Reducing vulnerability to extreme hydro-meteorological hazards in Mozambique after Cyclone *IDAI*

WEATHER CLIMATE WATER

WMO mission report following tropical cyclone *IDAI* (29 April–7 May 2019)

WORLD METEOROLOGICAL ORGANIZATION

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Data records at Beira after *IDAI*

INAM headquarter at Beira after *IDAI*

Informal setlements after *IDAI*

Acknowledgements

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Without the support and contributions of all the above, the mission would not have achieved its objectives.

Acronyms

ARA	Regional Water Administration
AWS	Automatic Weather Station
AWOS	Airport Weather Observing Station
CAP	Common Alert Protocol
CCDM	Coordination Council for Disaster Management
CENOE	National Emergency Operational Centre
CLS	Collect Localization Satellites
DFID	Department of international Development, United Kingdom
DNGRH	National Directorate of Hydrological Resources Management
DRMC	Disaster Risk Management Committees
EAP	Early Action Protocol
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
ESA	European Space Agency
FAO	Food and Agriculture organization of the United Nations
FFGS	Flash Flood Guidance System
GSM	Global System for Mobile Communication
IBF	Impact based Forecast
IBTRACS	International Best-Track Archive for Climate Stewardship
IMERG	Integrated Multi-satellite Retrievals for GPM (Global Precipitation Measurement)
INAM	National Institute of Meteorology
INGC	National Institute for Disaster Management
META	Meteorological Terminal Airport Report
NWP	Numerical Weather Prediction
PPCR	Pilot Project for Climate Resilience
RBW	Risk Based Warning
RSMC	Regional Specialized Meteorological Centre
SARFFGS	Southern Africa Regional Flash Flood Guidance System
SAWS	South Africa Weather Service
SOP	Standard Operating Procedure
SWFDP	Severe Weather Forecasting Demonstration Project
TC	Tropical Cyclone
TCDM	Technical Council for Disaster Management
TS	Tropical Storm
UM	Unified Model
UNAPROC	National Civil Protection Unit
USD	United States Dollars
UTC	Universal Time Coordinated
WB	World Bank
WFP	World Food Programme
WIGOS	WMO integrated global observing system
WRF	Weather Research and Forecasting Model

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Executive Summary

Tropical Cyclone *IDAI* caused the death of more than 600 people, injured an estimated 1600, affected more than 1.8 million and caused an estimated USD 773 million in damages to buildings, infrastructure and agriculture. The tropical cyclone started do develop on 4 March close to the coastline of the province of Zambézia as a tropical depression with wind speeds of about 55 km/h gusting up to 75 Km/h. During the following 4 days, the system headed north, then northwestward, before turning back east-southeastward on 7 May close to the Mozambique-Malawi border. Until 8 March the system caused persistent local and heavy rainfall associated with thunderstorms that affected the provinces of Zambézia, Sofala, Nampula, Tete and Niassa, causing floods in the lower Licungo and the city of Tete. On 9 March, the system moved back to the Mozambique Channel, where it intensified rapidly maturing into an intense tropical cyclone with winds gusting up to 250 km/h by 11 March, off the western coast of Madagascar, when it reversed its track back towards Beira.

On the evening of 14 March around 22UTC, intense Tropical Cyclone *IDAI* made landfall in the northern vicinity of Beira as a category 4 (out of 5) on the scale used in Mozambique, with 165 km/h winds gusting up to 230 km/h bringing torrential rains and very high seas, with wave height likely exceeding 10 meters. *IDAI* was not the strongest tropical cyclone to have hit Mozambique. Tropical Cyclones ELINE in February 2000 produced 185 km/h at landfall. Associated heavy rainfall spread over Central Mozambique moving inland up to eastern and central parts of Zimbabwe from 13 to 21 of March and fed the major and deadly flood event, mainly in the Búzi and Púngùe rivers that started three days after the cyclone passed over Beira.

Objectives of the mission

The World Meteorological Organization dispatched an expert mission to Mozambique to assess the requirements and capabilities of the National Institute of Meteorology (INAM) and the National Directorate of Water Resources Management (DNGRH) and their coordination with the National Disaster Management Institute (INGC) for an End-to-End Multi-Hazard Early Warning System in the context of disaster risk management. The results of the mission should inform plans and investments in strengthening the Early Warning System and disaster risk management in the country, particularly during reconstruction to ensure building back better and overall strengthening of resilience.

Future vulnerability

Downstream 9 of the 15 major river basins in Southern Africa, with more than 50% of the territory covered by international river basins and more than 50% of the total annual runoff originating outside the country, Mozambique is vulnerable to both floods and reduced water flows due to the use of water by upstream countries during droughts, aggravating drought impacts. The exposure of people and assets in floodplains and the coping strategies in place determine the level of vulnerability to floods. The floods caused by *IDAI* were not similar to those previously as the communities had no time to activate the community-based warning systems (e.g., in Búzi), where river level readings are measured and the alarm is raised in cases of rapid river level changes.

With a coastline of 2700 km in the South West Indian Ocean, Mozambique is in the path of tropical cyclones formed in or that cross the western part of Indian Ocean basin. On average one tropical storm or tropical cyclone hits the cost every 2 years, a number which would have been higher if Madagascar which serves as a natural protection against systems coming from the east was not there. Tropical cyclones are therefore low-frequency events requiring high levels of awareness and preparedness to ensure effective action in case of warnings. In the context of climate change, there is consensus on the global decrease in the numbers of tropical storms and tropical cyclones, but increase in maximum intensities and related rainfall. Thus, the number of most intense tropical cyclones (category 4 and 5) is expected to increase. Future sea level rise will exacerbate the impact of storm surge on coastal regions, assuming all other factors remain equal. For the provinces of Maputo, which have never suffered from direct hit of tropical storm or tropical cyclone, and the province of Gaza which was hit one (Tropical Depression Domoina in 1984) the likelihood of direct impact over these southern areas may increase over the next decades.

Capacities for End-to-End Multi-Hazard Early Warning Systems

The immediate priority is to rebuild the infrastructure and equipment of INAM and DNGRH to ensure it can sustain winds similar to those during *IDAI* and allow continuity of responsibilities and operations during severe events. There is an opportunity for INAM to replace its totally devastated headquarters in Beira with a larger modern facility. This facility could include an enhanced engineering presence with a technical centre to support maintenance in the Central region of Mozambique. The facility will also include the weather radar in Beira, an excellent source of information on rainfall distribution and intensity, and provider of critical tropical cyclone and flood forecasting information.

Currently there is a need to enhance the capacities of INAM in the following areas: observations; hazard risk assessment; detection, monitoring, analysis and forecasting of hazards and their possible consequences; dissemination of warnings and associated information on potential impacts in a timely and targeted manner; and to engage in public education and awareness about hazards. As a result, INAM is in dire need of investment. Similarly DNGRH needs investment for interventions to enhance resilience to floods. Therefore, appropriate prevention and risk management strategies need to be evaluated to reflect a variety of structural and non-structural measures to ensure risk exposure is assessed basin-wide. Integrated Flood Management approaches should be adopted across the country and incorporate the potential future impacts of climate change. A specific emphasis should be on non-structural measures aligned with the different contexts of focus region so that they are meaningful and targeted to audience’s needs.

Operationally, Standard Operating Procedures (SOP) need to be developed and implemented as a matter of priority to ensure consistency of operations, data and information sharing, clear roles and responsibilities; and provision of information to users in an understandable and timely manner.

Warning communication needs to be enhanced. The warning messages need to be user-oriented and targeted to various audiences, with clear indication of potential impacts. At present people do not understand the terminology used (e.g., 50 mm of rain or 150 km/h). The color coding system used for communicating warnings used by INAM and DNGRH needs to be harmonized, and should be differentiated from the color coding system used by INGC for the readiness levels of the institutions involved in disaster risk management. Failure to do so results in confusion of decision makers and the public during emergencies.

INAM and DNGRH should engage in education and public awareness activities to increase understanding of hazards, their characteristics and corresponding risk. INGC should promote education and awareness of disaster risk management. These activities should be coordinated and of ongoing nature, but not initiated during emergencies.

Major weaknesses identified by the mission on preparedness, emergency coordination and response, include the following:

- Absence of a communication system that can be used in the case of failure of normal communication means for warning and emergency operations;
- Ineffective land use planning and enforcement for efficient floodplain management;
- Absence of an evacuation plan for cities such as Beira, Búzi and Dondo;
- Limited capacities of INGC and CENOE at regional and provincial level to respond to emergencies;
- Limited capacities of UNAPROC in emergency response, particularly, search and rescue;
- Limited understanding of risk at institutional and individual levels. The low frequency nature of tropical cyclones in the province of Sofala might be an important factor in risk perception;
- Absence of an integrated approach for multi-hazard early warning systems;
- Accuracy of the warnings, particularly for floods in some river basins;
- Building codes not suitable to events of the magnitude of cyclone IDAI.

To address these deficiencies, interventions and investments are required in the short-, medium-, and long-term a summarized below. Annex 2 captures the details of investment requirements.

Meteorology Sector		
Timing/Activity	**Summary Description**	**Cost (USD)**
Forecasting		
Short-tem	Training on use and interpretation of products from global and regional centres, implementation of SOP and enhanced use of available equipment	1,075,000
Medium-term	Training and enhanced access to products from global centres	150,000
Sub-total		**1,225,000**
Communication of warnings		
Short-term	Upgrade of website and enhanced utilization of TV weather studio	100,000
Medium-term	Development of a strategy for social media presence	50,000
Long-term	Redundant systems for warning communication	100,000
Sub-total		**250,000**
Public Education and Awareness		
Short to medium-term	Training on public weather services and impact based forecasting	100,000
Medium-term	Further training on public weather services and impact based forecasting	200,000
Sub-total		**300,000**

Meteorology Sector		
Timing/Activity	**Summary Description**	**Cost (USD)**
Observations and Infrastructure		
Short-term	Rehabilitation of destroyed infrastructure, equipment, replacement of non-operational equipment, data management and integration of data from INAM and DNGRH	2,300,00
Medium-term	Construction of new facility at Beira, expansion of observing network including a radar at Beira, upper air sounding, and technical and logistical support nationwide	10,070,000
Long-term	Further expansion of observing network and improved data management	4,660,000
Sub-total		**17,030,000**
Maintenance		
Short term	Development of Standard Operating Procedures and training of staff	100,000
Sub-total		**100,000**
Total		**18,905,000**

Hydrology Sector		
Timing/Activity	**Summary Description**	**Cost (USD)**
Forecasting		
Short-term	Land surveys for flood risk mapping and harmonized satellite rainfall estimation	1,100,000
Medium-term	Automation of data collection, processing procedures and improved enhanced operational coordination	650,000
Sub-total		**1,750,000**
ICT & Infrastructure		
Short-term	Acquire high speed computer and improve IT infrastructure	550,000
Mid-term	Development of national standards construction of infrastructure	500,000
Sub-total		**1,050,000**
Capacity building		
Short-term-term	Training on hydrological modelling, flash flood guidance system and integrated flood management	490,000
Medium-term	Training on appropriate floodplain management and implementation	300,000
Long-term	Build continuous capacity building programme including training of trainers	200,000
Sub-total		**990,000**
Communication and awareness		
Short-term	Network of voice communication	100,000
Medium-term	Development of floodplain plans and review warning dissemination procedures	350,000
Long-term	Public education on floods	100,000
Sub-total		**550,000**
Observations		
Short-Term	Installation of hydrological equipment, data base management system and	3,300,000

Hydrology Sector		
Timing/Activity	**Summary Description**	**Cost (USD)**
	improvement of and products exchange	
Sub-total		**3,400,000**
Emergence response		
Short-term	Satellite communication for emergencies	100,000
Sub-total		**100,000**
Total		**7,840,000**
Overall total		**26,745,000**

Reducing vulnerability to extreme hydro-meteorological hazards in Mozambique after Cyclone IDAI

1. Introduction

Tropical Cyclone IDAI, one of the strongest to affect Mozambique, also impacted Madagascar, Malawi and Zimbabwe. In Mozambique, the impact of IDAI was catastrophic in and around Beira where it caused the deaths of more than 600 people. An estimated 1600 people were injured and approximately 1.8 million people were affected. The World Bank's rapid assessment (4 April 2019)[1] estimated USD 773 million in damages to buildings, infrastructure and agriculture.

2. Event characterization

Tropical Cyclone IDAI started to develop on 4 March close to the coastline of the province of Zambézia as a tropical depression with wind speeds of about 55 km/h gusting up to 75 Km/h. The system made a first landfall on the same day, north of Quelimane. During the following 4 days, a remnant of low pressure persisted over land while the system headed north and then northwestward until the 6 March, before turning back east-southeastward early on 7 March close to the Mozambique-Malawi border. From 6 to 8 March persistent local and heavy rainfall with associated thunderstorms affected southern Malawi and the provinces of Zambézia, Sofala, Nampula, Tete and Niassa (rainfall amounts in excess of 400 mm were recorded at some INAM's weather stations in Ulongue, Tsangamo, Mocuba). This caused a rise in water to above alert levels in the basins of Licungo, Raraga, Namacurra, Zambeze and in the sub-basin Revubuè. Resulting floods occurred in the lower Licungo and in the city of Tete

On 9 March, the remnant low pressure moved back towards the sea to the Mozambique Channel. At sea, it intensified rapidly maturing into an intense tropical cyclone with winds gusting up to 250 km/h by 11 March, off the western coast of Madagascar.

IDAI started to reverse its track early on the 11th towards the Mozambican coastline, as anticipated many days before by numerical weather prediction models. Since the 6th of March, this reversing track was well suggested by the European ensemble forecast with a possible threat of a mature tropical cyclone for central Mozambique. On 12 March track forecast uncertainty had reduced and was well below usual standards, clearly indicating that IDAI would hit the Beira area. Landfall eventually occurred on the evening of the 14th, around 22UTC, in the northern vicinity of Beira as an intense tropical cyclone based on the South-West Indian Ocean Basin terminology that corresponds to category 4 (out of 5) on the scale used in Mozambique. At landfall IDAI's winds estimated by the Regional Specialized Meteorological Centre (RSMC) La Réunion were blowing at 165 km/h and gusting up to 230 km/h (real time analysis) bringing torrential rains and very

[1] https://af.reuters.com/article/topNews/idAFKCN1RN19W-OZATP

high seas (wave height likely exceeding 10 meters). Despite these impressive characteristics, IDAI is not the strongest tropical cyclone to have hit Mozambique. Tropical cyclones ELINE, in February 2000, produced 185 km/h winds at landfall.

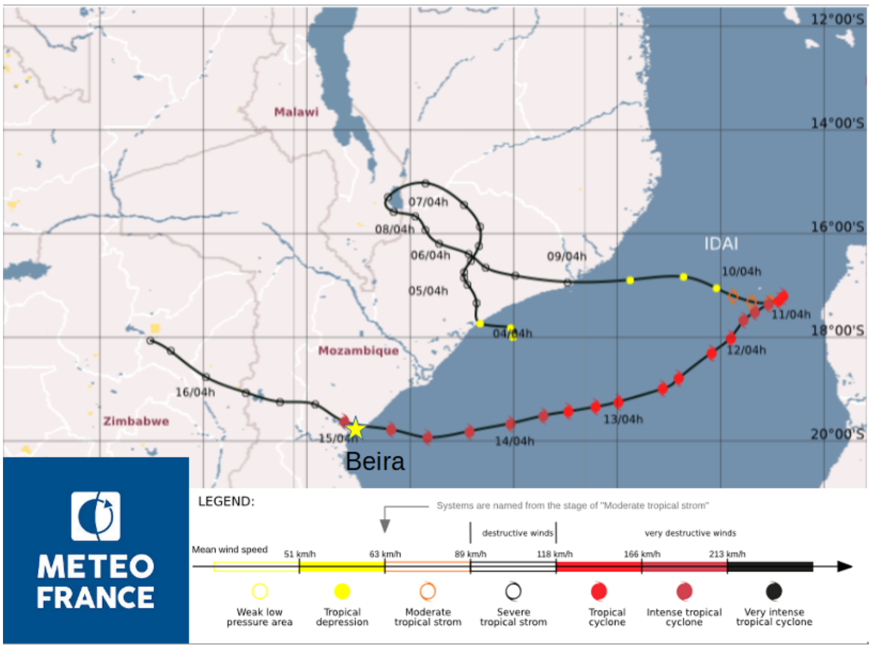

Figure 1. Track and intensity of Tropical Cyclone *IDAI*, 4–16 March 2019.
(*Source*: Météo-France /RSMC La Reunion)

From the 15 March, Tropical Cyclone IDAI started to weaken as it moved inland. Associated heavy rainfall spread over Central Mozambique going inland up to eastern and central parts of Zimbabwe from 13-21 of May, with the highest amounts during landfall exceeding 500 mm according to satellite estimation (Figure 2). The highest amounts were recorded to the west of Beira between Chimoio and Dondo over flat and low-lying areas.

The situation was made worse by the already high soil moisture due to the rains caused by tropical storm Desmond at the end of January in Sofala, Manica, Zambézia and Inhambane provinces. The rains after cyclone IDAI resulted in runoff, as the soils were already saturated. This, combined with the river flows from upstream countries, fed the major and deadly flood event, mainly in the Búzi and Púnguè rivers that started a few days (3 to 4 days) after the cyclone passed over Beira. The city of Beira and its outskirts recorded moderate floods. In the same period the Save river basin recorded high water flows as a result of water coming from upstream, yet without significant impacts. The Dams of Cahora Bassa and Chicamba had an increase of volume of storage to nearly 99% and 76%, respectively. A detailed analysis of Tropical Cyclone IDAI at landfall is presented in Annex 1.

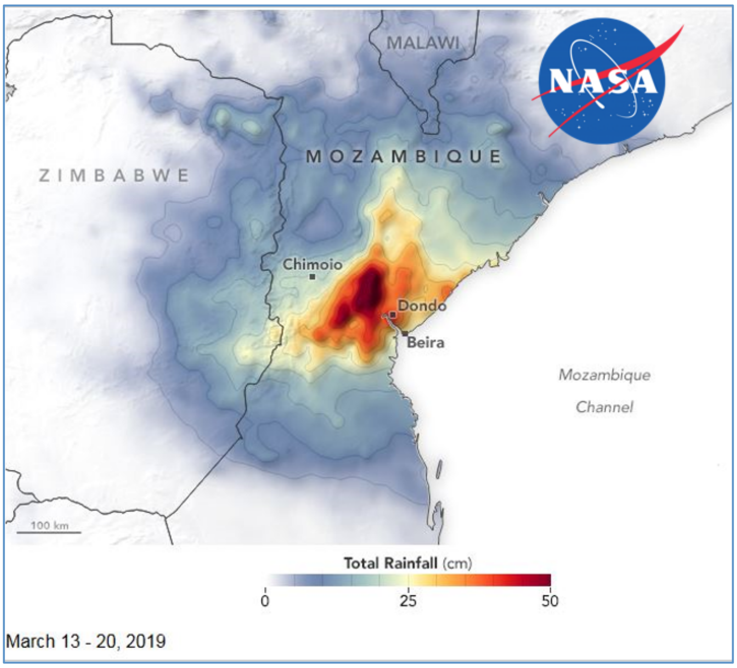

Figure 2. 7 days IMERG-GPM satellite-based rainfall estimates
(*Source*: NASA)

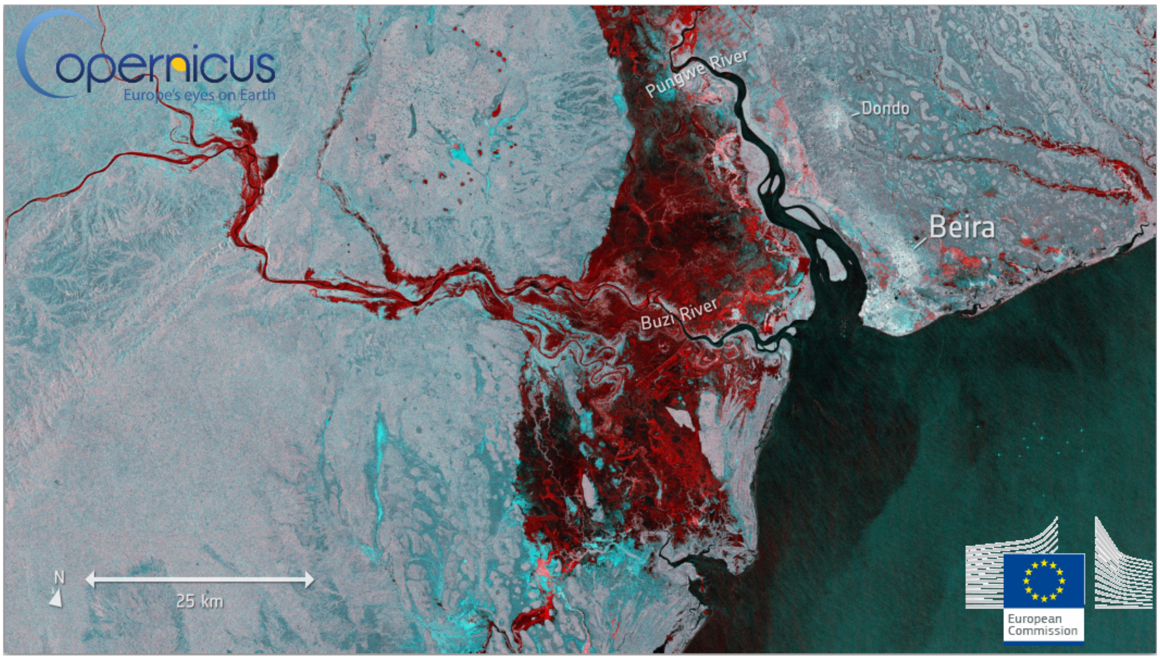

Figure 3. Extent of flooding (red areas) caused by IDAI on the 19 March.
(*Source*: European Commission/Copernicus Emergency Management Service)

3. Current and future vulnerability to extreme-events

Mozambique is vulnerable to the impacts of extreme weather-, water-, and climate events. On average droughts impact every 3 to 4 years. Floods of varying magnitudes occur every year in parts of the country and are exacerbated by the fact that Mozambique is downstream to 9 of the 15 major river basins in Southern Africa . More than 50 % of the territory is covered by international river basins and more than 50% of the total annual runoff originates outside the country. Being a downstream country means Mozambique is also vulnerable to reduced river flows due to the use of water by upstream countries, aggravating drought impacts. The country's vulnerability to floods is further exacerbated by geomorphological characteristics as approximately 40% of its topography is less than 200 m above sea level, and there is rapid change in land use and vegetation cover[2]. The biggest floods recorded recently were in 2000, causing the death of 700 people and affecting 2 million people. Economic damages were estimated at USD 600 million; and the floods of 2015. The floods caused by IDAI were not similar to previous floods in that communities had no time to activate the community based warning systems (e.g., in Búzi), which involves taking river level readings and raising the alarm if there are rapid river level changes.

With a long coastline of around 2700 km in the South West Indian Ocean, the country is in the path of tropical cyclones formed in or that cross the western part of the of the Indian Ocean basin. Over the last 5 decades, according to the International Best-Track Archive for Climate Stewardship (IBTRACS) and preliminary reanalysis from RSMC La Réunion, a total of 30 tropical storms (TS) and/or tropical cyclones (TC) affected the coast of Mozambique bringing with them damaging winds, heavy rainfall and hazardous sea state. Thus, on average one tropical TS or TC hits Mozambique every 2 years. This statistic be higher if Madagascar, which usually weakens the systems coming from the Indian Ocean towards Mozambique and therefore serves as a natural protection, was not there. For any province along the coast, the return period is higher and is in the order of 1-2 systems every 10 years for the most exposed provinces of Zambézia and Inhambane with 9 hits each. The province of Sofala experienced 5 hits in the last 5 decades with IDAI being the second TC on record to have hit the province (after TC Eline in February 2000 that made landfall 60 km south of Beira).

In Mozambique, TS and TC events are considered as low-frequency events. Owing to the low frequency nature of TS and TC, it is critical to maintain a high level of awareness and preparedness of people and institutions to ensure effective action in case of warnings.

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[2] The level of vulnerability to floods will depend on the degree of exposure of people and assets in the floodplains and the copping mechanism that are established.

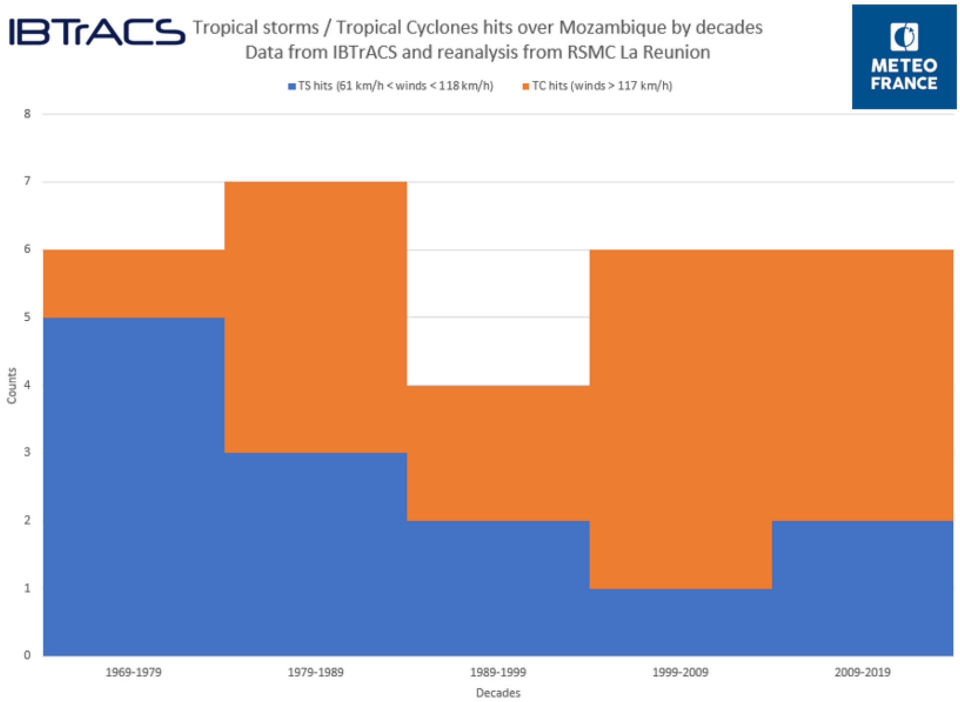

Figure 4. Counts by decades of tropical storms and tropical cyclones hits over Mozambique during the 1969–2019 period (satellite era). Data prior to 1979 should be taken with caution regarding intensity with possible underestimation (overestimation) of the TC number (TS number)

In a WMO International Workshop on Tropical Cyclones, held in December 2018[3], consensus projections of future TS and TC behaviour in the context of climate change, continue to indicate a global decrease in numbers of TS and TC. However, with increases in their maximum intensities and increases in TS and TC-related rainfall. The report of the workshop also indicates an observed poleward migration of the latitude where TS and TC reach their life maximum intensity. According to Knutson et al (2015), despite the global reduction in numbers of tropical cyclones for the warmer climate, the Geophysical Fluid Dynamics Laboratory (GFDL) hurricane models show an increase in the numbers of the most intense tropical cyclones. The tracks of all storms that reached at least category 4 (US Saffir-Simpson scale) intensity in the present day and late 21st century simulations, as shown in Figure 5, indicate an increase in the number of storms by 28%. The number of category 4-5 days is projected to increase by 35% globally[4].

[3] https://www.wmo.int/pages/prog/arep/wwrp/tmr/IWTC9TopicReports.html
[4] It is to be noted that projections of tropical cyclones in a warmer climate is still a subject of scientific research as there are large uncertainties associated with the projections.

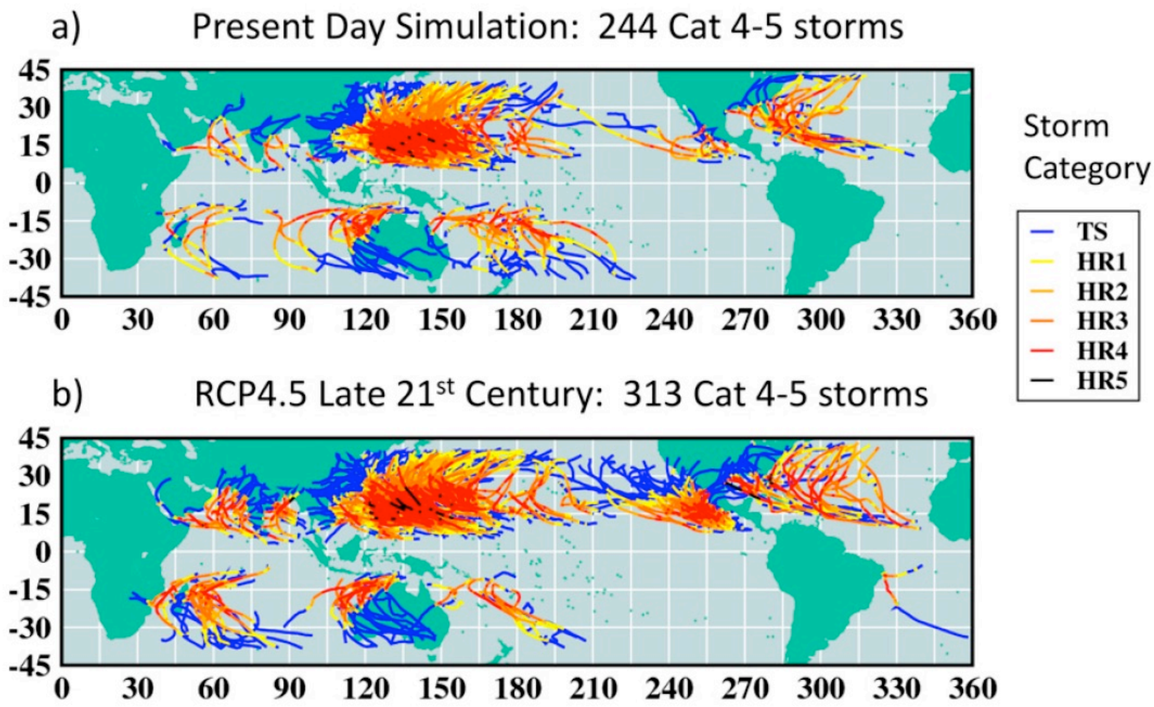

Figure 5: Tracks of simulated cat 4–5 tropical cyclones for (a) present-day or (b) late-twenty first-century (RCP4.5; CMIP5 multimodel ensemble) conditions obtained using the GFDL hurricane model to resimulate (at higher resolution) the tropical cyclone cases originally obtained from the HiRAM C180 global mode. (*Source*: Knutson et al, 2015)

Currently, the southern coastal province of Mozambique Maputo has never suffered from a direct hit of a TS and TC and the province of Gaza was hit once by Tropical Dopical depression Domonina in 1984. Although being still low, the likelihood of a direct impact over these southern areas may increase over the next decades. Future sea level rise will exacerbate the impact of storm surge on coastal regions, assuming all other factors are equal. These two latter points are highly critical and raise major concerns regarding Mozambique's vulnerability to flood from rivers and from the sea.

4. Status of capacities to support End-to-End Multi-Hazard Early Warning Systems and gaps to be addressed

The mission identified a number of challenges and proposed actions to address the deficiencies over short-term (0-2 years), medium-term (2 - 5 years) to long-term (5 -10 years +) periods. An indication is provided against the recommendations already planned in existing development projects and those still requiring investment, along with estimated costs. A summary of these can be found in Annex 2.

4.1 Meteorological

INAM has been receiving support from the World Bank Pilot Programme for Climate Resilience (PPCR) programme which terminates at the end of 2019. The Nordic Development Fund (NDF) Technical Assistance Programme, which is delivering to

Component B of the PPCR has been extended to December 2020. The latter programme funds technical advice to INAM on the design of a "functional" observations network, training needs and recommended courses associated with a forecasting platform and impact based forecast approach to early warnings and development of a strategic plan – aligned to the Government of Mozambique's 5 year Plan to 2025. In addition to this programme, FAO and WFP are working with INAM to understand how they might support agrometeorological requirements in the form of trainings or provision of Automatic Weather Stations (AWS). The NDF technical assistance programme is facilitating a coordinated and standardised approach to both training and equipment provision. However, the investment into INAM is limited (a maximum of USD 4 million across the board). When considering the funding for a radar in Xai-Xai, rehabilitation of the observations network nationwide, baseline training requirements across staff, the low national budget allocation to INAM for operations and maintenance of staff levels and equipment required it is clear INAM is in dire need of investment.

This report highlights what money is being spent and what money is needed to bring INAM up to the baseline of the World Meteorological Organization Standards as a National Meteorological Service. Key to any future funding objectives must be the requirement to increase INAM's skill in forecasting and capacity to communicate clearly to the public and government in times of extreme weather and climate events. The NDF Technical Assistance Programme, led by the Met Office, UK, and partnering with Deltares, Met Norway and Consultec, has started this journey. Future investments should build on this work to ensure consistency and quality of development of the early warnings nationwide.

a. Operational forecasting

Challenges	*Recommendations*
The operational forecast branch of INAM in Maputo has 20 forecasters, who are distributed between the head office and Maputo Airport, to support aeronautical activities on a 24h and 7 days basis and for the provision of services to the public and government institutions such as INGC and DNGRH, respectively. The forecasting centre at the headquarters operates 16 hours per day, 7 days a week. There is no night shift to cover events occurring at night.	Short-term: consider 24 hours and 7 days operations at the headquarters, particularly during emergence periods.
Operational staff have access to data and information from the South African Weather Services (SAWS) Regional Centre in Pretoria; global centres such as the European Centre for Medium Range Weather Forecasts (ECMWF), the UK Met Office, UK; the Regional Specialized Meteorological Centre (RSMC) La Réunion; and satellite data from the European Organization for the Exploitation of Meteorological Satellites (EUMESAT) and various data and products broadcast by EUMETSAT through EUMETCast. They also access the Severe Weather Forecasting Demonstration Project (SWFDP) Southern Africa Website. However, the capacities of staff to effectively use and interpret some of the high value products offered by the global and regional centres is lacking. For example, operational staff are not using the Flash Flood Guidance System (FFGS) information available on the SWFDP website although 3 people were trained on this system.	Short term: Immediate in-country training on use and interpretation of products offered by global and regional centres; and training on the use of methodologies and tools such as the FFGS should be implemented as a matter of urgency.
Numerical Weather Prediction (NWP) is based on the Weather Research and Forecasting Model (WRF) run at a coarse resolution	Short-term: INAM to introduce

Challenges	*Recommendations*
(14 km). Two of the forecasters have been trained in NWP. NWP could be enhanced by using higher resolution output available from the Unified Model (UM) run at 4km resolution at the South African Weather Service (SAWS), and from AROME-La Réunion (2.5km at least for the eastern part of Mozambique). WRF could be used as a capacity building tool to allow INAM staff to run models at much higher resolution (e.g., 1 km) as INAM will soon have a high performance computer provided under the PPCR project.	use of high resolution NWP products available from regional centres. Appropriate training should be carried out.
Some of the forecasting equipment is not operational or is partially operational (Meteo-France Synergy workstation – 2015 version). Installed DIANA[5] workstation should be enhanced to integrate observational data and products development modules. Use of this equipment would not achieve its full potential owing to the limited quality of the internet access.	Short-term: a technician to repair the Synergy Workstation and upgrade Dianna system. Internet speed must be increased
A major gap in operational forecasting and relationship of INAM with institutions such as DNGRH and INGC is the absence of Standard Operating Procedure (SOP) to ensure consistency of operations, data and information exchange, clear roles and responsibilities and provision of information to users in an understandable and timely manner.	Short-term: standard operational procedures (SOP) must be developed and implemented as a matter of urgency.
INAM's operational forecasting needs to be implemented as impact-based forecast and risk based warnings (IBF & RBW). This is an important gap in knowledge. Users of INAM products and services contacted during the mission clearly indicated need for INAM to change the language of its communications to ensure people understand the meaning and impact of the information (particularly warnings). For example 50 mm of rain per hour or winds of 150 km/h does not tell people what the potential impacts would be and the actions to be taken. INAM's messages should be user-oriented and targeted to the various audiences. For example the messages to INGC should not be the same as the ones going to the public or DNGRH. Hazard characteristics, their frequencies and trends should be updated. This information should be a critical input for risk assessments, which should be used for planning, preparedness, response and to support public education and awareness.	Short-term: INAM to receive training on hazard risk assessment and on how to engage in public education and awareness about hazards, hazard risk and impact based forecasting. This could be done as part of the disaster risk management and resilience programme approved by the World Bank (DRM program para 33). Medium-term solution: INAM to continue to update IBF methods through training and implement IBF and RBW.

[5] [5] https://wiki.met.no/diana/start

b. Communication of warnings

Warning communication is one of the four components of an effective multi-hazard early warning system, as described in section 3.3.

Challenges	*Recommendations*
INAM has not had a weather presenter on the TV for the past few years. A new TV studio has just been donated to INAM, which should be used to broadcast weather information and warnings. This studio could also be used for producing material for education and public awareness.	Short term: provide training and support to TV weather presenters with outfits to build their confidence on the screen
In the medium-term INAM should work to establish TV product development capabilities. This could be done through partnerships with TV stations and/or media companies.	Medium-term: INAM to seek partnerships with TV and/or media companies to produce awareness material.
Today, infographics, websites, social media, among others, are important means of communicating and reaching out particularly to young generations. It is also important for countering fake and unauthoritative news on weather.	Short term: Update website and develop a strategy for social media presence.
Communicating weather forecasts and warning should not be limited to TV broadcasts, radio, print media, websites and social media. All means, including community based social structures, e.g, community leaders should be used to complement conventional communication streams. INAM should pursue implementation of Common Alert Protocol, and various communication channels and means to reach out to the vast majority of the population of the country in ways that are appropriate for the different targeted communities.	

c. Observation systems

Observations underpin all products and services provided by a National Meteorological and Hydrological Service. Timely access to high quality observations can be invaluable in the lead-up to, during and after high-impact weather events - informing global and regional models, providing forecasters with an improved understanding of conditions on the ground, post event analysis and forecast, and warning verification.

Operating observation networks requires well trained, skilled and resourced staff to maintain equipment and ensure that the network delivers timely and accurate observation. It is also important that the engineering and maintenance staff tasked with maintaining this network is distributed across the country in order that they can access stations at short notice. A significant challenge faced by INAM is limited operational funding to support and maintain the existing observing network. Without sufficient funding any new capabilities are unlikely to remain operational beyond the short-term. Additionally, the internal capacities of INAM to maintain the observing network are limited, calling for the need to build capacity of INAM to support the observing network. In the short to medium-term, while INAM develops its capacity, out-sourcing or sub-contracting maintenance to third parties should be considered.

In the long-term, to sustain an adequate observation programme, it is recommended that a network of 5 engineering service centres are implemented across Mozambique to enable INAM to provide engineering support across the country. These engineering service centres would be developed at the existing INAM regional offices in: Xai-Xai, Beira, Nampula, Tete and Pemba.

The following represents a summary of the existing capabilities within INAM and identifies areas of the existing observation network which have been impacted by tropical cyclone IDAI.

Infrastructure

Challenges	*Recommendations*
The biggest impact on INAM infrastructure as a result of tropical cyclone IDAI was the devastation of the regional office at Beira. This office housed the regional administrative staff and observers, while the wider compound houses the existing C-band weather radar. An immediate priority should therefore be to return this office to an operational state, ensuring that it is able to sustain winds similar to those during IDAI, enabling INAM to resume its responsibilities and to remain operational during severe events.  **Figure 6. State of the INAM regional Office in Beira and paper records damages by rain after the roof of the building was blown away**	Short-term: rehabilitation of INAM's building (included in the PDNA assessment but not yet funded).
There is an opportunity to increase the value of the Beira facility to both INAM and the Central region of Mozambique by constructing a larger, modern facility with improved and more resilient communication links. This new facility should include an enhanced engineering presence, with a well-equipped technical centre enabling INAM to support and maintain the Beira weather radar. The new facility would also manage a radiosonde station and provide a centre for maintenance of manual and automatic surface observation network across Central Mozambique. A previous project has identified a requirement for an enhanced INAM facility at Beira. This proposal should be re-visited, and funding sought as part of the investment in infrastructure in the region following Cyclone IDAI.	Medium-term: Build a larger facility with resilient communication to provide technical support to the Central region of Mozambique.

Surface network

The surface observation network of Mozambique comprises a mixture of manual synoptic stations reporting at various frequencies depending on staff level, Automatic Weather

Stations (AWS) generating hourly synoptic messages, Automated Weather Observing Systems (AWOS) supporting INAM's Aviation forecasters at 8 airports across the country and generating regular METAR report and manual climate stations providing manual, daily climate observations.

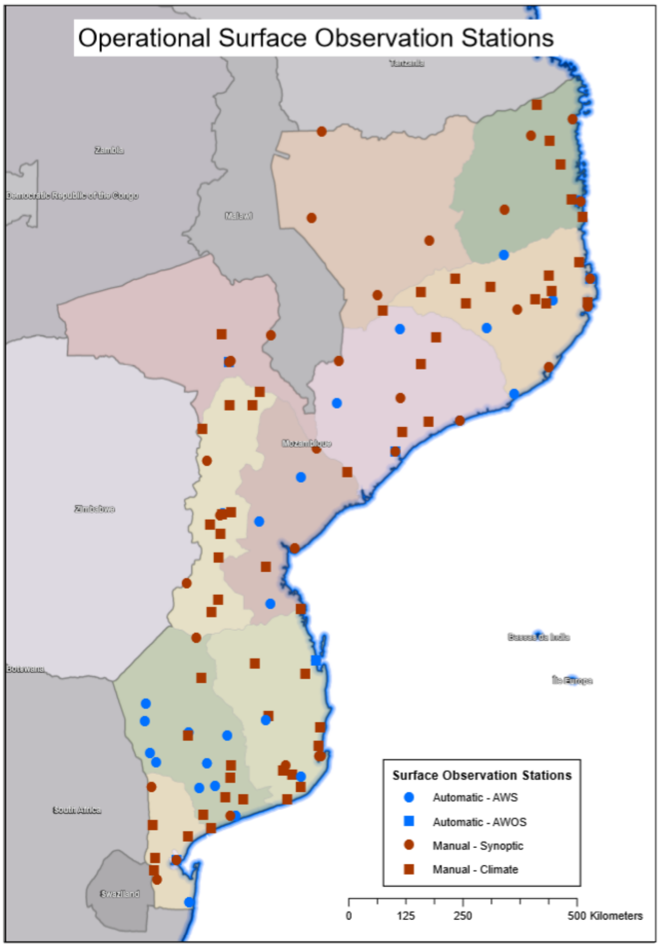

Figure 7. INAM's surface observations stations
(*Source*: INAM)

Challenges	*Recommendations*
The manual synoptic network is comprised of 42 stations which provide better coverage in the Southern half of the country. Observations are largely recorded by INAM staff and reported to Maputo via the NetSys system, or radioed through to Maputo, where the NetSys systems is not available locally. The frequency and number of synoptic observations from each station varies according to the hours the site is manned. This network uses mercury-in-glass thermometers and mercury barometers[6]. The quality of the observations from this network is high and staff-resources at the majority of stations is sufficient to provide reliable observations and maintain the observing equipment. The challenge for INAM is they lack replacement thermometers and consumables due to the limited annual operational budget they receive. This leads to delays in replacing broken thermometers and missed	Short-term: Replace mercury-based instruments. The PPCR project is supporting INAM to replace mercury instruments.

[6] According to the Minamata Convention, by 2020 manufacture, import and export of mercury-based instruments should not be allowed to prevent mercury pollution

Challenges	Recommendations
observations for individual parameters. Paper copies of the observations are periodically sent to Maputo for archiving.	
The network of automatic weather stations includes 26 AWS which are deployed across the country. Five AWS were destroyed by Tropical Cyclone IDAI. These AWS are built around Campbell Scientific data loggers procured in 2012. The AWS network faces two main challenges: (i) lack of funds to procure replacement sensors and for the sensors to subsequently be deployed at the AWS by suitably skilled engineers; and (ii) the mobile phone network enables telemetry of observations from stations via GSSM network to INAM, but this access is often suspended as a result of delayed payments. The 5 destroyed AWS were Davis Personal Weather Stations, installed as part of a funded project. These stations were providing little useful information to INAM as the observations were not available to INAM staff outside of the office where they are located. INAM should replace these with full, professional grade AWS which will integrate with the current AWS network. The PPCR project is procuring 27 AWS to complement the existing AWS network, with the locations for installation identified as part of the Salomon Report (2017). These AWS are expected to arrive in Maputo in early July. However, to provide full coverage of the country INAM would require at least one AWS in each of the 145 districts, an optimal number being 198 ground stations.	Short term: Replace five AWS damaged by IDAI with equipment which will integrate with the existing AWS network (included in the PDNA but not yet funded). Medium-term: Install 60 AWS to provide minimum coverage for forecasting and service delivery.
The AWOS network also suffers from a lack of replacement sensors. Parameters are supplemented by human observations from INAM observers based at the airports once a sensor stops reporting. The World Bank has recently procured 3 new AWOS systems which are in the process of being installed by a local contractor. Five additional AWOS are required for the operation of the 8 airports.	Short-term: Develop capacity for maintenance and spare parts
The climatological network comprises 58 manual stations and is currently using mercury in glass thermometry. The majority of observations are recorded by INAM staff. However, some stations are located at DNGRH sites and observations are recorded by DNGRH staff. Climate observations are sent to Maputo on a quarterly basis where they undergo quality control and are subsequently archived. Data is digitised by staff at Maputo on request.	Short-term: replace all mercury-based instruments from the observing network (manual synoptic and climate stations). The PPCR project is supporting INAM in replacing mercury instruments.
After IDAI, INAM was not able to maintain observations, critical during emergence response and recovery. Portable observing equipment should be available at INAM to sustain continuous provision of data and warning.	Short term: acquire portable observing stations.
To increase availability of observational records, INAM should implement the WMO Integrated Global Observing System (WIGOS). WIGOS would integrate the observations from INAM, DNGRH and other institutions operating observing networks. INAM should	

Challenges	Recommendations
also work with WMO to begin the process of recognising climate stations eligible to be classified as Centennial Stations. This would help to raise the profile and importance of these stations.	

Radar network

Challenges	Recommendations
INAM has a network of two C-band, single polarisation radars, installed in 2004 at Xai-Xai and Beira. Neither radar have been operational for many years. The theoretical coverage provided by the two radars would give good coverage of the Southern, more populated half of Mozambique and provide forecasters with an excellent source of information on rainfall distribution and intensity over a large area in real time. When in operation, data from these radars was shared with the SAWS, where it was incorporated into a radar composite and available to INAM. For the radar in Xai-Xai and Beira, options were investigated with regards to their re-habilitating. It was decided that it would not be economical to do this in the longer-term. In the case of Beira, an additional problem is the debilitated state of the radar tower. Thus, the two radars need to be replaced. This would offer the opportunity to move to dual polarisation technology with associated benefits to users. The radar of Xai-Xai will be replaced under the PPCR project. As part of the recovery efforts following Cyclone IDAI a replacement radar should also be considered for Beira. In addition to the procurement of the radar itself, the site requires extensive work to rehabilitate the infrastructure destroyed by IDAI.	Short term: The ongoing PPCR project is in the process of tendering for a replacement radar for Xai-Xai, with an ambition to have it commissioned by the end of 2019. Medium-term: Replacement of the Beira radar and associated infrastructure work should be given high priority.
INAM has an aspiration to develop a network of seven radars, which would provide coverage of the entire country. At a minimum, a radar installed on the Northern coast of Mozambique and those of Xai-Xai and Beira would provide enhanced coverage of the coastline. INAM has identified Nacala as a suitable location. This would provide INAM with a very valuable source of information for the monitoring of intensity of rainfall associated with tropical cyclones and also small-scale, localised thunder-storm activity.	Long-term: consideration should be given to an additional radar in Nacala.
As Mozambique considers investing in radars, it is essential that installation of radars is matched with investments from the government for maintenance of this valuable source of real time data and a commitment to increasing the operational capacities of INAM. Furthermore, to ensure effective operational support for the radars the same model of radar should be installed at all locations in the network, reducing the requirement for INAM to have detailed knowledge of multiple systems and spare parts from multiple manufacturers.	

Climate records

Challenges	Recommendations
INAM currently holds a wealth of historic climate and weather data in paper format which is at risk of being lost due to poor archiving and storage facilities. Some of this data has been digitised (Maputo quality control staff will digitise data for stations on-request, but is not a default practice). Digitised records are held across a number of local drives climate database, CliData.	Medium-term: a data rescue programme to recover and digitise data in paper format is needed.

Challenges	*Recommendations*
Under the PPCR project a proposal has been presented for the inventory of existing INAM archive (digital and paper) and transfer of paper records to a more appropriate storage facility in order to reduce the risk of loss and begin work to digitise the records. The project has recently introduced an open-source climate database, Climsoft at INAM. This is part of an effort to establish an interoperable data management system integrating in near-real time data from INAM and DNGRH in a common data base, thus, facilitating data access and sharing. Ultimately Climsoft should be the single repository for all climate observations held by INAM. This work is also valuable in supporting INAM's future engagement on climate research programmes regionally and nationally.	The PPCR project would procure the equipment required for digitisation and put in place a process for the digitisation of records, importing to Climsoft and subsequent quality control.

Lightning detection

Challenges	*Recommendations*
INAM currently has a network of 11 short range Earth Networks lightning detection receivers, predominantly installed on mobile phone infrastructure owned by Movitel. Of these 11 sensors, 7 are currently operational. Lightning observations from this network are available to INAM via a web-portal provided by Earth Networks. However, this lightning data is not routinely accessed by INAM forecasters and the network of receivers does not provide sufficient coverage to provide a reliable indication of lighting activity across the entire country. INAM forecasters also have access to lighting information available via satellite products. Lightning detection efficiency via satellite is very variable and typically not very high. Lightning data could be used for thunderstorm.	Short-term: Ensure that forecasters all have access to and are making full use of the Earth Networks lightning observations available to them.

Radiosonde

Challenges	*Recommendations*
Historically INAM has operated 3 radiosonde stations, located at Maputo, Beira and Nampula. Since 2000 no station has reported any observations. The radiosonde station at Nampula requires repair to the hydrogen generator to operate. This should be investigated further by means of a site visit from a suitably experienced radiosonde expert who can detail whether there is scope to rehabilitate the existing sonde station. Nampula has a reserve of sondes and balloons which would cover sounding for a couple of years. If it is not possible to return the existing equipment at Nampula to an operational status, then a replacement station and associated infrastructure should be commissioned and installed. Radiosondes provide extremely valuable information to global and regional models regarding temperature, water content and wind speeds through the earth's atmosphere. The radiosonde network across Africa is sparse due to the expense of sondes, balloons and maintenance of hydrogen generators and the required staff to launch the sondes. It would therefore be a very valuable addition to INAMs observing network to see the re-introduction of regular radiosonde launches.	Short –term: Assess the feasibility of repairing the hydrogen generator in Nampula.
As part of the investment in an improved INAM facility at Beira a new radiosonde station should be considered, with modern	Medium-term: introduce sounding

hydrogen generator and appropriate training for staff to conduct launches. In addition, engineers to support and maintain the ground station and hydrogen generator would be required.	at Beira.
In the long-term, assuming INAM is able to operate the Beira radiosonde station in a reliable manner, a station should subsequently be installed at Maputo. INAM's compound in Benfica, Maputo, should be prepared for this.	

Third party data

Challenges	*Recommendations*
At present DNGRH collates daily rainfall observations from a network of over 500 manual rain gauges operated by the regional water agencies (ARAs) across the country. The observations for the vast majority of these sites are posted to DNGRH every three months, where they are keyed into the DNGRH database and undergo quality control. Daily observations from a very small sub-set of 31 stations are shared by the ARAs with DNGRH along with river level observations from approximately 70 manual river level stations via a WhatsApp group. This comprises the DNGRH early warning system. INAM and DNGRH are mandated to share rainfall and meteorological observations between the two organisations at no cost. In practice this information must be requested and so the observations are not routinely shared. Eight DNGRH rainfall stations and 70 hydrological stations (river level) stations were destroyed by Cyclone IDAI. It will be the responsibility of the local ARAs to ensure that they are replaced. It is also understood that the ARA's operate a network of automatic rain gauges. However, the data from these networks is not shared with DNGRH or INAM. These observations, if shared in real-time between with INAM and DNGRH, would provide high resolution rainfall data which could potentially be very valuable to both during extreme weather events. This begs for the immediate implementation of WIGOS.	Short-term: implementation of WIGOS at a national level. WMO to support the development of a WIGOS implementation plan for Mozambique. In doing this it is also important to work with key partner agencies recording environmental observations to be part of WIGOS implementation.
INAM should endeavour to migrate all their surface network metadata, for all stations, to the WMO Oscar/Surface portal. This would provide a resilient and easy to access repository for this information. As part of the migration of metadata to Oscar a thorough review of station metadata should be undertaken, in particular to review station co-ordinates. Metadata for the surface observation network is currently managed by a series of Excel spreadsheets with details on station location, parameters reported and instrumentation deployed. There are currently 56 surface observation stations registered in Mozambique on the WMO Oscar-Surface portal.	Short-term: WMO to provide technical assistance to INAM and DNGRH to migrate metadata to WMO Oscar/Surface portal.

Mozambique benefited from the Southern Africa component of the Hydrological Cycle Observing System Project (SADC-HYCOS)[7], which contributed to developing and/or strengthening national and regional capacity in the fields of water resources monitoring,

[7] https://hydrohub.wmo.int/en/projects/SADC-HYCOS

assessment and management, including provision of water resources data and information for integrated water resources development and management. Continuation of this project or a similar initiative is deemed necessary for improved international water resources management in the region.

4.2 Hydrological

Mozambique is pursuing efforts in disaster risk management through the implementation of specific measures and policies in the field of hydrology. Despite this, the catastrophic nature of IDAI and the corresponding floods overwhelmed the DRM measures in place. The following section provides recommendations for strengthening the weaker aspects of previous actions to reduce vulnerability; and enhance prevention, preparedness and response to flooding, thereby increasing the nation's resilience.

To develop resilience to floods, appropriate prevention and risk management strategies need to be evaluated to reflect both structural and non-structural measures to reduce basin-wide risk exposure. Integrated Flood Management approaches[8] should be adopted across the country and embed the potential future impacts of climate change. Specific emphasis should be on non-structural measures aligned to the context and needs of each focus region, so that they are meaningful and enable users to take action.

a. Operational flood forecasting

Challenges	*Recommendations*
Automation of river basins data collection and processing Basic data processing tasks are carried out manually, taking considerable time of staff in hydrological offices. Automation of data collection and processing, including quality analysis and quality control procedures should be given consideration to improve efficiency and improved utilization of the limited human resources.	Medium to long-term: Implementation of complete network of hydrological automatic and river basin stations and automation of processes at data processing centers.
Operational forecasting models Hydrological real time forecasting models have special requirements. They need preprocessing of rainfall forecasts, flood forecast model calibration and post processing of forecasted discharge. Robustness, easy interpretation and rapid calculations are needed. Currently, running of hydrological models by the DNGRH takes too much time for provision of warnings in a timely manner, because tools in use are designed for studies rather than operational forecasting. In addition, different models are used by DNGRH	Short to medium-term: Make available a selection of informatics tools that take into consideration the special requirements of real time forecasting models. Implement operationally proven models using freely available software to meet the needs of real time flood forecast operations. Short-term: Involve staff of DNGRH in the use of tools such as Southern Africa Regional

[8] https://www.floodmanagement.info/about-us/ifm-concept/

Challenges	*Recommendations*
and ARAs. This calls for the need to standardize the models in use with the adoption of similar models or models that can provide outputs which can be used between the institutions. Efforts should be made to enhance the capacities of the ARAs in modeling. This should accompanied with enhanced access to spatial information (e.g., terrain models, satellite imagery, etc.).	Flash Flood Guidance System (SARFFGS), through forming a workgroup that gather people from INAM, ARAs and DNGRH to advance understanding and use of the system. Undertake additional training of INAM, ARAs and DNGRH staff in understanding and use of SARFFGS.
Currently DNGRH generates satellite rainfall estimates used as input to hydrological models. These estimates should be carried out by INAM and the results shared with DNGRH to ensure consistence of satellite rainfall estimates used for weather forecasting and hydrological modelling	Short-term: INAM to start producing satellite rainfall estimates which should be shared with DNGRH and ARAs
Despite the existence of specific agreements between DGNRH and INAM, the data and forecast product exchanges need to be improved to prevent failures in operational coordination. The lack of data and forecast product exchanges is linked to deficiencies in a number of areas: data processing, IT resources, automation of stations and a suitable database. Through the PPCR project, a modern database management system is being implemented, which will automate data collection and exchange among the relevant institutions. The project is also helping with standardization of data collection.	Short-term: a) improve general IT infrastructure by improving internet speed for operational purposes as a matter of priority; b) implementation of a modern database management systems and transfer of existing data into the new system. This to be complemented with appropriate operational quality assurance and quality control procures. Medium-term: design and implement an automatic system for data processing, using a hydrological database having modern database management software.
DNGRH is currently understaffed for effectively delivering on its operational responsibilities. The situation could worsen as staff number are expected to reduce further in the near future.	Short-term: maintain, at least, the current staff and consider additional recruitments.
Staff at DNGRH and ARAs could benefit from additional training in various areas as there is currently limited training available to enhance work-related competences.	Short term to long-term: To develop and implement a continuous training and capacity building program. Training sessions should be aimed at enabling staff solving practical problems in the context of Mozambique. In-country

Challenges	Recommendations
	training should underpin any technological transfer to ensure effectiveness and sustainability in the long run.
The quality of data that underpins flood forecasting is limited. Hydrometry data collection to ensure sufficient number of rating measurements is needed. Rating curves need to be systematically and periodically adjusted.	Medium-term: develop and implement a continuous hydrometry to program ensure rating measurements are taken and rating curves are adjusted.

Transboundary river basin data sharing is critical for Mozambique as a downstream country. A protocol under the Sothern Africa Development Community (SADC) allows exchange of data on water storage and flows. A specific river basin agreements has been signed on the Púnguè basin with Zimbabwe. Under this agreement there are regular coordination meetings involving the water and meteorological institutions of the two countries before and after the rain season. An agreement on the Búzi river is expected soon. Agreements on river basins should be pursued for all the transboundary river basins which do not have them for more efficient water and flood management.

b. Non-structural measures

Challenges	Recommendations
Capacity Building for Integrated Flood Management Capacity Building Programs through flood risk management campaigns and education opportunities targeting various groups of stakeholders in flood-vulnerable areas can help strengthen preparedness against floods under different flood scenarios, and thus contributing to minimizing flood damages.	Short-term, Medium-term, Long-term. consider training programs for different levels in Mozambique for INAM, DNGRH and the ARAs. WMO to support through Associated Programme on Flood management (APFM) and FFGS and Integrated Drought Management Programme (IDMP)
Flood Hazard Mapping These are among the most important non-structural measures to provide information about flood-prone or vulnerable areas. Limited availability of hydrometric data has not enabled development/updating of flood hazard maps for the entire country. These are a vital component to support appropriate land	Short-term to medium-term: update flood hazard maps for the entire country.

Challenges	Recommendations
use planning in flood-prone areas. It creates easily-read, rapidly-accessible charts and maps which facilitate the identification of areas at risk of flooding and also helps prioritize mitigation and response efforts.	
Land use planning for effective floodplain management To effectively manage flood plains, development on flood-prone areas should be restricted to the extent possible. This will result in reduced risk of flood damages. Flood plains can be used for specific activities provided measures have been taken to protect investments (combined with structural measures like flood proofing).	Medium to long-term: enhance land use planning and implement appropriate floodplain management, including limiting occupation of floodplain, where appropriate.
In the recent past, villages and cities have expanded along rivers. This associated with limited enforcement of effective land use planning and flood plan policies resulted in loss of human life and assets during flood events. Thus, implementation of best management practices is required.	Medium-term and Long term WMO to support through APFM and FFGS.

c. Structural measures

Though structural measures require significant investments, there is value in implementing structural measures as Mozambique is a downstream country.

Challenges	Recommendations
Controlled Overtopping and Breaching of Levees and dykes During a flood event, the risk of a levee overtopping can be significant and the consequences can be catastrophic. Controlled overtopping of levees or engineered overtopping involves designing a levee to allow overtopping in the least hazardous location. This can be done by using different levee heights. Most of the existing levees in Mozambique were constructed mainly with soil alone. During the flood season, they tend to easily collapse and do not provide a sufficient level of stability and safety.	Medium to long-term: develop national standards construction of levees or ring dykes.
Levees, floodwalls, seawalls, and other pertinent structures These structures are designed to prevent floodwater and storm surges from reaching areas at risk. Consequences of failure of implemented structures can be catastrophic as it would result in rapid inundation and flooding conditions more severe than if the floodwaters had risen gradually.	Medium-term, Long-term: consider implementation of flood management structures, as appropriate, supported by research on selection of sites and flood

	prevention structures..

Mozambique has developed its Water Resources Management Plan with a vision to 2040. The plan is costed at USD 13 billion and provides the main elements to improve water resources management, including the construction of structural measures. For Central Mozambique, Dams on the Búzi and Púnguè rivers would contribute substantially to flood management and storage of water, needed in cases of predicted drought. However, resources for the implementation of the Plan are yet to be identified[9].

4.3 Institutional linkages and coordination

Early warnings are an essential component of disaster risk reduction. They prevent loss of life and contribute to reducing the socio-economic impacts of extreme hazard events. According to WMO (2018)[10], for early warnings to be effective, they must consist of the following 4 elements: disaster risk knowledge based on the systematic collection of data and disaster risk assessment; detection, monitoring, analysis and forecasting of hazards and possible consequences; dissemination of authoritative, timely, accurate and actionable warnings and associated information on potential impacts by an officially designated source; and preparedness at all levels to respond to the warnings issued and to build back better in recovery, rehabilitation and reconstruction. These 4 elements must be underpinned by: effective governance and institutional arrangements, including effective coordination and collaboration of the key institutions and stakeholders; a multi-hazard approach to early warnings; involvement of concerned communities and stakeholders, including local communities and appropriate consideration of gender, age, disability and cultural issues.

Analysis of hazard characteristics and their changing patterns should inform risk knowledge and support the development of building codes, land use planning (including urban planning), and the design and siting of infrastructures. Policies and strategies for floodplain management should be based on knowledge of hazards and risk assessments.

a. DRR governance and legislation in Mozambique

The governance of disaster management is per the structure shown below.

[9] Development of Master Plan for Water Resources Management in Mozambique: Interim Report, March 2017

[10] Mullti-hazard Early Warning Systems: A Checklist. WMO, 2018

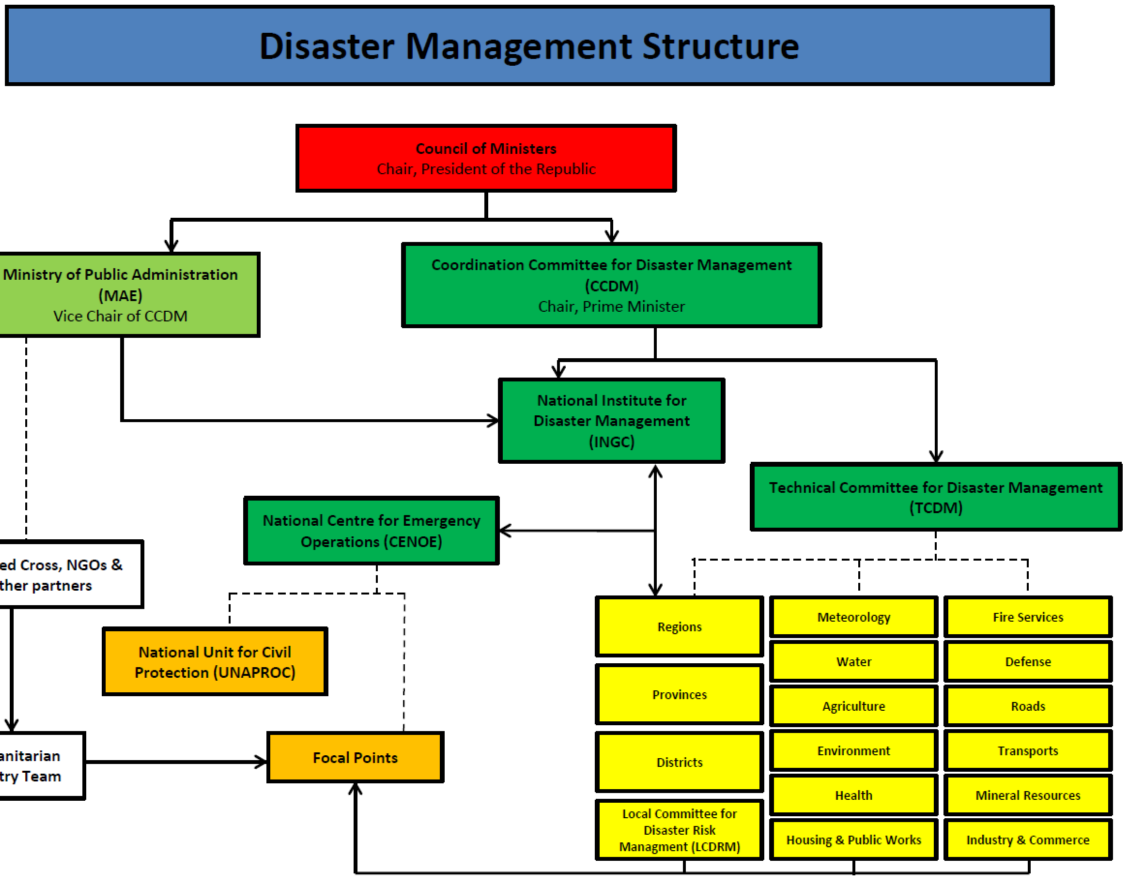

Figure 8. Disaster risk management structure in Mozambique
(*Source*: INGC)

Major milestones in disaster risk management include:

1999 Establishment of a National Disaster Management Policy;

Creation of the National Institute for Disaster Management (INCG), Coordination Council for Disaster Management (CCDM), and the technical council for disaster management (TCDM);

2006 Establishment of the National Emergency Operational Centre (CENOE) and the National Civil Protection Unit (UNAPROC);

Approval of the Master Plan for Prevention and mitigation of Natural Disasters;

Establishment of Local Disaster Risk Management Committees (DRMC;)

2014 Adoption of Disaster Risk Management (Law 15/2014),

2017 Master Plan for Disaster Risk Reduction for the period 2017-2030.

These milestones represent steps towards proactive preparedness, coordination and response to disasters. They also represent efforts to decentralize disaster risk management to community levels, empowering community to take part in preparedness and response to disasters through the establishment of community-based early warning systems. The development of annual contingency plans informed by seasonal forecasts is an effort to use scientific information in support of disaster risk reduction decision-making in the country.

b. Early Warnings

The institutions mandated to issue early warnings for meteorological and hydrological hazards are the National Institute of Meteorology (INAM) and the National Directorate of Water Resources Management (DNGRH) supported by its operational entities, the Regional Water Administrations (ARAs). The National Institute of Disaster Management (INCG) is responsible for issuing response measures to the warnings issued by INAM and DNGRH.

With the imminence of tropical cyclone IDAI, INAM issued alerts and warnings as shown in the table below.

Table 1. Alerts and warnings issued by INAM

Date	**04/03/19**	**05/03/19**	**06/03/19**	**07/03/19**	**08/03/19**	**09/03/19**
Warning	Heavy rain, severe thunderstorm and strong wind	Tropical depression	Heavy rain, severe thunderstorm and strong wind	Heavy rain, severe thunderstorm and strong wind	Heavy rain, severe thunderstorm and strong wind	Tropical depression
Target Area	Zambézia, sofala and Tete	Zambézia, Sofala, Manica, Tete and Niassa	Zambézia, Sofala, Manica, Tete and Niassa	Zambézia, Sofala, Manica, Tete Nampula and Niassa	Zambézia, Sofala, Manica, Tete and Niassa	Zambézia, Sofala, Manica, and Tete
Alert color code	Yellow	Red	Red	Red	Orange	Orange
Observed data	Wind: 56km/h gust 74km/h Precip (mm): Quelimane - 63.6; Mocuba - 187.0	Wind: 37 km/h Gust 56 km/h Precip(mm): Mocuba -88; tsangano - 103.1; Milange - 224.1 ; Caia - 53.1	Wind: 37 km/h Gust 56 km/h Precip(mm): Mocuba - 98.9 Furacungo: - 134.4; Tsangano - 166.4; Ulongue – 139.2; Songo – 65.7; Tete – 69.9; Cuamba – 64.7; Milange – 66.2 ;Luia – 65.4 Moatize – 75.3 Zobwe – 110.7	Wind: 36km/h Precip(mm): Furancungo – 135.4; Tsangano – 168.7; Ulongue – 309.5; Caia – 86.4 Milange - 66.5; Pebane – 78.2 ;Zobwe - 147	Wind:34km/h Precip(mm): Lumbo – 47.8 ;Milange 37.0	Wind: 56km/h Gust 83km/h Precip(mm): Angoche 30.8
Date	**10/03/19**	**11/03/19**	**12/03/19**	**13/03/19**	**14/03/19**	**15/03/19**
Warning	Moderate tropical Storm IDAI	Intense Tropical Cyclone IDAI	Intense Tropical Cyclone IDAI	Tropical Cyclone IDAI	Intense Tropical Cyclone IDAI	EX- Tropical Cyclone IDAI
Target Area	Mozambique Channel, Zambezia , Sofala, Manica and Tete	Mozambique Channel, Zambézia, Sofala, Manica, and Tete	Mozambique Channel Zambézia and Sofala	Mozambique Channel, Sofala, Manica, Zambezia and Inhambane	Sofala, Manica, Tete, Zambezia and Inhambane	Sofala, Manica, Tete and Inhambane
Alert color code	Orange	Orange	Red	Red	Red	Orange
Observed data	Wind: 120 km/h Gust 167 km/h Precip(mm): below 30	Wind: 176 km/h Gust 250 km/h Precip(mm): Pemba – 55.7 ; Montepuez – 32.6	Wind: 158 km/h Gust 213 km/h Precip(mm): below 30	Wind: 185km/h Gust 259 Precip(mm): Quelimane – 47.4	Wind: 194 km/h Gust 278 km/h Precip(mm): Above 250 (Satellite estimate)	Wind: 167 km/h Gust 231 km/h Precip(mm): Chimoio – 233.3 Espungabera – 220.6

DNGRH also issued alerts and warnings as shown in Table 2.

Table 2. Warnings issued DNGRH

Date	08/03/19 (warning 1)	09/03/2019 (Warning 2)	10/03/19 (Warning 3)	13/03/2019 (warning 4)	17/03/2019 (warning 5)
Warning	Water levels in the Licungo river 1.85 m above alert levels. Water levels rising rapidly in the rivers Revubuè, Liua and Chire. People and instititutions in the along the Licungo and Zambeze rivers to evacuate immediately from at risk zones to higher ground.	Zambeze river under maximum alert. Water levels at 10meters in the Revúbue sub-basisn at Chingodzi. Peoplle and institutions along the river to evacuate immediately from at risk areas to higher ground	Risk of urban floods in the cities of Beira and outskirts and Qualimane and outskirts dur to a propical depression in the Mozambique channel. People to evacuate immediately from at risk zones to higher ground	Probability of heavy rains due to tropical cyclone IDAI with the risk of moderate to big floods in the citiy of Beira and outskirts, Dondo and outskirts, Quelimane and outskirts. People to evacuate to higher ground	Duee to intense rainfall in the rpovinces of Sofala, manica and neighbouring Zimbabwe, Chicamba dam might release water flows of the order of 500 m3/s.Increased risk of flooding in the districts of Búzi, Nmamatanda, Donmdo, Muanza and Chibabava. People to evacuate from at risk areas to high ground
Target Area	Districts of maganja da Costa, Namacurra, Chemba, Mutarara, Cais, Luabo, Marromeu and Chinde	Districts of Chemba, Tambara, Caia, Chinde, Luabo, Mopeia and Marromeu	Cities of Beira, Quelimane and Donndo and in the basisn of Licungo, Zambeze, Púnguè and Búzi	Cities of Beira, Quelimane and Dondo and in the basins of Licungo, Zambeze, Púnguè and Buzi	Districts of Búzi, Nmamatanda, Donmdo, Muanza and Chibabava

INAM has a color coded tropical cyclone warning system that consists of 3 colors indicating the number of hours before a tropical cyclone makes landfall (blue – between 24 and 48 hours; yellow – within 24 hours; and red – within 6 hours). In the alerts and warnings issued by INAM, the tropical cyclone color system was confused with a color system used by INGC to indicate the required readiness levels for institutions contributing to disaster risk management. INGC's color coded system also consists of three colors (Green – alerting institutions for a potential emergency; Orange – institutional focal points are activated, who start monitoring hazards and preparing for emergency; and Red – Emergency clusters activated). Apparently the readiness level color coding system, should only be restricted to institutions involved in emergency management. To the public, the tropical cyclone color coding system should have been used. In Buzi, where community based risk management committees had been trained on INAM's color system for tropical cyclone warning, the population raised flags according to the colors of tropical cyclone warning system and not according to INCG readiness levels. Similarly, DNGRH has a color coding systems which indicates the level of risk of flooding (green – low; yellow – moderate; orange – moderate to high; and red – high).

The above begs the need to harmonize the color coding system used by INAM and DNGRH to warn about meteorological and hydrological hazards and creation of a different system for readiness levels of the institutions involved in disaster risk management. One option could be for one system to use colors and the other to be based on numbers (e.g., 1 to 3) or code names. Failure to harmonize the color coding system used by INAM and DNGRH and its separation or distinction from the readiness levels of INCG will result in confusion and ineffectual response by people and various stakeholders. It is essential to establish clear and agreed Standard Operational Procedures (SOP) between INAM, DNGRH and INCG so each have clear roles and responsibilities.

Operationally, when INAM and/or DNGRH issue a warning, INGC calls a meeting of institutional focal points to jointly produce a communiqué with response measures to be taken by the public. During the 2018-2019 rainy season the warnings issued by INAM and DNGRH also included response measures. INGC should be the authoritative institution issuing response measures to avoid confusion. Development of impact-based forecasts and risk based warning by INAM and DNGRH will provide expected impacts which should be integrated in decision support tools housed at INGC. INGC will then generate scenarios of potential impacts on the basis of which appropriate response measures can be determined and the vulnerability information they have for each district. INAM and DNGRH should engage in education and public awareness activities to increase understanding about hazards, their characteristics and corresponding risks. INGC should promote overall education and awareness of disaster risk management. These activities should be of ongoing nature, but not initiated during an emergencies.

Warnings issued by DNGRH called for evacuation of people from at risk areas to higher and safer places from the 8th of March. Though floods were recorded in the lower part of the Licungo river and in the city of Tete, most of targeted areas for the warnings did not have floods until four days after tropical cyclone IDAI made landfall. The issue of continuous warnings for evacuation without people experiencing actual floods in the days that preceded the major floods in the Búzi and Púnguè river basins might have contributed to the low response to warnings after cyclone IDAI. This was also impacted by the breakdown of communications following IDAI.

In addition, there is an immediate need to identify safer areas in case of floods and involve the population in drills or simulations with a view to enhance effectiveness of response during emergencies.

c. Institutional coordination

All people the WMO mission met consistently indicated a limited understanding of warnings by the population and decision makers. The terms used in meteorological and hydrological warnings (e.g., 185km/h winds and 500 m3/s) are not understood. There is need to make it clear what the potential impacts are and in a way people can relate to, enhancing level of response to warnings.

During and after tropical cyclone IDAI landfall, the total breakdown of communications and electricity meant communication of warnings, and coordination was made impossible. People who had seen the impacts of IDAI in the form of rain and strong winds, were left without means of receiving warnings of impending floods. In addition, the very rapid increase of water levels which occurred at night caused the failure of the community based flood warning system in place in the Búzi district for example.

IDAI uncovered multiple weaknesses in the emergency preparedness, coordination and response, as follows:

- Absence of a communication system that can be used in the case of failure of normal communication means for warning and emergency operations;
- Ineffective land use planning and enforcement for efficient floodplain management;
- Absence of an evacuation plan for cities such as Beira, Búzi and Dondo;
- Limited capacities of INGC and CENOE at regional and provincial level to respond to emergencies. the regional and provincial offices had to be supported by staff from the capital in the lead up and during the emergency;
- Limited capacities of UNAPROC in emergency response, particularly, search and rescue;

- Limited understanding of risk at institutional and individual levels. It is said that Beira was prepared for floods, but not for tropical cyclones. The low frequency nature of tropical cyclones in the province of Sofala might be an important factor in risk perception;
- Absence of an integrated approach for multi-hazard early warning systems;
- Accuracy of the warnings, particularly for floods in some river basins;
- Building codes not suitable to events of the magnitude of cyclone IDAI.

d. Forecast Based Financing in Mozambique

There is a growing movement within international and national development finance institutions to create mechanisms to fund and disburse early action and preparedness financing[11]. The Forecast Based Financing Programme[12] in Mozambique is led by the German Red Cross that works with the National Red Cross and volunteers in the country. Together with INAM, DNGRH and INGC they are developing the thresholds for the triggers needed for Early Action Protocols (EAP) and disbursement of funds ahead of a hazard to people so they can prepare for severe weather and climate events. Under the programme, the Red Cross facilitates development of the EAPs and the World Food Programme works at ministerial level to support policy development for early action early finance for preparedness and embed this work into the national economic and social psyche programme. At present, the EAP for Mozambique is still in development and one of the key challenges is improving coordination and capability across the three technical agencies to support this work. The capability and coordination required will be addressed through WMO report recommendations to clarify Standard Operating Procedures and trainings in impact based forecasting, into which the Red Cross and World Food Programme (WFP) will be incorporated. DFID[13], the WFP (ARC Replica[14]) and the African Development Bank (ADRIFI)[15] are also establishing Disaster Risk Finance programmes with the Ministry of Finance in Mozambique. Effective implementation of this approach could significantly contribute increased preparedness to hazards.

e. Disaster Fund

A disaster management fund has been recently created . The fund is primarily aimed at supporting emergence response. However, the operations of INAM and DNGRH, who are key actors in the early warning system and their contribution to disaster risk management is hampered by limed budgets. This results in the limited operational capabilities of INAM and DNGRH thereby compromising the quality of their contributions to the national warning system. To address this major shortcoming consideration should be given for INAM and DNGRH to tap into the disaster management fund and complement the operational budgets of these institutions. In the event this can't be done, a dedicated fund to support operational capabilities for the early warning system should be considered to ensure that these institutions are adequately funded to effectively support the early warning capacity and corresponding preparedness and response capabilities.

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[11] This approach is being pursued by organizations such as DFID, World Bank, German Government, World Food Programme, FAO, among others

[12] https://www.forecast-based-financing.org/projects/mozambique/

[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/723220/Mozambique-July-2018.pdf

[14] https://www1.wfp.org/publications/2018-arc-replica

[15] https://www.afdb.org/en/news-and-events/african-development-bank-rolls-out-programme-to-boost-climate-risk-financing-and-insurance-for-african-countries-18618/

5. Overall recommendations

Various efforts on disaster risk management, including an early warning system for hydro-meteorological hazards have been pursued in Mozambique. Effective early warnings prevent loss of life and contribute to reducing the socio-economic impacts of extreme hazard events. However, the catastrophic nature of IDAI overwhelmed those efforts. Moving forward, Mozambique needs to rethink and invest in strengthening all components of its early warning system adopting a multi-hazard approach. It also needs to revisit the weak elements of disaster risk management interventions, to improve overall resilience to extreme hydro-meteorological hazard events. Mozambique will have to build coping mechanism to deal with tropical cyclones, floods and droughts in an integrated manner.

Based on the findings of the WMO expert mission, recommendations are provided below. Specific actions to implement the recommendations are provided in Annex 2.

- INAM and DNGRH should create capacity development plans, as part of strategic plans, to provide continuous training to staff to enhance the efficiency of operations and the quality of products and services generated by both institutions. INAM requires further funding in addition to the "knowledge transfer pprogramme provided under the NDF project and basic training provided under the World bank PPCR. Training needs should be extended to allow for consistent and repeated upskilling of staff.;
- There are currently different warning systems for meteorological and hydrological hazards. These warning systems need to be harmonized and simplifies. In addition, the warnings issued should be targeted, user-oriented and should provide the potential impacts from the hazards;
- A national integrated flood risk assessment for all types of floods should be developed to guide adoption of appropriate measures;
- Implementation of structural measures should be considered, along with effective maintenance of new and existing structures;
- Implementation of non-structural measures, along with best management practices in flood management should be considered and given priority;
- The country needs to build multi-purpose resilient infrastructure, which could be used as shelters in cases of tropical cyclones and accommodation centres in cases of floods (e.g., schools, stadiums, etc.). There is also a need for some public infrastructure to be retrofitted or designed to withstand intense tropical cyclones or be sited on safe ground for floods to ensure provision of basic services during emergencies (e.g., hospitals, police and fire brigade station, etc..);
- Moving into the future and in the reconstruction process, and to build back better, building codes which were designed in the 60s need to be updated taking into account changing return periods of hazards, increase in rainfall and tropical cyclones intensities. Better supervision of constructions could yield benefits in the short-term;
- Standard Operating Procedures to ensure consistence of operations, data and information exchange, clear roles and responsibilities and provision of information in an understandable and timely manner need to be established;
- High levels of public awareness and preparedness need to be maintained for tropical cyclones and extreme floods, which are low frequency events. Many people who received warnings during and after IDAI did not understand the danger associated with the warnings;

- Future rise in sea level will exacerbate the impact of storm surge on coastal regions, raising concerns with respects to floods from the sea. Coastal protection measures need to be considered;
- Many people did not respond to warnings owing to fear of losing assets and livelihoods. There is need for security to be ensured during emergencies to protect people assets.

All in all, these measures need to be accounted for and incorporated into a National Climate Adaptation Plan which all sectors contribute to and which is informed by future climate scenarios to ensure activities are resilient and can withstand the impacts of climate change.

6. References

Associated Programme for Flood Management:
https://www.floodmanagement.info/about-us/ifm-concept/

IWTC-9, 2018: Proceeding of the 9th international Workshop on Tropical Cyclones, Honolulu, Hawaii, USA, 3 – 7 December 2018 (https://www.wmo.int/pages/prog/arep/wwrp/tmr/IWTC9TopicReports.html).

Knutson et al, 2015: Global Projections of intense Tropical Cyclone Activity for the late Twenty-First Century from Dynamical Downscaling of CMIP5/RCP4.5 Scenarios, Journal of Climate

Mozambique Disaster Risk Management and Resilience, 2019 (http://documents.worldbank.org/curated/en/328661553004113498/pdf/Mozambique-Disaster-Risk-Management-and-Resilience-Program-Project.pdf)

Mullti-hazard Early Warning Systems: A Checklist. WMO, 2018 (https://public.wmo.int/en/resources/world-meteorological-day/wmd-2018/multi-hazard)

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7. Annexes

Annex 1. Detailed Analysis of Tropical Cyclone *IDAI*

Meteorological

Tropical Cyclone *IDAI* started to develop on the 4th March close to the coastline of the province of Zambézia as a tropical depression with wind speeds of about 55 km h^{-1} and 1005 hPa in the center of the system. The system made a first landfall on the same day, north of Quelimane. During the following 4 days, a remnant of low pressure persisted over land while the system headed north then northwestward until the 6th of March, before turning back east-southeastward early on the 7th of March close to the Mozambique-Malawi border. Persistent local and heavy rainfall with associated thunderstorms linked to the cyclonic vortex, affected southern Malawi and the provinces of Zambézia, Sofala, Nampula, Tete and Niassa until the 8th March. On the 9th of March, the remnant low pressure moved back towards the sea – Mozambique Channel. At sea, it intensified rapidly maturing into a tropical cyclone by the 11th of March, off the western coast of Madagascar.

IDAI started to reverse its track early on the 11th towards the Mozambican coastline as anticipated many days earlier by numerical weather prediction models. On the 12th of March track forecast uncertainty had reduced (well below usual standards) clearly indicating that *IDAI* would hit the Beira area. Landfall eventually occurred on the evening of the 14th, around *22 UTC*, in the northern vicinity of Beira, with the city experiencing the calm eye of the storm. Tropical cyclone *IDAI* then started to weaken as it moved inland.

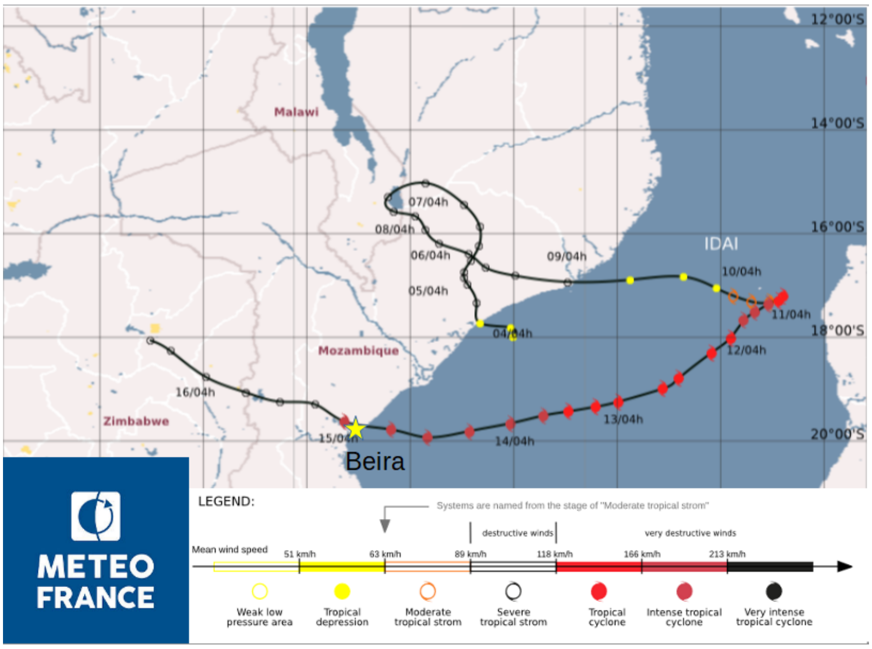

Figure 1. Track and intensity of Tropical Cyclone IDAI, 4–16 March 2019.
(*Source*: Météo-France /RSMC La Reunion)

Characteristics of IDAI at landfall:

Winds: based on operational (real time) analysis from the Regional Specialized Meteorological Centre (RSMC) La Reunion, *IDAI* was assessed with maximum 10-min winds at 165 km h^{-1} gusting up to 230 km h^{-1}. This made it an intense tropical cyclone based on the South-West Indian Ocean basin regional terminology that corresponds to category 4 (out of 5) on the scale used in Mozambique. *IDAI* is not the strongest tropical cyclone to have hit Mozambique. Tropical cyclones *ELINE* in February 2000 produced 185 km h^{-1} winds at landfall.

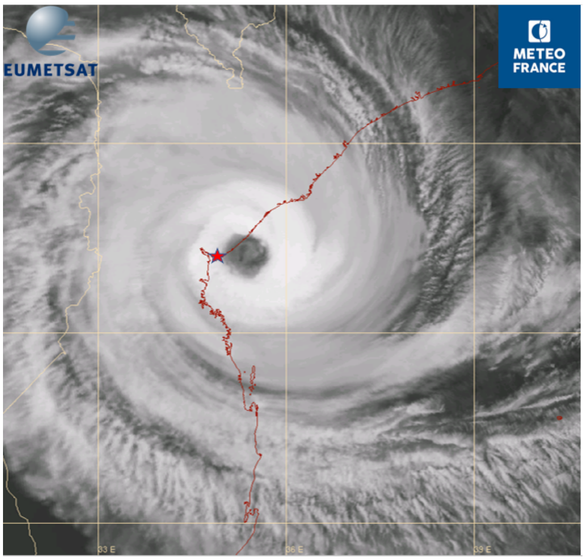

Figure 2. Metop-B Infrared image on the 14 March at 18:48 UTC shortly before landfall. The red star indicates the position of Beira.
(*Source*: Eumetsat and Meteo-France)

The structure of *IDAI*'s windfield just before landfall is revealed by an invaluable Synthetic Aperture Radar acquisition onboard European Satellite Agency (ESA) Sentinel 1-B satellite. Destructive winds (winds greater than 90 km/h gusting to more than 125 km/h) extended up to 100 km from the center. Very destructive winds (winds greater than 118 km h^{-1} gusting to more than 165 km h^{-1}) extended up to 70 km from the center. The strongest winds were located on the eastern side of the eye (the rear side) at a distance of about 35 km from the centre of the eye. The relatively calm eye had a diameter of about 45-50 km. Those dimensions made IDAI a normal-sized cyclone.

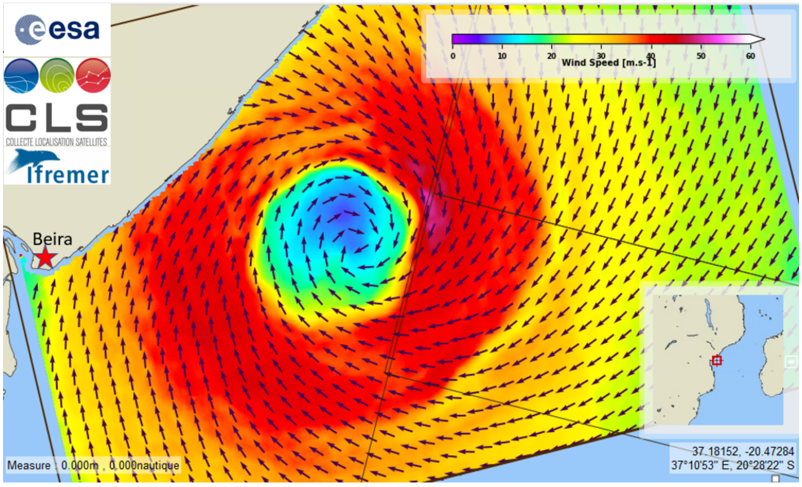

Figure 3. Sentinel 1-B Synthetic Aperture Radar 3-km winds data on the 14 March at 16:06Z. The red area shows the extension of very destructive winds with gusts higher than 165 km h^{-1}.
(*Source*: ESA and CLS)

Rain: *IDAI* brought heavy rainfall over parts of northern Mozambique and Malawi between the 4th and 10th of March. Later on, and associated with the second landfall near Beira, heavy rainfall was recorded in the Beira region on the 14th of March and spread inland up to eastern and central parts of Zimbabwe until the 17th of March. After the 17th, additional rainfall occurred over central Mozambique until the 21st of March. A 7 days satellite-based rainfall amounts estimate between the 13th and the 20th March from the IMERG-GPM product is presented below. The highest amount of rainfall, likely exceeding 500 mm, occurred inland Mozambique between Chimoio and Dondo over flat and low-lying areas after *IDAI* made landfall. Those rains fed the major and deadly flood event mainly in the Búzi and Púnguè rivers that started a few days (3 to 4 days) after the cyclone passed over Beira.

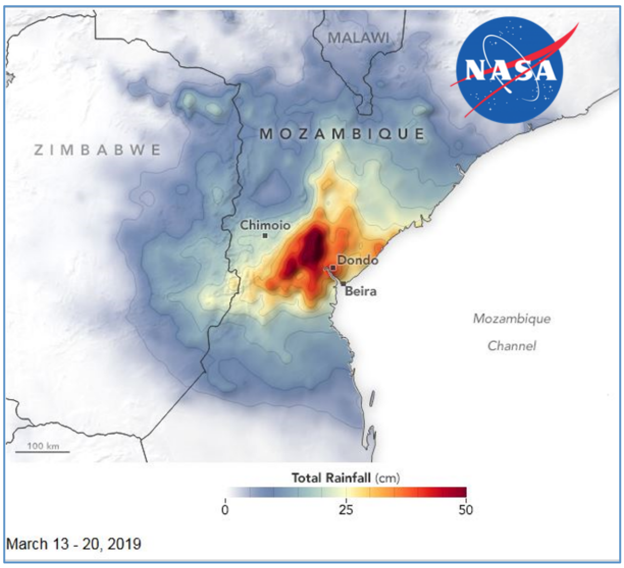

Figure 4. 7 days IMERG-GPM satellite-based rainfall estimates
(*Source*: NASA)

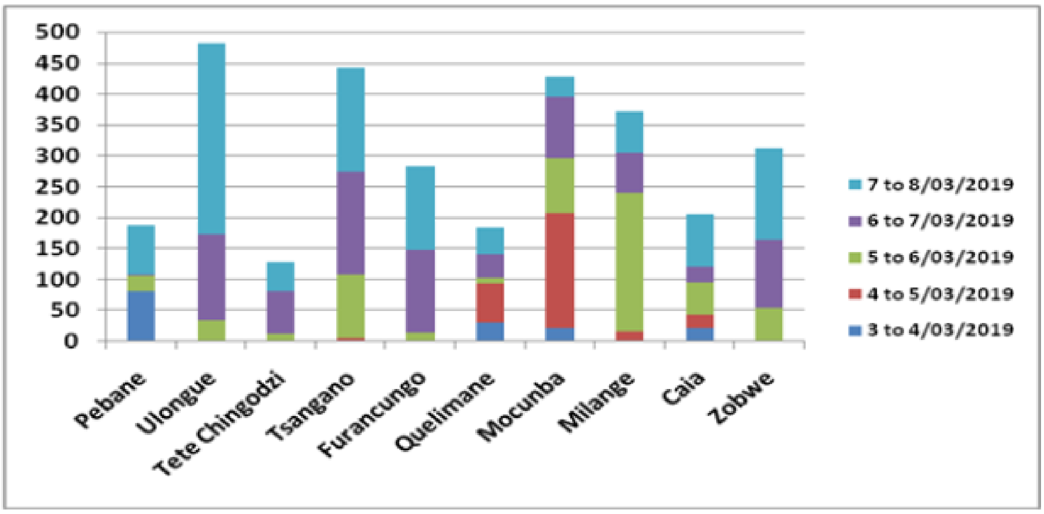

Figure 5. Accumulated rainfall observed from 3 to 8 March in INAM's weather stations

Sea: large battering waves along with abnormal sea level rise occurred along the Sofala province coastal areas between the 13th and 15th of March. The maximum impacts along the coastal areas are estimated to be south of *IDAI*'s eye. No observed data is currently available about the sea state. Major concerns were raised days before the event as the geographical configuration of the area around Beira is highly prone to storm surge and resulting sea flooding. However, reports from Beira indicate only moderate damage due to the combined effects of waves and storm surge. Two elements seem to have contributed to dampen flood from the sea at Beira: *IDAI* had its eye (the calm part of the cyclone) over Beira meaning that the strongest winds blew parallel to the coasts and not from the sea towards the coast. Therefore, the maximum storm surge likely occurred south of Beira along less populated coastal areas. Secondly, when the eye passed through Beira, it was low tide, which enabled the recently rehabilitate drainage system in Chiveve to evacuate the rain waters to the sea.

Hydrological

From the 6th to the 8th of March, heavy rains were recorded in the Ligonha, Licungo, Raraga, Zambeze, Púnguè, Búzi and Save river basins in Central Mozambique. Malawi also experienced heavy rains causing a rise in water to above alert levels in the basins of Licungo, Raraga, Namacurra, Zambeze and in the sub-basin Revubuè. Resulting floods occurred in the lower Licungo and in the city of Tete. From the 15th to the 18th of March persistent and above normal rains were brought by tropical cyclone *IDAI*. This resulted in floods of a great magnitude in the river basins of Búzi and Púnguè and the city of Beira recorded moderate floods in its outskirts. In the same period the Save river basin recoded high water flows owing to water coming from upstream yet without significant impacts. The Dams of Cahora Bassa and Chicamba had an increase of volume of storage to nearly 99% and 76%, respectively.

The situation was made worse by the already high soil moisture due to rains in the before cyclone *IDAI*. Thus, rains after cyclone *IDAI* resulted in runoff as the soil was already saturated, combined with the river flows from upstream countries resulted in extreme floods around Beira.

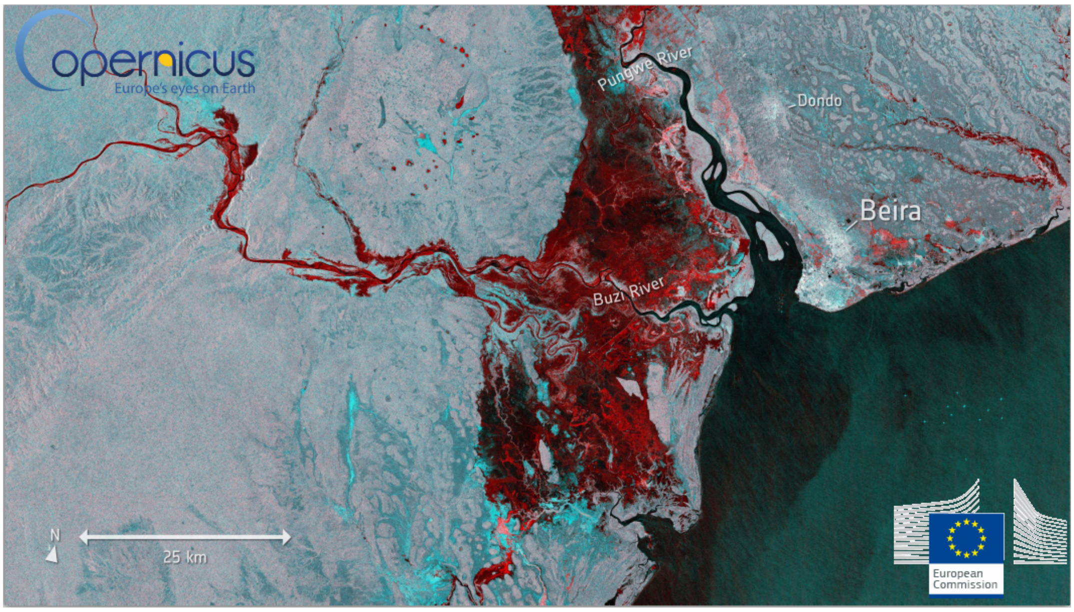

Figure 6. Extent of flooding (red areas) caused by *IDAI* on the 19 March.
(*Source*: European Commission/Copernicus Emergency Management Service)

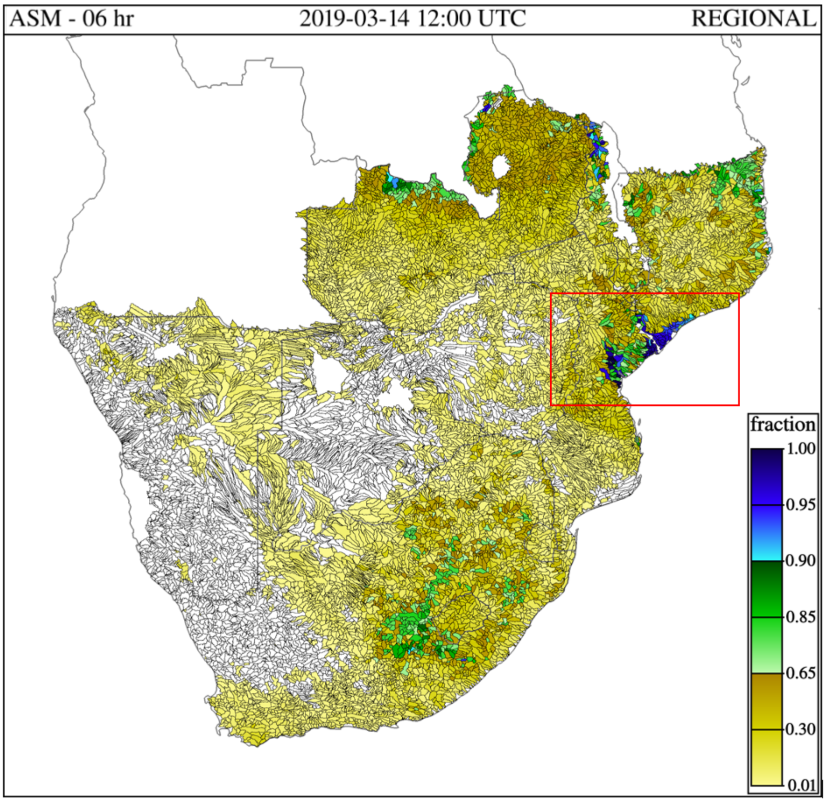

Figure 7. Average Soil Moisture (ASM) from the Southern Africa Regional Flash Flood Guidance System products one day before *IDAI* made landfall.

Annex 2. Recommended actions over short-, medium-, and long term and associated costs

Meteorology Sector

Issue/s	**Recommendations**	**Estimated cost (USD)**
Forecasting		
Shor- term		
No 24/7 operational forecasting programme on the public side at INAM headquarters (no night shift) while operational forecasting for aviation is a 24/7 programme.	INAM to implement operational 24/7, 365 days per year operation, including at the forecasting centre at the headquarters (night shift at the headquarters)	1000,000
Limited access and use of data and product from Reginal and Global centres	In country training on the use and interpretation of products offered by Global and Reginal centres	250,000
Status of Numerical Weather Prediction	Acquire an HPC to run a High Resolution model. Work with WMO to request from Meteo-France an extension to the domain of the AROME La Reunion to cover Mozambique and make available its data. In addition, data from UM model from SAWS should also be made available. [A HPC being provided under PPCR project] and secure fast internet access for NWP and operational forecasting	350,000
Synergie system available but not functional	INAM to work with WMO to repair the system	25,000
New DIANA workstation installed, tested and awaiting full roll out: at present it is not ready to ingest observing data. [Ongoing NDF project is to complete ingestion of observations data into DIANA - expected to complete end of the year]. Observations data is currently viewed on another system, the NetSys which is a system developed for aeronautical meteorology, is capable of producing flight plans.	INAM with support from UKMet Office to accelerate the implementation of a fully operational DIANA workstation to ensure all the information needed by forecasters is available in one place with possibility of overlaying data/information from multiple observations including access to China Meteorological Administration satellite information to facilitate forecasting decision-making. This should include the automatic integration of all synoptic observations that are currently gathered manually.	50,000

Issue/s	Recommendations	Estimated cost (USD)
Manual plotting of synoptic observations	Acquire a plotters to plot automatically synoptic observations and other data	50,000
Lack of Standard Operating Procedure (SOP) for operational forecasting, data information sharing, clear roles and responsibilities and provision of information to users in an understandable and timely manner	Develop as a matter of priority SOP for the operational forecasting Office of INAM and data and information exchange with DNGRH and INGC	100,000
No implementation of impact based forecasts and risks base warning	Training on hazards risks assessment, impact based forecasting and how to engage on public awareness	150,000
Sub-total		**1,075,000**
Medium-term		
No access to high value information for forecasting activities to ensure forecast quality	Acquire a 5 year licence of EC-Chart an ECMWF system and conduct t related staff training	100,000
No implementation of impact based forecasts and risks base warning	Further training on impact basing forecasting	50,000
Sub-total		**150,000**
Long-term		-
Total		**1,225,000**
Communications and warning		
Short term		
No television weather broadcasts for 2 years. A new equipment for a TV studio has been acquired under the NDF project and is close to being operational (in 2 to 3 months)	Train staff on generating content using the refurbished TV studio in collaboration with TV stations	50,000
Low quality of INAM's website(website not regularly updated and poor in content)	Update INAM website content and conduct training on web maintenance - link to social media outlets and measure 'hits' for future development.	50,000

Issue/s	Recommendations	Estimated cost (USD)
Sub-total		**100,000**
Medium-term		
Limited presence of INAM on social media to counter fake news on weather and to communicate the value of their services	Develop and implement a strategy on visibility on social media such as YouTube, Facebook or twitter to inform and counter incorrect messages from non-authoritative sources	**50,000**
Sub-total		**50,000**
Long term		
Lack of redundant system for communicating warnings when normal channels of communication are down	Explore option for providing alternative meaning for communicating warning(satellite phones, weather radio system, permanent mobile provider to reach remote, vulnerable communities)	100,000
Sub-total		**100,000**
Total		**250,000**
Public Education and Awareness		
Short term		
Limited understanding of hazard risks by the population and decisions makers. This is exacerbated by lack of clear mandate to raise community awareness and education on weather phenomena and likely impacts; Lack of communication of likely impacts of weather phenomena;	Training on public weather services, impact based forecasting (both in Maputo and with regional centres to introduce the concepts and strengthen messaging & cooperation across INAM, INGC and ARAs at national and provincial level	100,000
Sub-total		**100,000**
Medium term		
Limited understanding of hazard risks by the population and decisions makers. This is exacerbated by lack of clear mandate to raise community awareness and education on weather phenomena and likely impacts; Lack of communication of likely impacts of weather phenomena;	Training on public weather services, impact based forecasting (both in Maputo and with regional centres to introduce the concepts and strengthen messaging & cooperation across INAM, INGC and ARAs at national and provincial level	200,000
Sub-total		**300,000**

Issue/s	Recommendations	Estimated cost (USD)
Long term		
Lack of redundant systems for communicating warning when the normal channel of communication is broken	Explore options for providing alternative means for communicating warnings (satellite phones, weather radio system with a permanent frequency, mobile network providers to reach remote, vulnerable communities)	100,000
Sub-total		**100,000**
Total		**300,000**
Observations and Infrastructure		
Short term		
INAM's Headquarter office in Beira destroyed	Rehabilitate existing INAM facilities at Beira	250,000
Loss of 5x AWS from network during Cyclone IDAI	Procure 5x AWS which will integrate with existing INAM AWS network	100,000
Limited recognition of importance of climate observations within Mozambique Government	Identify climate stations eligible for WMO 'centennial station' status and begin certification process	10,000
No real-time wing and rainfall intensity information available to INAM staff for tropical cyclones, storms and flood forecasting	Restore Xai Xai radar to operational status	1,500,000
No regular radiosonde measurements of temperature / humidity / wind profiles, informing global and regional models	Investigate whether it is possible to rehabilitate the existing radiosonde station at Nampula	70,000
Use of Mercury observing equipment in the manual observing sites	Remove mercury from manual observing stations [The PPC project is providing some support for this activity]	250,000
Poor climate data management and analysis	Climsoft implementation and training	100,000
No integration of observations taken at national level by various institutions	Implementation of WIGOS at a national level. WMO to support the development of WIGOS Implementation Plan for Mozambique. Work with key partner agencies recording environmental observations to be part of the WIGOS implementation	100, 000
No migration of surface network metadata for all stations to the	WMO to provide technical assistance to INAM and DNGRH to migrate metadata to	20,000

Issue/s	Recommendations	Estimated cost (USD)
WMO OSCAR/ Surface portal. This is necessary to provide an easy and access to the repository of this information	WMO OSCAR/ Surface portal	
Sub-total		**2,300,000**
Medium term		
Limited functionality of INAM regional office in Beira	Invest in an improved regional facility at Beira	2,500,000
Lack of engineering resources distributed across the country in order to support and maintain INAM infrastructure	Implement a network of 5 suitable staffed and equipped regional maintenance centres across Mozambique	2,500,000
Lack of observations during response and recovery when the normal observing station is destroyed	Equip regional observing sites with 7 portable observing stations to ensure support of stakeholders during the response and recovery periods	70,000
Limited availability of real-time synoptic observations in remote areas.	Technical and logistical support for INAM for the installation of the 27x AWS being procured as part of the PPCR project [Stations being procured under PPCR project]	100,000
Not all the 145 districts have an observing sites to provide a representative weather and climate observations	Complement the current observing site with additional 60 AWS	2,000,000
No real-time wing and rainfall intensity information available to INAM staff for tropical cyclones, storms and flood forecasting	Replace Beira radar, including infrastructure works for the radar	2,500,000
No regular radiosonde measurements of temperature / humidity / wind profiles, informing global and regional models	Installation of new radiosonde station at improved INAM Beira facility.	300,000
Real time rainfall data not exchanged between INAM, ARAS and DNGRH	Establish protocols to share and exchange real-time rainfall data between INAM, DNGRH and ARAS and agree on a national weather and climate data repository. Integration of meteorological and related data between national institutions [This activity should be part of the data management system being introduced under PPCR]	50,000
No upper air observations in the country	Repair of the hydrogen generator and restoration of the upper air station in Nampula	50,000

Issue/s	Recommendations	Estimated cost (USD)
Sub-total		**10,070,000**
Long term		
No real-time wing and rainfall intensity information available to INAM staff for tropical cyclones, storms and flood forecasting	Installation of C-band weather radar at Nacala, including infrastructure works, power generation and telecommunications	4,000,000
No regular radiosonde measurements of temperature / humidity / wind profiles, informing global and regional models	Installation of new radiosonde station in Maputo, including infrastructure works	300,000
Data Quality Control is only conducted at INAM HQ manually by a limited number of personnel (13);	Procure data server, implement automatic Data Quality Control and train personnel	10,000
Declining number of volunteers at climate stations	Procure observing equipment and train volunteer observers	100,000
Loss of climate data on paper records	Implement a Data Rescue Plan	250,000
Sub-total		**4,660,000**
Total		**17,030,000**
Maintenance		
Short term		
No standard Operating Procedure for the maintenance of instruments	Develop as a matter of priority an SOP for equipment maintenance	50,000
Limited training of technicians	Train staff on maintenance and implementation of SOP	50,000
Sub-total		**100,000**
Total		**100,000**
Grand Total		**18,905,000**

Hydrology Sector

Issue/s	Recommendations	Estimated cost
Forecasting		
Short term		
Hydraulic studies to analyse possible effects of high flows (flood extent on the landscape) and to improve estimation of flood discharge magnitude	New land surveys to develop flood risk mapping	1,000,000
Lack of harmonized and standard use of satellite rainfall estimates carried out by INAM	INAM to start producing satellite rainfall estimates which should be shared with DNGRH and ARAs	100,000
Sub-total		**1,100,000**
Medium term		
Time consuming routines in basic hydrological data processing	Implementation of automated river basin data processing centres aimed at automation of the processes	200,000
Quality of real-time operational flood forecasting models	Design and implementation enhanced real-time operational flood forecasting models	300,000
Limited understanding of the effects of the storm surge associated with the cyclones, local features such as bathymetry, tide phase, runoff from inland rainfall and human settlement	To evaluate different scenarios of possible combined effects of storm surge and runoff of inland rainfall and the development of coupled surge-hydrological modelling for forecast and warnings	100,000
Inadequate communication and cooperation between forecasters and dam managers to allow for effective dam and flood management	To establish effective communications between forecasters and dam managers in order to include future operation of dams and reservoirs in forecasting models and provide forecast products to the dam managers in order to be used in their decision-making process	50,000
Sub-total		**650,000**
Long term		
Sub-total		**0**
Total		**1,750,000**

Issue/s	**Recommendations**	**Estimated cost**
ICT & Infrastructure		
Short term		
Limited of hydrological capabilities and equipment for modelling and forecasting	Acquire high-speed performance computing	350,000
DGNRH and ARAS do not have an adequate telecommunications technology to access information	Improve general IT infrastructure and provide fast internet access of for NWP and operations	200,000
Sub-total		**550,000**
Medium term		
Limited flood management infrastructure facilities, controlled overtopping and breaching of levees and dykes	Develop national standard construction of levees/ ring dykes [to be done as part of the Water Resources Management Plan] approved by the government management	500,000
Sub-total		**500,000**
Long term		
Sub-total		0
Total		**1,050,000**
Capacity Building		
Short term		
No use of Flash Flood Guidance System (FFGS) available for Mozambique through the SWFDP for Southern Africa website	Training and implementation of Flash Flood Guidance Systems	100,000
Limited expertise in integrated flood management	Conduct training on Integrated flood management	90,000
Limited expertise in operational Hydrological modelling	Conduct training Operational Hydrological Modelling	100,000
Effective implementation of IFM across the country	Conduct targeted training on IFM training for various groups, including training of trainers in IFM	200,000
Sub-total		**490,000**
Medium term		
Effective implementation of land use planning for effective flood management [This activity is to be carried out by the entity responsible for land use planning]	Enhance land use planning and implement appropriate floodplain management, including limiting occupation of floodplains where appropriate	200,000
Population growth and occupation of floodplains along rivers	WMO to support through Associated programme of flood management and Integrated Drought Management policies	100,000
Sub-total		**300,000**
Long term		

Issue/s	Recommendations	Estimated cost
Limited training and exposure of staff at DNGRH and ARAs to the use of different methodologies and tools	Build continuous training and capacity building programme, including training of trainers	200,000
Sub-total		**200,000**
Total		**990,000**
Communications & Awareness raising		
Short term		
Lack of an integrated voice communication system for warnings	To design and implement a network for voice communication all over the country that ensures links amongst the main stakeholders	100,000
Sub-total		**100,000**
Medium term		
Absence of evacuation plans for all communities at risk	Development floodplain plans that include relocations routes and identification of centres accommodation of people[To be done in collaboration with INCG]	300,000
Failures in forecast dissemination	Review of the current procedures for warning dissemination and design a new end-to-end flood warning dissemination protocol	50,000
Sub-total		**350,000**
Long term		
Lack of public education on floods	Conduct public education training programmes on floods, and increase public awareness	100,000
Sub-total		**100,000**
Total		**550,000**
Observations		
Short term		
Operation and maintenance of automatic hydrological stations	Comparative analysis of solutions/ options and implementation of suitable solutions	100,000
Obsolete data management software and hardware	Provide adequate solution for hydrological data management (hardware and software, and maintenance of the existing database).	100,000

Issue/s	**Recommendations**	**Estimated cost**
Limited coordination in observations, data and products exchange between INAM and DNGRH	Improve data and product exchange through automated processes. Establish interdisciplinary working groups	100,,000
Quality of hydrological network design (insufficient number and location of gauges)	Install additional real-time rainfall gauges and hydrometric (hydrological) gauges to fill the identified gaps	1,000,000
Low quality of data flows	Include hydrometry in the continuous capacity building programme. Ensure a sufficient number of rating measurements and rating curves are systematically and periodically adjusted	100,000
Limited Hydrometric stations	Install 50 automated Hydrometric stations	2,000,000
Sub-total		**3,400,000**
Medium term		
Sub-total		**0**
Long term		
Sub-total		**0**
Total		**3,400,000**
Emergency response		
Short term		
Breakdown of coordination during emergencies due to communication breakdowns	Acquire satellite based communications for emergency situations	100,000
Sub-total		**100,000**
Medium term		
Sub-total		**0**
Long term		
Sub-total		**0**
Total		**100,000**
Grand Total		**7,840,000**
Overall Total		**26,745,000**

Annex 3. Programme and people met by the mission

Date	Time	Institution	People met	Contact Info
29/04/19	Morning	INAM	DG: Conselho de Direcção do INAM. DG Adérito Aramuge DDG – Mussa Mustafa Acting Head of Forecasting – Cesar Tembe Head of Obs – Francisco Nostado Comms - Goncalves Junior WMO Team - ALL	acelso73@gmail.com mussa2503@gmail.com cesartembe2@gmail.com fnostado@gmail.com gjunior8@gmail.com
	Afternoon 14:00	GCF Pledge Discussion	GCF lead @ Ministry of Finance	Albano Manjate albanomanjate@gmail.com Sónia Silveira sgsilveira1@gmail.com
	15:15	MTC	Ministry of Transports and Communications INAM – DG Adérito Aramuge WMO mission – Filipe Lúcio, Nyree Pinder, Abdoulaye Harou, Angel Valverde	Minister, Carlos Mesquita Mrs Ludovina Bernardo, Director of Communications
	16:30	WB PDNA Lead	Senior Urban and Disaster Risk & Management Specialist INAM - DDG Mussa Mustafa WMO – Mark Majodina, Jake Brown, Firas Aljanabi	Mr Michel Matera Mmatera@worldbank.org
	17:30	DNRGH	Head of River Basin Management & WMO Hydrology Experts: Angel Valverde & Firas Aljanabi	Dr Agostinho Vilanculos afvilanculos76@gmail.com José malanço zemalano@yahoo.com.br Ana Fotine anafotine@yahoo.com.br
30/04/19	Morning and afternoon	Beira Provincial government	Governor of the Province of Sofala. Provincial Representative of the Ministry of Transports and Communications	Governor, Alberto Ricardo Mondlane hochanhane@gmail.com Bonifácio António, Direcot of Coordination Cabinet

Date	Time	Institution	People met	Contact Info
			Adérito Aramuge, Filipe Lúcio & Nyree Pinder in Beira Hosted by Head of INAM Beira Office: Mr Achado Jamal achadojamal@gmail.com	bonyantonio@gmail.com
		Ara Centro	Director of ARA Centro ARA Hydrologists	Mrs Cacilda Machave Mr António Malembe Melembe@gmail.com Mr Castro Ntemausaka Castro.ara.centro@gmail.com
		INGC Beira Municipality	INGC Provincial Representative Beira Municipality Adérito Aramuge, Filipe Lúcio & Nyree Pinder in Beira Achado Jamal	Mr Paulo Tomás Mayor of Beira, Mr Davis Simango
		DNRGH	Angel Valverde & Firas Aljanabi DDG Mussa Mustafa Sebastien Langlade & Jake Brown	Mr José Malaço zemalano@yahoo.com.br Ms Alcino Nhacume anhacume@dnaas.gov.mz
01/05/19	Morning and afternoon 10:00	Team writing day WFP	WFP Climate Lead INAM - DG Adérito Aramuge WMO – Filipe Lúcio & Nyree Pinder	Ms Daniela Cuellar Daniela.cuellar@wfp.org
	12:30	AFDB	AFDB Coordinator, Africa Disaster Risk Financing Programme WMO – all team	Mr Cecil Nartey c.nartey@afdb.org
	15:00	CONSULTEC	CONSULTEC Consultants - Hydrology WMO-all team	Prof. Alvaro Carmo Vaz cvaz@consultec.mo.mz Mrs Maria Isabel Vaz ivaz@consultec.co.mz
02/05/19	Morning	Ministry of Public	Minister of Public Works and	Minister, João Machitine j.machatine@mophrh.gov.mz

Date	Time	Institution	People met	Contact Info
	08:30	Works	Housing INAM – DG Adérito Aramuge WMO – Filipe Lúcio, Firas Filipe Lúcio, Adérito, Firas Aljanabi, Mark Majodina	Umberto Gueze, Director of International Planning
	10:30	CENOE	Senior Information Officer	Feliciano Mataveia, Head Information Management mataveiaf@gmail.com Mr Dennis Guiamba, Information Management Officer dennis.guiamba@gmail.com
	Afternoon	CENOE continued WMO - Sebastien Langade	CENOE Information Officer	Mr Dennis Guiamba, Information Management Officer dennis.guiamba@g mail.com
03/05/19	Morning 08:00	Ara Sul	Director of Ara Sul Experts at ARA Sul INAM: DG Adérito AramugeWMO: Filipe Lúcio, Firas Aljanabi, Angel Valverde	Hélio Banze, Director Heliobanze2016@gmail.com Mr Delario Sendo dsengo@yahoo.com Mr João Costa jnfdacosta@gmail.com Ms Lizete Dias lizetedias@gmail.com
	08:30	DNRGH	Director, DNGRH INAM: DG Adérito Aramuge WMO: Filipe Lúcio, Firas Aljanabi, Angel Valverde	Dr Messias Macie, Director jmacie@yahoo.com.br Dr Agostinho Vilanculo Afvilanculos76@gmail.com Egidio Govate egovate@dngrh@gov.mz Hilário Pereira hpereira@dngrh.gov.mz

Date	Time	Institution	People met	Contact Info
	11:00	Red Cross	Mozambique Red Cross Project Manager for Forecast Based Financing INAM DG Adérito Aramuge WMO: Filipe Lúcio, Nyree Pinder	Mr Janio Dambo Janio.dambo@redcross.org.mz
	Afternoon 14:00	Noon - 1400 – all team work INGC	INGC. INAM DG Adérito Aramuge WMO: Filipe Lúcio, Nyree Pinder	Mr Domingos Cuana, Director HR Arq. Rui Costa, Dputy National Director Mrs olga, Cooperation technician
	17:00	Mr Moises Benessene	Former DG of INAM and GIZ Project Manager	benessene@gmail.com
06/05/19	Morning 08:30	TVM interview with	Filipe Lúcio	Mr Brito Simango
	11:00	Ministry of Land, Environment and Rural Development	Vice-Minister INAM: DG Adérito Aramuge WMO: Filipe Lúcio & Nyree Pinder	Vice Minister, Celmira da Silva Celmira.dasilva@mitader.gov.mz Mrs Ivete Maibaze, national Director of Environment imaibaze@yahoo.com Mrs Yolanda Goncalves, Director of Planning and cooperation yogoncalves@yahoo.com.br Mr Luis Varela Luisvarela66@gmail.com
	Afternoon 12:00	Ministry of Transports and Communications	Debriefing to Minister DG Adérito Aramuge WMO – Filipe Lúcio & Nyree Pinder	Minister Carlos Mesquita

Date	Time	Institution	People met	Contact Info
	14:00	FAO	FAO Technical Advisors and Coordinators	Mr Pedro Junior Simpson Pedro.SimpsonJunior@fao.org Mr Eugenio Macamo Eugenio.Macamo@fao.org
	16:00	UNDP Samuel Akera TBC		Mr Samuel Akera samuel.akera@undp.org
07/05/19	Morning	1000 – PDNA team UNDP & WB WMO: Nyree Pinder	PDNA Coordinators	Mr Xavier Agostinho Chavana xchavana@worldbank.org Mr Samuel Akera samuel.akera@undp.org
10/05/19	Morning 09: 00	British Council WMO: Nyree Pinder	Country Director Academic Manager	Mrs Vivien Esslemont Vivien.esslemont@britishcouncil.org.mz Mr James Woodhead James.woodhead@britishcouncil.org.mz

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