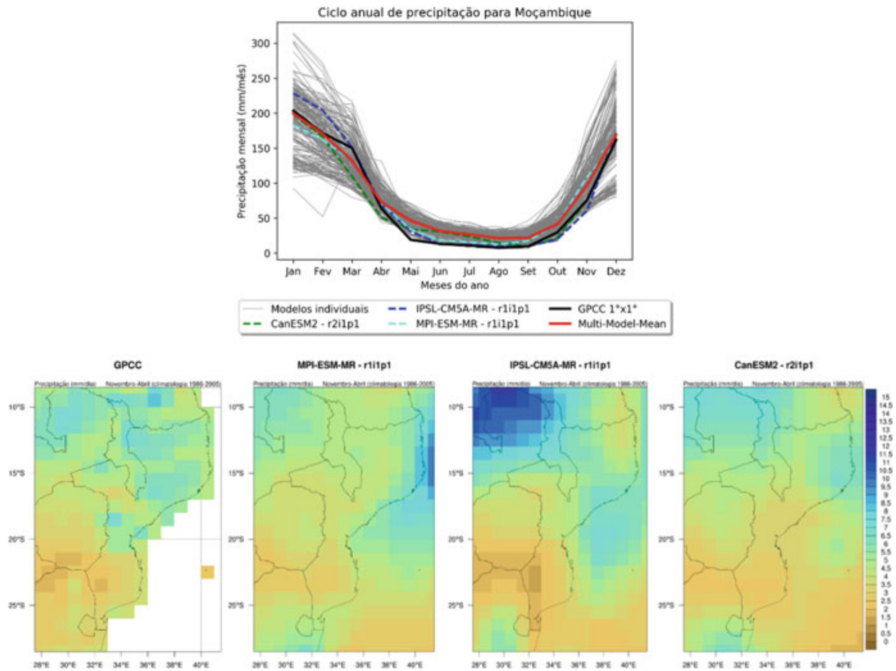


Fig. 3 GCM validation of annual cycle of precipitation in mm/day for 1986–2005 (top, solid dark line shows GPCC, while green, blue, and cyan dashed lines show CanESM2, MPI-ESM-MR, and IPSL-CM5A-MR, respectively). GCM validation of spatial distribution of the precipitation climatology in the humid period (November to May) in mm/day (bottom, from left to right pictures show GPCC, MPI-ESM-MR, IPSL-CM5A, and CanESM2). (Source: Authors)

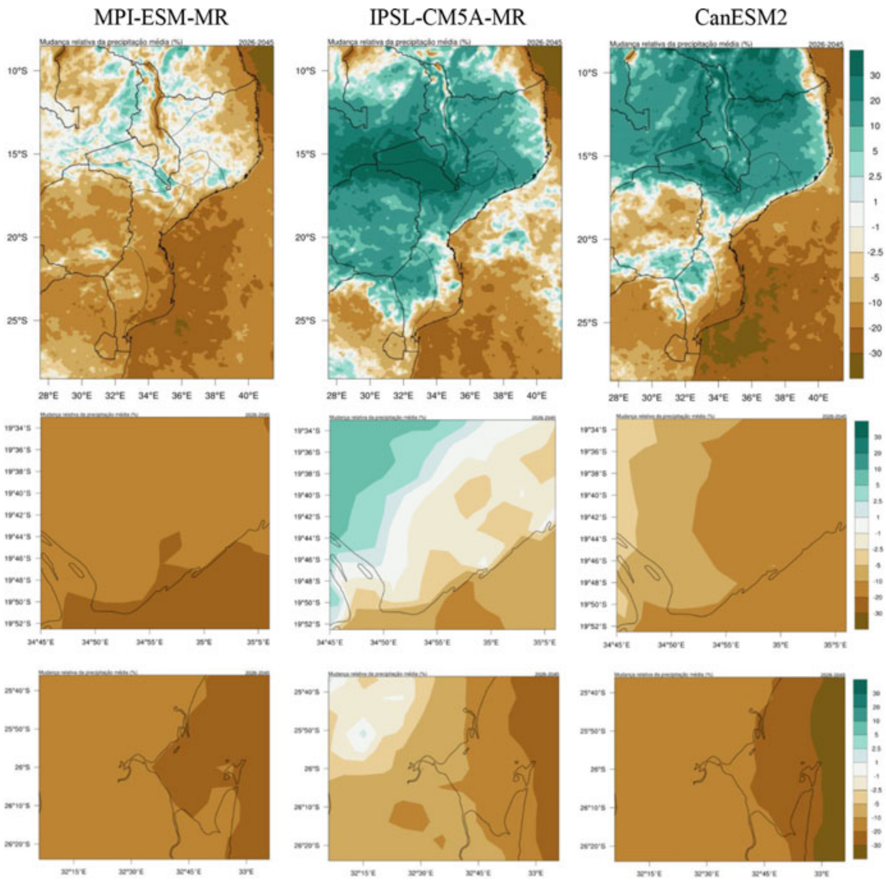


Fig. 4 Change (%) in annual mean precipitation between reference (1986–2005) and future (2026–2045) periods in Mozambique (top), Beira (central), and Matola (bottom) for the three downscaled models MPI-ESM-MR (left), IPSL-CM5A-MR (central), and CanESM2 (right). Mesoscale model: WRF. RCP8.5. (Source: Authors)

return period (time span between two consecutive rain events).) Durations from 10 min to multiple days are considered as well as recurrences from 1 to 500 years return level. The change between future and historical periods in absolute (mm) and relative (percentage) values is analyzed.

Some of the obtained results are illustrated in Fig. 4, which show the change in percentage in the climatology of annual precipitation between future and reference periods for the three downscaled models for Mozambique, Beira, and Matola. IPSL-CM5A-MR and CanESM2 indicate an increase of mean precipitation between 5% and 20% in the norther part of the country (comprising R2, R4, R5, R6, R7, and R8, located mainly in Zambézia, Niassa, and Tete provinces) and also R1 in the inner southern part of the country, while MPI-ESM-MR shows insignificant changes for those regions. By contrast, a precipitation decrease is agreed with all three models in the R3, including the provinces of Gaza and Maputo. In the city of Matola, a decrease in precipitation of between 10% and 20% is expected. Similarly, in the city of Beira, the MPI-ESM-MR and CanESM2 forecast a decrease in the mean precipitation of between 10% and 20%, whereas IPSL-CM5A-MR forecasts a decrease lower than 10%.

In terms of the annual variability, no significant changes are concluded from the downscaled models, which indicates that the presence of a wet season between November and April and a dry season between May and October will remain in the future. This is in line with previous studies such as GoM (2012), in which it is concluded that climate projections show a diverging change in the wet season precipitation, although they show a decrease in the dry season. In addition, the strengthening of the subtropical anticyclones during winter may lead to a delay in the southward migration of the ITCZ. It may also lead to a southward shift of midlatitude cyclones. A combination of these dynamic changes and a reduction in moisture availability during winter could lead to a delay in the start of the rains over some areas (INGC 2009).

Looking at the IDF curves, an increase in the precipitation intensity for the same return period and a general duration for all the country are agreed for all three models. The detected change is much more significant for short durations, as it is shown in Fig. 5 for 10-year return period values for Matola and Beira. This also indicates that extreme precipitation phenomena are expected to be more frequent and with a shorter recurrence time. The most abrupt changes in precipitation intensity are expected to occur in R4, R7, and R8, which corresponds to the mountainous zones of the provinces of Tete, Niassa, and Zambezia. In the case of the city of Beira, a significant increase in the precipitation intensity is detected for all return periods and durations until 1 day, although the change is much more significant for the short durations.

In terms of the projection of dry spells, an increase between 20 and 30 days in the number of consecutive dry days is agreed among the three downscaled models in the provinces of Cabo Delgado, Nampula, and the coast of Inhambane. In these areas, the number of consecutive dry days is lower than 100 in the case of Cabo Delgado and Nampula and lower than 75 in the case of Inhambane. That supposes an increase in the number of consecutive dry days in areas in the north of the country, where this phenomenon is not so frequent.

Considering that modifications in design standards can substantially reduce the impacts of climate change in Mozambique, even without additional resources (WB 2010), one of the main activities carried out using the results of the climate modelling as inputs was reviewing the existing regulations, technical standards and norms, and design criteria in water, sanitation, and flood control. This task had two objectives: to identify any possible inconsistencies or gaps and include the adaptation component. A total of six official documents were analyzed:

- Water Law (Law 16/91)
- Water Policy (August 2007)
- National Strategy for Water Resources Management (August 2007)

- National Water and Sanitation Strategy 2011–2025 (January 2012)
- Regulation of Public Systems of Water Distribution and Wastewater Drainage (Decree 30/2003)
- National Program for Water Supply and Rural Sanitation (Ministerial Diploma 258/2010)

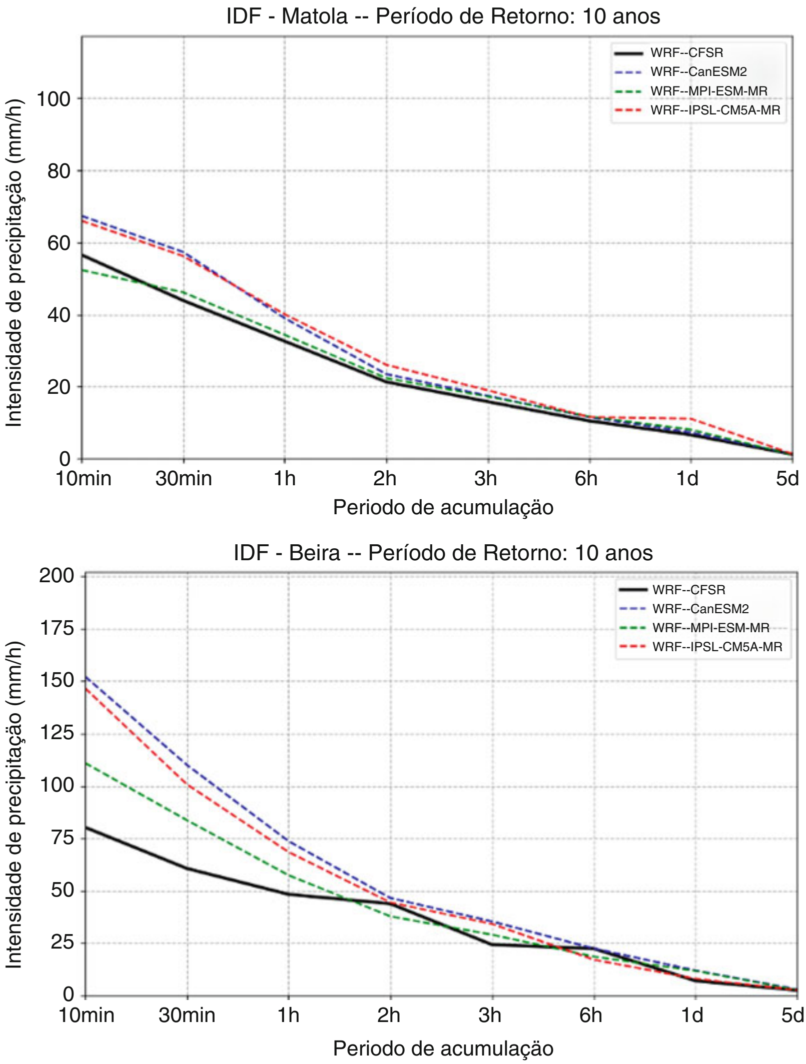


Fig. 5 Change (mm/h) in the precipitation intensity between reference period (WRF-CFSR) annual mean precipitation between reference (1986–2005) and future (2026–2045) in Matola (top) and Beira (bottom) MPI-ESM-MR (green shaded line), IPSL-CM5A-MR (red shaded line), and CanESM2 (blue shaded line). Mesoscale model: WRF. RCP8.5. (Source: Authors)

Fig. 6 Priority/decision-making tool for investments on urban water management. (Source: Authors)

Relevant modifications were only proposed for two of these documents. Regarding the Water Law, climate change has been incorporated into water resources management, enhancing the integral management of the basins as the best way to guarantee the adequate use of these resources and emphasizing the defense of the public water domain as a preventive measure to protect them. Regulation 30/2003 is the main technical standard in force for water and sanitation projects in Mozambique. An in-depth revision was carried out, in order to include a "climate factor" within the calculation of the precipitation design value for each one of the climate regions previously defined in the climate modelling exercise. Modifications to these regulations was then proposed and subsequently reviewed and approved by AIAS and DNAAS. The bureaucratic process until the official approval and publication in an official bulletin was not completed during the development of the CDP, as a wider institutional consensus was required.

The last technical activity completed within the scope of the CDP was aimed at streamlining the process of selecting and prioritizing adaptation measures that could effectively be applied in the Mozambican urban water, sanitation and drainage sector. The existing water and sanitation facilities were found to be suitable for most climates, perhaps with minor adaptation; however, the challenge is in selecting the technology to suit the predicted future climate (Charles et al. 2010). For this purpose, a specific decision tool was implemented. Based on a multivariate matrix, the tool has been designed to be an easy-to-use worksheet (Fig. 6) that allows consultation and presents the most appropriate adaptation options according to:

- Type of adaptation measure required: planning (9 different measures), infrastructure designing (29), operation and maintenance (8)

- Related threat: flash flooding, riverine flooding, sea level rise-coastal erosion, droughts, and average temperatures raising
- Geographic scope: local or regional
- Type of infrastructure: water and/or sanitation and/or drainage

All adaptation measures are described in specific fact sheets, including widely accepted selection criteria: vulnerability, urgency, synergy, no-regret, efficacy, feasibility, flexibility, and cost-benefit (UNFCCC 2011).

In order to effectively disseminate the results of the activities mentioned above and to foster the technical capacity of AIAS and other stakeholders, a series of thematic training workshops was programmed within the CDP project. Table 5 presents the main contents of each of these workshops held in Maputo and Beira.

The number of participant institutions in the different training activities carried out was significant. In addition to the technical staff and managers of AIAS, SASB, and EMAS, representatives of DNAAS, DINAB, INAM, INAHINA, INCG, the ARA Center, and municipal technical professionals from Quelimane and Nacala offered regular assistance as well. The feedback received from attendants after each workshop held was satisfactory, in terms of contents, scope, training materials, and complementary resources.

Two study tours were organized in order to complete the capacity development program. The attendees were from AIAS, Beira, Matola, and other key stakeholders

Table 5 Workshops held in Maputo and Beira

Topic	Main contents
Climate change	Basic concepts. Causes and consequences. International action. Presentation of national public policies and achievements exposed by DINAB/MITADER representatives
GIS. Basic concepts	Main GIS features and utilities. Projections and coordinates systems Geo-referencing. Raster and vector models. Spatial operations (geoprocessing). Layouts
Climate impacts on WASH systems	Climate risk concepts (threats, exposure, vulnerability). WASH climate vulnerability. Adaptation measures
GIS applied to hydraulic modelling	Digital elevation models. GIS hydrologic modules. Input data for hydraulic models. Outputs refinement
Climate modelling	Basic concepts on climatology and meteorology. General circulation models. Downscaling techniques (statistical, dynamic)
Urban adaptation planning	Urban planning relevance and concepts. Urban planning in Mozambique. Multidisciplinary approaches. Adaptation plans. Study cases: João Pessoa (Brazil) and Sevilla (Spain)
Adaptation measures	Sustainable Development Goals. Nature-based solutions. Sustainable urban drainage systems. Application in practice of the reviewed Regulation 30/2003, considering climate variability
Climate impacts on WASH systems	Hydrologic and hydraulic modelling. Application in practice, based on the completed drainage studies for Beira
Climate downscaling	Sharing of the obtained results from the climate modelling exercise. Operation guidelines for the climate database generated

Source: Authors

(ten participants each). The first trip was to Brazil, where two cities were visited. In the city of João Pessoa, some of the adaptations projects defined within the Action Plan as part of the Emerging and Sustainable Cities Initiative (ESCI) were seen. ESCI has been launched by Inter-American Development Bank in a number of Latin American and Caribbean cities, where IDOM has been actively collaborating, developing vulnerability and urban growth studies. In Rio de Janeiro, the delegation participated in the "Rio Water Week," an important international event that served to give the group exposure to innovative initiatives and allowed them to make contact with other actors of the WASH sector. The second study tour was in Spain. The first stage of the trip included Seville, where with the collaboration of the public water and sanitation company (EMASESA), the regulatory framework of the city on drainage was shared and different infrastructures of interest (storm tanks, water and wastewater plants) were visited. In Madrid, the group was welcomed by municipal technical staff (the so-called Blue Department), who presented different projects related to sustainable urban drainage systems and held useful technical exchange sessions with Mozambican counterparts. The public company in charge of water and sanitation services in Madrid (Canal de Isabel II) also participated.

Finally, to improve the capabilities of the AIAS technical staff in the use of GIS tools, a hands-on training program "ad hoc" was organized. A specialist from the institution received specific training during the CDP project, including a 2-week internship in the GIS Division at IDOM's headquarters in Madrid.

Resilient Urban Water Management Studies

African countries, in particular, face twofold challenge of managing climate change risk while at the same time, using sustainable approaches to extend the services provided, housing, and infrastructure (Campos et al. 2012). Adaptation is indeed an opportunity to promote social cohesion. In this sense, the cities of Beira and Matola are representative of other urban areas in the country.

Beira is a colonial city, established as a seaport to export raw materials from the African continent. Below the sea level, the city is located on a large estuary formed by the convergence of two large rivers (Pungwe and Buzi). It is also located in the path of the periodical tropical systems formed in the Indian Ocean. The city is exposed to frequent flooding which can be very disastrous when a cyclonic situation is combined with high tide. Certain coastal areas of the city suffer high rated of erosion. The main flood protection system to protect the city from coastal hazards was constructed decades ago and has deteriorated due to limited maintenance since its construction. This system is based on a network of open channels which divide the city and are controlled by floodgates. In some cases, they are connected to the retention basins. The city was barely affected by the Idai cyclone (GoM 2019b). Fortunately, given that landfall occurred at low tide, the city did not experience widespread coastal flooding. Therefore, it is more than obvious that actions must be taken to improve the resilience in the city. This problem has been addressed for many years and various studies and projects have been carried out, funded mainly by international sources.

Matola is a city in the metropolitan area of Maputo. In the last few decades, its population has been growing exponentially due to the migratory flows both from rural areas and also from the capital city itself, since urban growth in Maputo is limited. Urban facilities do not meet the needs of this expanding residential occupancy. In particular, sanitation and drainage systems are insufficient and highly vulnerable to episodes of intense precipitation.

The CDP project has contributed to improving the urban sanitation and drainage systems of these two cities with the development of specific analysis. To achieve this, the municipal entities SASB and EMAS have been working together in agreement on the needs and action priorities of each urban area. The climate modeling that has been carried out will permit decision-makers to consider possible future impacts.

In Beira, all the completed works related to the improvement of the sanitation and drainage systems and the coast protection were firstly identified and analyzed. In the next stage, the impact of floods on the existing storm water and sanitation network in the urban and peri-urban areas of the city was assessed using climate scenarios and a combination of hydrological and hydraulic models, calibrated with existing data in order to simulate flooding scenarios. This work allowed a series of specific needs to be defined to promote and improve the system. Following a common approach with AIAS, a detailed study of the identified no-regret options was developed, improving the drainage system of a specific neighborhood in the city (Chota-Estoril). In addition, a comprehensive feasibility study (technical, economic-financial, environmental) was carried out.

The analysis and studies focusing on Matola were based on a detailed revision of the city sanitation and drainage master plan, considering the climate factor. A conclusion of this analysis is that the proposals included in the city's drainage master plan, issued in 2015, can be considered climate-proof. In addition, some improvements in technical aspects of the basic design of the sanitation and drainage system as well as some alternative solutions based on SUDS were proposed.

It may be possible to build on these activities through the projects and works, which would effectively address the needs of each urban area. In both cases, the business development plans mentioned earlier are an important component to guarantee the feasibility of the defined actions.

Conclusions

According to the evaluations given by both donor agencies (the Nordic Development Fund and the World Bank) and national counterparts (AIAS and the cities of Beira and Matola), the CDP has successfully contributed to mainstreaming climate adaptation in the Mozambican urban water, sanitation, and drainage sector.

The technical output of the CDP will serve an important input for the planning and design of resilient infrastructure. The capacity building activities have served to effectively transfer knowledge and good practices to AIAS, the city of Beira and the city of Matola, and other relevant stakeholders of the Mozambican WASH sector. To some extent, the support given during institutional strengthening will reinforce the sustainability of AIAS and other municipal entities as well as improving the success rate of their initiatives, although financial feasibility will require extensive structural reform and progress.

This type of assignment, combining institutional strengthening, capacity building and the provision of specific technical know-how, can be replicated in other African countries to promote climate resilience in other infrastructure sectors and activities.

Recommendations and Further Steps

Mozambique is a country under development. In addition to those growth prospects based on an improvement in the productive activity and the sustainable exploitation of country's natural resources, international cooperation is itself a key support in order to promote new urban infrastructures and/or improve the existing ones. Climate resilience holds an important role in this support, either as principal target or as a transversal component. As an example, it is worth mentioning two recently approved support programs. One of them aims to strengthen the capacities in disaster risk management at a country level (providing effective resources for developing the National Disaster Risk Reduction Master Plan 2017–2030), and the other is focused on improving Beira's coastal protection system. For both of them, the CDP contributions will be definitely useful.

The work along more than 2 years in close collaboration with numerous Mozambican institutions gave the chance of inspiring a few ideas, proposals, or even desires that may be taken as possible future areas of interest to develop.

The first suggestion refers to explore the possibility of carrying out an institutional reformulation of the national water sector as a whole. Concentrate attributions around a fewer number of public bodies without overlooking decentralizing objectives is clearly feasible. This would ease the decision-making process regarding key aspects, such as the integration of climate concerns on policies and developments. A "hydrographic basin" management approach – including transboundary negotiations and agreements – is highly recommended.

As can be found in many other regions around the world, it is been noted that urban planning in Mozambique still does not have the necessary power to manage the "cities growing" phenomena in a proper manner. This affects negatively and doubly those who are (socioeconomically) forced to find an urban habitat in unappropriated areas, exposed to natural threats. Adaptation plans are strategic instruments that may certainly contribute to urban resilience; based on spatial risk assessments, they indicate those spaces in which it is not appropriate to develop certain land uses or activities.

Regarding international agreements and commitments assumed by Mozambique to act in climate adaptation, coordinate action within WASH sector is mandatory in order to make articulate decisions, avoid redundancies, and hold an agile sharing of information. In this sense, the creation of a "sector-based committee," with own statutes and binding capacities, would be beneficial. In fact, this was a failed intent along CDP's enterprises, but it would be worthwhile took this idea up in the next future.

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