A REGIONAL ANALYSIS OF WEATHER, CLIMATE, WATER AND EARLY WARNING SERVICES IN SOUTHERN AFRICA: STATUS QUO AND PROPOSED ACTIONS

Building Disaster Resilience in Sub-Saharan Africa

WORLD BANK GROUP

GFDRR
Global Facility for Disaster Reduction and Recovery

WORLD METEOROLOGICAL ORGANIZATION

The World Bank

August 2021

1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org

Citation

Please cite the report as follows: World Bank. 2021. A Regional Analysis of Weather, Climate, Water and Early Warning Services in Southern Africa: Status Quo and Proposed Actions. Washington, DC: World Bank. Translations—If you create a translation of this work, please add the following disclaimer along with the attribution: This translation was not created by The World Bank and should not be considered an official World Bank translation. The World Bank shall not be liable for any content or error in this translation.

ACKNOWLEDGMENT

The World Bank team would like to acknowledge the Southern African Development Community (SADC), the SADC Climate Services Centre and the World Meteorological Organization (Regional Office for Africa) for their continued guidance throughout the analysis, coordination with stakeholders in the region and contributions to the report. The report was made possible thanks to the contributions from national services responsible for meteorology, hydrology, early warning and disaster risk management in the 16 member states of SADC, River Basin Organisations, regional technical organisations and representatives from private sector, universities and communities in Southern Africa.

The report was made possible and prepared in the context of the Building Disaster Resilience to Natural Hazards in Sub-Saharan African Regions, Countries and Communities Program, which is an initiative of the Organization of the African, Caribbean and Pacific States (OACPS), financed by the European Union (EU) and implemented by the World Bank and Global Facility for Disaster Reduction and Recovery (GFDRR). The World Bank team is grateful to the Organization of the OACPS, the EU and the African Union Commission for their overall guidance and leadership to this program.

The report was prepared with the technical guidance and support from Royal HaskoningDHV, AquaLinks and Weather Impact, with a team led by Tjeerd Driessen and Marieke de Groen with contributions from Pleun Bonekamp, Fiona van der Burgt, Bradwell Garanganga, Karel Heijnert, Omar Khan, Alphonse Mujinga, Seun Oyebode, Rene Pearson, Hanneke Schuurmans, and Nicholas Steffens. The World Bank team for was led by Prashant Singh and Carl Dingel with contributions from Giovanni Castellanos, Makoto Suwa, and Deon Terblanche. Sonia Quiroga conducted the socio-economic analysis. Darcy Gallucio edited and Miki Fernandez of Ultra Designs, designed the report. The report also benefited from overall strategic guidance and support of Sameh Wahba, Meskerem Brhane, Sylvie Debomy, Niels Holm Nielsen and Ana Campos.

The World Bank as well as all partners and consultants extend their gratitude and appreciation to the many stakeholders who in many different ways contributed to the study and the development of this report.

DISCLAIMER

This report was prepared by the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) with contributions from consultants. The findings, analysis and conclusions expressed in this report do not reflect the views of the World Bank, its Board of Directors, the governments they represent or any of its partner organizations.

Although the World Bank and GFDRR have made all efforts to ensure that the information in this report is correct, its accuracy cannot be guaranteed. Use of any data or information from this report is at the user's risk. The World Bank, GFDRR or any of its partners shall not be liable for any loss, damage, liability, or expense because of use of data contained in this document.

The boundaries, colors, denomination, and other information shown in any map in this work do not imply any judgment on the part of the World Bank and its partners concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

The program under review in this report was financed by the EU under the 10th European Development Fund through the ACP Secretariat and was implemented by the World Bank in association with GFDRR.

TABLE OF CONTENTS

ACRONYMS

ACCESS	Applied Center for Climate and Earth System Science
ACP	African, Caribbean and Pacific countries
AfDB	African Development Bank
ANACM	National Agency of Civil Aviation and Meteorology
AUDA-NEPAD SANWATCE	African Union Development Agency–New Partnership for Africa's Development Southern African Network of Water Centers of Excellence
CBA	Cost-Benefit Anaysis
CICOS	Commission Internationale du Bassin Congo-Oubangui-Sangha
CDFS	ClimDev-Africa Special Fund
CIRDA	Climate Information for Resilient Development and Adaptation
CLIMSOFT	Climatological Software
CNDRS	Centre National de Documentation et de Recherche Scientifique (Comoros)
CREWS	Climate Risks and Early Warning Services
CSC	Climate Services Center
DCCMS	Department of Climate Change and Meteorological Services
DCP	Department of Civil Protection (Zimbabwe)
DGPC	Direction Generale de la Protection Civile
DODMA	Department of Disaster Management Affairs
DRC	Democratic Republic of Congo
DMA	Disaster Management Agency
DMMU	Disaster Management and Mitigation Unit
DNGRH	Direcção Nacional de Gestão de Recursos Hídricos (Mozambique)
DRM	Disaster Risk Management
DWA	Department of Water Affairs
DWR	Directorate of Water Resources (Tanzania)
DWS	Department of Water and Sanitation (South Africa)
ECMWF	European Center for Medium-Range Weather Forecasts
ENEAM	Ecole Nationale d'Enseignement de l'Aéronautique et de la Météorologie
ESPA	Ecole Supérieure Polytechnique d'Antananarivo
ECCAS	Economic Community of Central African States
EU	European Union
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EWS	Early Warning System
FEWSNET	Food Early Warning System-Net
GBON	Global Basic Observation Network
GCF	Green Climate Fund
GISC	Global Information System Center
GNI	Gross National Income
GPC	Global Production Center

GTS	Global Telecommunication System
HYCOS	Hydrological Cycle Observing System
Hydromet	Hydro-meteorological
HYDSTRA	Hydstra/TS is a time-series data management system by Kisters (proprietary)
ICPAC	IGAD Climate Prediction and Applications Center
ICT	Information and Communications Technology
IGAD	Intergovernmental Authority on Development
IHP	International Hydrological Program
INAM	Instituto Nacional de Meteorologia (Mozambique)
INAMET	National Institute for Meteorology and Geophysics (Angola)
INGD	Instituto Nacional de Gestão e Redução do Risco de Desastres (Mozambique)
INRH	National Institute for Water Resources (Angola)
IOC	Indian Ocean Commission
IT	Information Technology
LAM	Limited Area Model
LIMCOM	Limpopo River Basin Commission
LMS	Lesotho Meteorological Services
LRR	Loss Reduction Rate
MASA	Meteorological Association of Southern Africa
METCAP	Common Alerting Protocol
METTELSAT	Agence Nationale de Météorologie et de Télédétection par Satellite (DRC)
NOAA	National Oceanic and Atmospheric Administration
NDMA	National Disaster Management Authority
NDMC	National Disaster Management Center
NHS	National Hydrological Services
NMHS	National Meteorological and Hydrological Services
NMS	National Meteorological Services
NPV	Net Present Value
OKACOM	Okavango River Basin Commission
ORASECOM	Orange-Senqu River Basin Commission
PeriPeri U	Partners Enhancing Resilience for People Exposed to Risks
PMO-DMD	Prime Minister’s Office - Disaster Management Department (Tanzania)
PPE	Public-Private Engagement
RSMC	Regional Specialized Meteorological Center
RTC	Regional Training Center
RTH	Regional Telecommunications Hub
SADC	Southern African Development Community
SARCOF	South African Regional Climate Outlook Forum
SARFFGS	Southern Africa Regional Flash Flood Guidance System

SASSCAL	Southern African Science Service Center for Climate Change and Adaptive Land Management
SAWS	South African Weather Service
SEB	Socio-Economic Benefits
TAHMO	Trans-African Hydro-Meteorological Observatory
TMA	Tanzania Meteorological Authority
UNDP	United Nations Development Programme
VLab	Virtual Laboratory
WARMA	Water Resources Management Authority (Zambia)
WIGOS	WMO Integrated Global Observing System Center
WISER	Weather and Climate Information Services for Africa
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
ZAMCOM	Zambezi River Basin Commission
ZAMWIS	Zambezi Water Resources Information Systems
ZINWA	Zimbabwe National Water Authority
ZMD	Zambia Meteorological Department
SMA	Seychelles Meteorological Authority

Southern Africa is highly vulnerable to extreme weather, climate and water-related events. These include droughts and floods; severe convective storms accompanied by heavy rain, lightning, hail and strong winds; tropical storms and cyclones causing storm surges, strong wind and heavy rainfall; and frontal systems that bring freezing weather and snowfalls to the southern parts of the region. The region is home to approximately 345 million people whose lives and livelihoods are directly affected by the impacts of extreme weather and climate events. The southern African nations are organized through the Southern African Development Community (SADC) which comprises of 16 Member States.

In line with global trends, natural hazards in the SADC region have been increasing in frequency and intensity over the past three decades and warming over the region is faster than the global average. The entire region is affected (in descending order of exposure) by droughts, floods, cyclones, and earthquakes. Meteorological, climatological, and hydrological services, in this context referred to jointly as "hydromet services", play an important role in providing timely and adequate information for early warning. Early warning can save lives and will improve the management of sectors of the economy, such as agriculture, industry, power production and transport. The objective of the report is threefold:

- gain a better understanding of the status of the hydromet services in the different SADC Member States,
- identify challenges that could best be addressed with a regional approach, and to
- identify needs for strengthening hydromet services with a specific focus on early warning services.

Status of Hydromet Services in Southern Africa

Using the metric developed for this study, most National Meteorological Services (NMSs) have a higher level of maturity than the National Hydrological Services (NHSs) in the same country (see table ES1). The NHSs are often non- or semi-autonomous departments as part of the Ministry of Water. Their limited capacity is therefore often focusing on providing advice on water use licenses and decision support to feasibility studies for infrastructure. As a result, the scope of further hydrological services including flood and drought warnings is generally very limited.

Most organizations have basic challenges such as insufficient funds to pay staff salaries and basic infrastructure needs. Few NMHSs engage actively with sectors and users providing only in few cases dedicated services to those sectors. As a result, services for the large economic sectors, including the important agricultural sector, are generally basic.

The early warnings for floods and hydrological droughts are mainly based on observations and weather forecasts or climate outlooks, not on hydrological and/or hydraulic modeling. The cascading forecasting process, which promotes the use of global and regional forecasts to be interpreted nationally, is applied, but its value is limited due to the low number of observations feeding into the global models and/or validating outputs of such models. This is a result of challenges in the observation infrastructure, but also of limitations in information technology (IT) infrastructure, license fees and human capacity to make use of the global and regional services.

Many current meteorological and hydrological stations are not operational, while networks are already not sufficiently dense for initialization and calibration of the global weather models and for early warning on hydrological events. While there are needs expressed for extending these networks, the current capacities are not sufficient to get the operability of the current networks higher.

Communication and coordination with Disaster Risk Management (DRM) agencies can be improved. To some extent Standard Operating Procedures are in place. However, the NMHSs are resourceful in managing with the limited means they have and are attempting to apply concepts such as impact based forecasting to improve early warning services.

Table ES1: Maturity scores for national meteorological and hydrological services

Maturity score	National Meteorological Services			National Hydrological Services		
	Questions answered (%)	Score	Level	Questions answered (%)	Score	Level
Angola	78%	59%	Essential	68%	38%	Basic
Botswana	73%	50%	Essential	77%	23%	Basic
Comoros	47%	25%	Basic	Not applicable		
DRC	47%	14%	Below Basic	Not assessed		
Eswatini	84%	42%	Essential	79%	23%	Basic
Lesotho	88%	45%	Essential	83%	47%	Essential
Madagascar	77%	62%	Full	42%	9%	Below Basic
Malawi	86%	57%	Essential	79%	36%	Basic
Mauritius	96%	67%	Full	64%	28%	Basic
Mozambique	50%	32%	Basic	60%	53%	Essential
Namibia	94%	43%	Essential	94%	42%	Essential
Seychelles	97%	63%	Full	Not applicable		
South Africa	99%	92%	Advanced	91%	75%	Full
Tanzania	92%	84%	Advanced	83%	38%	Basic
Zambia	91%	50%	Essential	72%	43%	Essential
Zimbabwe	95%	66%	Full	81%	42%	Essential

Guidance for strengthening hydromet and early warning services

Drawing from the analysis of the status of weather, climate, water and early warning services in the region, an action plan for strengthening hydromet services has been formulated. The goal of the proposed action plan is "*to have NMHSs within the SADC region that are capable to (better) provide impact-based early warning services on climate, weather and water hazards*."

The vision is that by 2030 (and, where possible by 2025) in all SADC member states essential early warning services can be provided and that service levels have improved in this regard. Regional Centers have sustained and modernized their operation, providing adequate services to the countries, communities and businesses in Southern Africa, and support Member States in a cascading approach. Based on the analysis in the stocktaking report, four outcomes were identified to achieve this goal:

A. Stronger institutional capacity of and collaboration between NMHSs and regional organizations

B. Observations and monitoring networks in the region are better equipped to support early warning services

C. Improved lead time and accuracy of the hydromet forecast with emphasis on the key locations

D. Improved generation and dissemination of impact-based early warnings for specific user groups

Based on the findings of the stocktaking phase, a regional investment framework and action plan has been prepared to strengthen early warning services. It should be highlighted that:

- The needs to strengthen are estimated at US$ 116 million. In addition, US$ 89.4 million would be required as operation expenses for 10 years and 277 staff would need to be mobilized to execute the actions.
- The total operational costs and the additionally required staff costs would considerably exceed the gross capital investments. This makes explicit the liabilities that are a result of the investments, which need to be carried by the Member States.
- Member States will also need to reserve additional funding for annual depreciation of goods and works to sustain the services after the lifespan of equipment. This reservation is not included in the total budget.

In table ES2 below the estimated costs per outcome and for regional and national level are presented.

Table ES2: SADC region hydromet investment costs per outcome

Outcome	Gross Capital Investments and Actions (in US$ million)				
	Works	Goods	Consultancies	Training	Total
Outcome A	0	0.5	3.0	6.7	10.2
Outcome B	4.9	25.2	8.1	8.6	46.8
Outcome C	0	3.8	9.7	18.7	32.2
Outcome D	2.6	2.6	20.4	1.6	27.1
Total	**7.5**	**31.2**	**41.2**	**35.6**	**116.3**

Benefit of Investing in Hydromet Services

The benefits of investing in hydromet services, also with narrow focus on early warning services, are substantial, particularly due to the foregone damages and losses from floods and droughts in the region. The report focusses only on hydromet services related to early warning. The estimation of socio-economic benefits is thus also related only to the direct and indirect benefits of early warning services and not for example on agrometeorology. It is however acknowledged that potentially the socio-economic benefits would be higher, but also that substantially more would need to be done to effectively provide different user communities with, such as agriculture, transport, or insurance, with adequate early warning services. The socio-economic benefit analysis highlights the potentially huge benefits, which can be achieved for different sectors of the economy. With the proposed actions and investments benefits of US$ 7 to US$ 12 for every US$ 1 invested are estimated.

Recommendations

Building upon the existing strong regional institutions the following recommendations are proposed for the implementation of those actions:

- Strengthening hydromet services in Southern Africa requires substantial investments and concerted efforts from governments, development partners and the private sector. For actions to strengthen hydromet services related to early warning, the gross investment costs are estimated to be US$ 116 million. In addition, commitments from governments on operation and maintenance, staffing and training are prerequisite for making the envisioned outcomes of such investment sustainable. These costs can be substantial and are estimated over a period of 10 years at US$ 89.4 million for operation and maintenance. While it makes sense for governments to prioritize funding of hydromet services, additional grants, loans and public-private partnerships might be needed to source this finance, in particular during this difficult period of recovery from the COVID-19 pandemic. Adequate provision of hydromet services to vulnerable communities and economic sectors needs such investments. However, it is realized that implementing all actions simultaneously may not be possible financially and in terms of capacity of the organisations. Therefore, allowing an incremental increase in capacity of NMHS may be the most durable way forward.

- Regional cooperation between the various role players in the hydromet value chain, of which the NMHSs and disaster management structures are central, is a key success driver for improving hydromet services and EWS in the region.
- Differences in climate, organizational structure, existing hydromet value chain, potential partnerships with the private sector and available financial and human resources all need to be considered for a detailed design of country-level investments and actions.
- The modernization of hydromet and early warning services in Southern Africa should complement and leverage ongoing initiatives, such as the Global Framework for Climate Services, Climate Risks and Early Warning Services (CREWS), WMO's Systematic Observations Financing Facility (SOFF) and other projects or programs targeted towards hydromet modernization. Notably, the SOFF would be an important program, as it aims to provide finance for bringing observation networks to Global Basic Observation Network (GBON) standards. These GBON standards are developed to improve the performance of global weather forecasting models, which are important in the cascading approach of forecasting. Also, the program coordinated by the Indian Ocean Commission that has started in 2021 may cover some of the actions for the island states.
- A program for modernizing hydromet and early warning services in Southern Africa should be the joint effort of national governments, regional organisations, including SADC and River Basin Organisations, private sector and development partners and be part of the global structure, such as GBON. As a next step, the report should be taken forward through the Hydromet Alliance, which is a partnership of WMO, other UN organisations and multilateral development Banks, including World Bank. Individual country assessments, with operation, maintenance and staffing plans would need to follow to operationalize the recommendations of the report.

1.1 Introduction

Southern Africa is highly vulnerable to extreme weather, climate, and water-related events. These include droughts and floods; severe convective storms accompanied by heavy rain, lightning, hail and strong winds; tropical storms and cyclones causing storm surges, strong wind and heavy rainfall; and frontal systems that bring freezing weather and snowfalls to the southern parts of the region. The region is home to approximately 345 million people whose lives and livelihoods are directly affected by the impacts of extreme weather and climate events. The southern African nations are organized through the Southern African Development Community (SADC) which comprises of 16 Member States: Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia, and Zimbabwe.

In 2021, the SADC, together with the World Meteorological Organization (WMO), World Bank, European Union (EU) and other partners, hosted the first Hydromet Forum. The purpose was to discuss and set priorities to strengthen weather, water, and climate information as well as disaster risk management strategies and services for sustainable development and reducing regional disaster and climate risks. The participants discussed the critical role of hydromet and early warning services for sectors that drive the region's economies, such as agriculture, urban and industrial activities, and aviation and marine services, and for combating the socio-economic impacts of disaster and climate risks. In this context, the term "hydromet" services is defined as meteorological (weather and climate) and hydrological (water resources and flooding hydrology and hydraulic) services. In this report, the organizations responsible for meteorological services and hydrological services are referred to as respectively National Meteorological Services (NMSs) and National Hydrological Services (NHSs), or jointly National Meteorological and Hydrological Services (NMHSs). To provide timely and accurate early warning, they need to cooperate and coordinate with each other. They also need to make use of regional and global information as many weather systems impact several countries at a time and several river catchments are shared between countries. However, they are all resource constrained. To further improve early warning, they would need support from each other, the private and academic sectors, and development partners.

In Southern Africa, the coordination between disaster risk reduction and hydromet services is among others advanced by SADC. It formulated the SADC Disaster Risk Reduction Strategic Plan, and it facilitates the Southern African Climate Outlook Forums through SADC Climate Services Centre (SADC CSC). It assists NMSs through regional investment programs and facilitated the establishment of river basin organizations (RBOs) to manage transboundary river basins. The region is also home to several WMO designated regional centers covering topics ranging from training and meteorological data communication to guidance on severe weather, seasonal forecasts and tropical cyclone advice, based on the competencies of the host organizations.

The study's objective is to take stock of the state of hydromet services and early warning systems in SADC Member States, to identify opportunities for regional collaboration and to inform investment planning in those services. This study builds on various previous studies for evaluating and advising on national hydromet services in developing countries (Rogers et al. 2019; WMO 2015; World Bank 2019, among other) to identify good fit for NMHSs in Southern Africa.

The study was carried out in a fully virtual manner during the COVID-19 global pandemic. The analysis was based on an online questionnaire with responses from 49 organizations, 23 online workshops, many bilateral phone calls and expert judgment. The analysis and study results have been validated with the region in two virtual workshops. This summary report is informed by the following components:

- Taking stock of the existing national climate, weather and water services in Southern Africa as well as the challenges, needs and opportunities
- Providing guidance on strengthening early warning services in Southern Africa
- Analyzing academic and private-sector engagement in the provision of hydromet and early warning services in Southern Africa

1.2 Regional Context

The total population in the SADC region has grown from 277 million in 2010 to over 340 million in 2018 and is expected to continue growing to about 500 million by 2050. Southern Africa also has countries with very different country sizes and population densities, development statuses and economies. Botswana, Namibia, Mauritius, Seychelles, and South Africa are high-income or upper-middle-income countries, where agriculture contributes marginally to GDP. Democratic Republic of Congo, Madagascar, Malawi, and Mozambique are low-income countries where agriculture contributes significantly to GDP. In Malawi and Mozambique, more than 70 percent of the population is employed in agriculture. Table 1 provides an overview of the key country and development indicators.

Table 1. Overview of key country indicators for SADC member states

Country	Total Pop. 2018 million	Rural Pop. 2018 %	GDP* 2018 $ billion	GDP* per capita 2018 $	Agriculture 2014-18 avg % of GDP	Employment in Agriculture 2018 % of total	Income level Income group (GNI per capita, 2018)**
Angola	30.8	34.5	99.6	3,234	9.03	50.9	Lower middle
Botswana	2.3	30.6	18.1	8,033	2.06	20.4	Upper middle
Comoros	0.8	71.0	1.2	1,403	31.3	35.0	Lower middle
DRC	84.1	55.5	35.2	418	18.9	64.8	Low
Eswatini	1.1	76.2	5.4	4,762	8.9	12.5	Lower middle
Lesotho	2.1	71.8	2.6	1,248	4.5	44.9	Lower middle
Madagascar	26.3	62.8	12.7	484	25.1	64.7	Low
Malawi	18.1	83.1	9.5	521	25.5	76.6	Low
Mauritius	1.3	59.2	13.4	10,577	3.1	6.2	High
Mozambique	29.5	64.0	17.5	593	23.9	70.6	Low
Namibia	2.4	50.0	14.8	6,029	7.4	22.6	Upper middle
Seychelles	0.1	43.3	1.4	14,140	2.1	n/a	High
South Africa	57.8	33.6	429.5	7,432	2.2	5.2	Upper middle
Tanzania	56.3	66.2	52.4	959	27.3	65.7	Lower middle
Zambia	17.4	56.5	29.1	1,678	5.1	50.1	Lower middle
Zimbabwe	14.4	67.8	18.6	1,289	7.5	50.1	Lower middle

Source: World Bank (2021b). Note: *Gross domestic product (constant 2010 dollars); **World Bank classification.

In urbanization, the region paints a very diverse picture. Urban population growth in the last five years (2016-2020) has ranged between 1.6 percent in Eswatini to 5.0 percent in Tanzania (World Bank 2021a). Mauritius is the only regional country not to experience urban population growth in this period. Angola, Botswana and South Africa are the most urbanized countries, while Eswatini, Lesotho and Malawi are the least urbanized countries. In many cases, dense cities are prone to flash floods. Food security is an issue across Southern Africa due to limited purchasing power and high climate variability.

1.3 Climate and Disaster Profile of Southern Africa

Apart from human density differences and economic circumstances, Southern Africa also has a wide variety of climates and geographies. Climate types include an arid coastal desert along the west coast of South Africa and Namibia, a semi-arid temperate climate with summer rainfall over the interior central plateau, a humid subtropical climate over the low-lying coastal regions of the southeast, and a winter rainfall Mediterranean climate in the south-western part of South Africa. The oceans and the geography influence the differences, with the movement of the Inter Tropical Convergence Zone and the influence of tropical systems and cyclones as well as frontal systems also playing a role in annual variations. Large parts of the region are also affected by convective storms that are often accompanied by heavy rain, strong winds, reduced visibility, lightning and hail.

In line with global trends, natural hazards in the SADC region have been increasing in frequency and intensity over the past three decades and warming over the region is faster that the global average. The entire region is affected (in descending order of exposure) by droughts, floods, cyclones. However, these hazards are only the most extensive ones; countries and cities in the region are affected by other hazards such as sea level rise, heat stress, fire hazards, storm surges and volcanic eruptions. Disasters resulting from these hazards have a domino effect especially on urban systems, as they have primary local impacts (infrastructure damage and loss of lives and livelihoods) and secondary ripple effects in neighboring and distant cities and towns due to interconnected trade networks and ecosystems. Table 2 summarizes the average annual flood loss based on EMDAT data between 1960 and 2019 (Guha Saphir et al., 2021).

Table 2: Southern Africa regional flood impacts and potential benefits of hydromet services for floods (source: Guha Saphir et al., 2021)

Country	A. Flood episodes	B. Flood frequency 1	C. Total affected per episode	D. Estimated average annual damages* ($ millions)	E. Estimated average annual avoided damages ($ millions)
Angola	45	1.50	28,793	306.54	39.85
Botswana	11	0.23	16,235	26.97	3.51
Comoros	2	0.20	33,819	48.01	6.24
DRC	35	1.21	31,006	248.47	32.30
Eswatini	3	0.16	91,633	102.69	13.35
Lesotho	5	0.15	37,000	38.62	5.02
Madagascar	10	0.30	29,646	63.76	8.29
Malawi	42	0.81	91,684	525.59	68.33
Mauritius	1	0.17	82	0.10	0.01
Mozambique	42	0.81	239,760	1,374.47	178.68
Namibia	16	0.84	68,960	412.17	53.58
Seychelles	2	0.09	2,836	1.83	0.24
South Africa	42	0.70	13,939	69.26	9.00
Tanzania	52	0.95	24,532	164.62	21.40
Zambia	22	0.54	267,473	1,018.66	132.43
Zimbabwe	12	0.57	28,669	116.27	15.12
Total					**543.99**

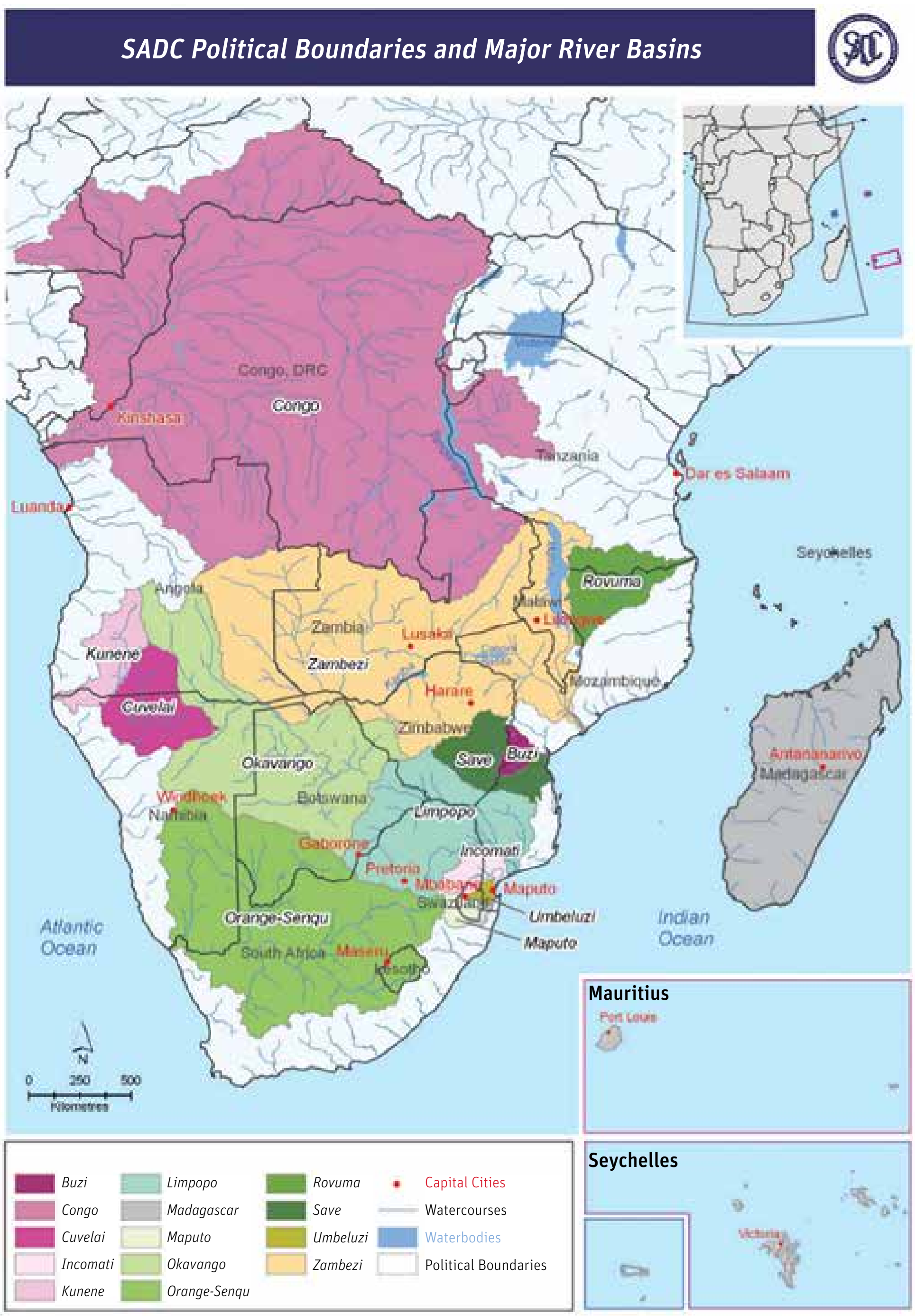
Note: Calculations are based on annualized avoidable damages. $1 = LRR 0.32; * Damage x Affected x FP.

Note: The values are annualized considering the flood frequency, so considered for every year, not only for those years with a flood episode occurring.

[1] Flood frequency is calculated as EM-DAT reported episodes with respect to total based on Lesk, Rowhani and Ramankutty (2006).

Ecosystems do not follow administrative boundaries. Apart from local impacts of climate, also transboundary aspects play a role and regional cooperation is therefore important. In Southern Africa, climate and hazard patterns are not equally distributed and are often transboundary. Several river basins responsible for major floods are transboundary (Figure 1) and droughts often have impact on several countries at the same time.

Figure 1: SADC political boundaries and major river basins[2]



2 SADC (2016).

Droughts occur frequently in the region and have devastating and far-reaching impacts. Each year in most countries, drought is experienced somewhere, dependent on the definition used. Between 1980 and 2000, the SADC region was struck by four major regional droughts.

- In 2015/16, El Niño disrupted the agricultural season, with major parts of Eswatini, Lesotho, Namibia, South Africa and Zimbabwe declaring drought emergencies and this drought cycle lasted for some years. Prolonged droughts have impacted food security. For example, in the 2018/19 agricultural season, about 10.8 million people were affected by food insecurity (OCHA 2019).

Floods and tropical cyclones often lead to significant damage and loss of infrastructure, lives and livelihoods:

- Flooding impacts nearly every country in Southern Africa. Floods are common events in the river basins of the Congo, Limpopo, Okavango and Zambezi and affect cities and human settlements in Angola, Botswana, DRC, Mozambique, Namibia, South Africa, Zambia and Zimbabwe. In the Zambezi River catchment areas, floods frequently impact Malawi, Mozambique, Zambia and Zimbabwe.
- Cyclones and tropical storms mostly impact countries along the Indian Ocean Coast: Madagascar, Mozambique and the Indian Ocean islands. The cyclone season runs from November to May. While the area of land affected is vast, the threat to coastal cities in Mozambique and river basins stretching inland to areas in neighboring countries (Malawi and Zimbabwe) is equally important. The impacts can cause flooding and subsequent landslides. Hence, these storm events often lead to severe flooding and cause acute damages and losses. In 2018/ 2019, Cyclones Idai and Kenneth caused extensive damage, even reaching inward-located countries: 975,600 and 270,000 people were affected in Malawi and Zimbabwe, respectively.

The frequency and intensity of these hazards differ but their risk has been increasing with climate change and the growing population within the region. However, uncertainty surrounds the extent and location of the increasing extremes. Temperature changes are more certain than precipitation changes. Projections suggest that Southern Africa will be substantially affected by changing temperature and rainfall patterns as well as an increased number and possibly more severe cyclones in the Indian Ocean region (Sesolle 2012). In general, SADC has experienced a downward trend in its regional rainfall pattern, with below normal rainfall becoming more frequent, which in combination with higher evaporation losses due to warmer temperatures, impacts regional water resources negatively.

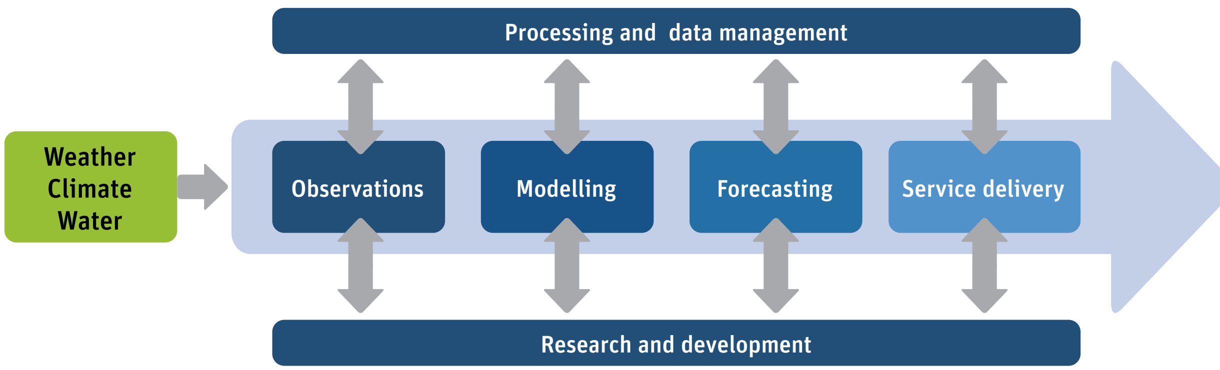
Livelihoods and economies in Southern Africa are vulnerable to weather and climate shocks. Notably, countries that are highly dependent on agriculture and employ a large part of the population in agriculture have experienced substantial impacts on livelihoods and economies.

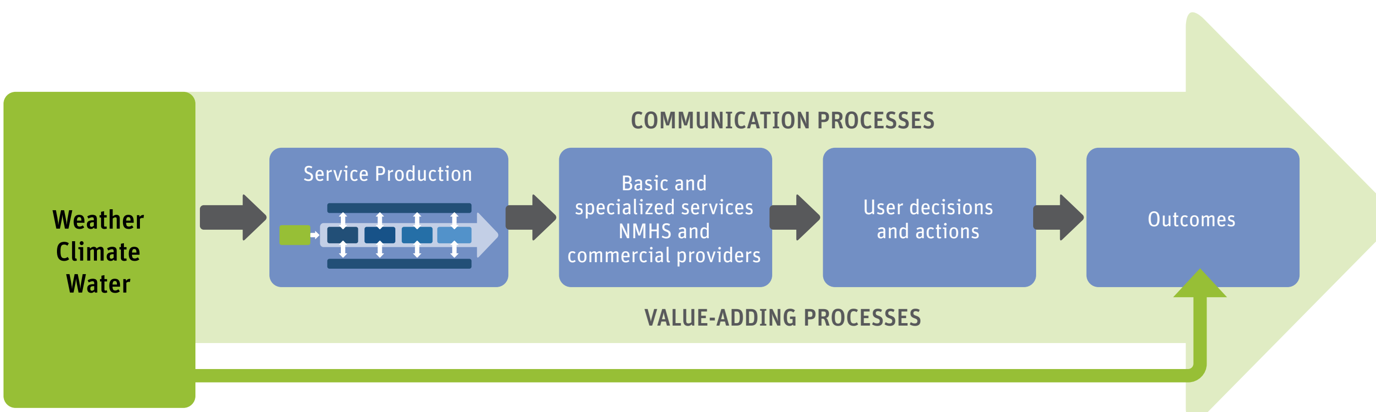
1.4 Hydromet Value Chain

Investing in hydromet services is commonly considered a priority "low regret" climate adaptation and disaster risk reduction strategy. While methodologies to assess the economic benefits of these investments are still evolving, the literature suggests that such activities can be extremely beneficial. These investments help to avert losses associated with climate hazards and enhance the productivity of climate-dependent sectors, such as agriculture, water resources management, hydropower and transport.

The hydromet value chain (figure 3) shows that value, in economic and social terms, starts with observation of climate through to decision-making and outcomes (WMO 2015a). As such, the value of an accurate, timely and relevant forecast can only be maximized if a beneficial value is achieved at the end of the process. Any project design on the modernization of hydromet and disaster risk management services should be designed around an effective value chain that links the monitoring and modeling with concrete services to different sectors of the economy and communities. Merely improving observations or forecasts, through improved technologies, for example, will not necessarily generate economic value unless the entire value chain process works to facilitate impacts and end-user decision-making.

Figure 3: National Hydromet Services production and delivery system components (above); Hydromet value chain (below)[3]



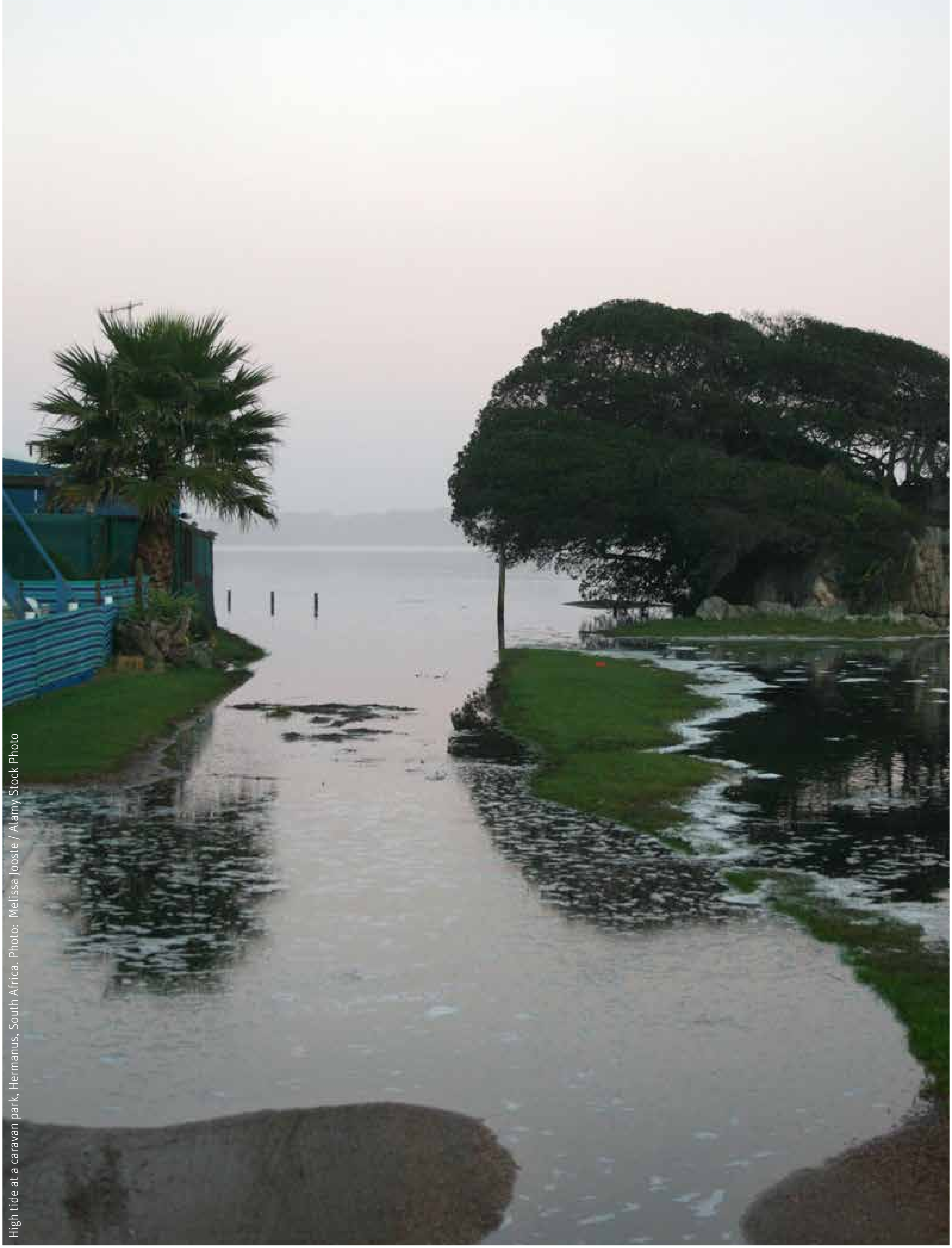


[3] *Source:* WMO 2015a.

In this report, hydromet services are a combination of weather, climate and hydrological services, not of hydrometeorology in its stricter sense. Weather and climate services that do not have a direct relationship with hydrology (such as aviation) are included in the stocktaking. However, not all hydrological services have been included in the stocktaking. Groundwater and water-quality services have not been included, as in most cases they are not in the hydrology section of the water departments that were involved in the survey. The hydromet value chain represents the interlinked and interdependent building blocks that are needed to translate the actual weather, water and climate conditions into services and products to inform wise decisions be society. For the analysis in this study, the hydromet value chain described in WMO (2015) has been applied in a simplified form:

- Enabling factors strengthen all blocks of the value chain and include institutional capacity, such as staff numbers, overall IT capacity and power supply and ways of dissemination.
- Observation and monitoring include surface-based observations and remote-sensing observations.
- Data processing, analysis and modeling include modeling for analyses and forecasts.
- Services include all services for end-users.

The NMS and NHS in each country, are jointly in charge of organizing and/or facilitating the strengthening of the hydromet value chain while a growing number of other stakeholders are involved and contributing to the value chain, especially in recent years. The DRM organization is an important user of information from the NMHS for early warning and the inputs of the DRM organizations have therefore also been received during this study.



High tide at a caravan park, Hermanus, South Africa. Photo: Melissa Jooste / Alamy Stock Photo

2.1 Methodology for taking stock and evaluating NMHSs

This stocktaking of existing weather, climate, and water services in Southern Africa, including the challenges and needs, aims to better understand the status of hydromet services in the region. Three reports played a key role for the development of the survey and to assess maturity levels: Weathering the Change (Rogers et al. 2019), The Power of Partnership (World Bank 2019) and WMO Capacity Development Strategy and Implementation Plan (WMO 2015). After the survey, virtual workshops in each country and bilateral telephone calls took place to fill any gaps and clarify or correct responses. This resulted in a comprehensive set of responses that crystalized the status of hydromet services in Southern Africa.

The categorization and evaluation of the NMHSs on the four components of the hydromet value chain was assisted by scoring to describe the level of maturity. The maturity score is based on the information provided by the organizations, on all four components of the hydromet value chain and on multiple choice questions in the survey. The categories described in the WMO Capacity Development Strategy and Implementation Plan (WMO 2015) were used as a reference to link multiple choice answers to certain levels. Those WMO-categories are Basic, Essential, Full and Advanced. In addition, a fifth category 'Below Basic' was introduced for instances where the Basic level was not achieved. The method is further explained in Box 1.

Box 1: Calculation maturity scores and levels

For each question that contributed to the maturity score, the multiple-choice options were connected to a certain WMO-category. For the organizational maturity score, the scores for all answers (1 for Basic, 2 for Essential, 3 for Full and 4 for Advanced) were summed up and divided by the maximum number of points that could be obtained from the questions answered. For example, if a country answered a question in a way that corresponds with a 'Basic' level where one could score 'Advanced' as highest score, the country retrieved 1 out of 4 points, while 4 was added to the maximum number of points that could be obtained. Since not all organizations answered the survey to the same extent, it should be noted that the organizational maturity score is not always calculated based on the same number and type of questions. Hence, caution and diligence are needed to correctly interpret the organizational maturity scores. The organizational maturity scores described as a percentage were then translated to 1 of the 5 maturity levels (that is, Below Basic: not more than 20%, Basic: between 20% and 40%, Essential: between 40% and 60%, Full: between 60% and 80%, Advanced: more than 80%). The overall maturity scores are based on averaging and this does not mean all requirements of WMO for a certain lower category are then fulfilled. The scores are used to get an overall impression on how the NMHS organizations for the different countries compare. Hence, the maturity levels are qualitative levels after assessment of the entire hydromet value chain of the organizations and explain how advanced an organization is in addressing all components of the hydromet value chain.

2.2 Status of National Meteorological And Hydrological Services

The 16 member states of SADC have a very diverse range of NMHSs, which are in most cases under the authority of different ministries and departments. Table 3 provides an overview of the national organizations responsible for weather and climate services, water services and early warning and disaster risk management. In most countries, the NMS is an autonomous organization and the NHS is part of the ministry responsible for water resource management. As a result, the NHS is not only providing early warning services, but also conducting hydrological analyses for water-use licenses, for monitoring water use and for supporting feasibility studies. The responsibilities of the NHSs between countries also differ, depending on the presence/absence of catchment management agencies and whether geohydrology and water quality departments are separate or included in what is referred to as the NHS.

Table 3: Overview of National Meteorological and Hydrological Services and Disaster Risk Management Organizations in SADC Member States

Country	NMS	NHS	DRM
Angola	National Institute for Meteorology and Geophysics	National Institute for Water Resources	Angola DRM*
Botswana	Department of Meteorological Services	Hydrology/Surface Water Division, Department of Water Affairs	National Disaster Management Office
Comoros	Direction de la Météorologie (represented by L'Agence Nationale de l'Aviation Civile et de la Météorologie de l'Union des Comores	Limited activity or non-existent	Direction Generale de la Protection Civile, represented by Centre National de Documentation et de Recherche Scientifique
Democratic Republic of Congo	Agence Nationale de la Météorologie et de Télédétection par satellite		Direction Nationale de la Protection Civile
Eswatini	Eswatini Meteorological Service	Directorate Hydrology: Department of Water Affairs	National Disaster Management Authority
Lesotho	Lesotho Meteorological Services	Department of Water Affairs	Disaster Management Agency
Madagascar	Direction General de la Météorologie		National Bureau for Disaster Risk Reduction*
Malawi	Department of Climate Change and Meteorological Services	Department of Water Resources	Department of Disaster Management Affairs
Mauritius	Mauritius Meteorological Services	Ministry of Energy & Public Utilities (Water Resources Unit)	National Disaster Risk Reduction and Management Center
Mozambique	Instituto Nacional de Meteorologia	Direcção Nacional de Gestão de Recursos Hídricos	Instituto Nacional de Gestão e Redução do Risco de Desastres)
Namibia	Namibia Meteorological Service	National Hydrological Services of Namibia, Ministry of Agriculture, Water and Land Reform	Directorate Disaster Risk Management
Seychelles	Seychelles Meteorological Authority	Limited activity or nonexistent	Department of Risk and Disaster Management*
South Africa	South African Weather Service	Directorate: Surface and Groundwater Information, Department of Water and Sanitation	National Disaster Management Center
Tanzania	Tanzania Meteorological Authority	Ministry of Water - Directorate Water Resources	Prime Minister's Office - Disaster Management Department
Zambia	Zambia Meteorological Department	Zambia Water Resources Management Authority	Disaster Management and Mitigation Unit
Zimbabwe	Meteorological Services Department	Zimbabwe National Water Authority	Department of Civil Protection

* Organizations that did not participate in the study.

The maturity scores for the NHSs and NMSs as per the described method, are presented in table 4 and illustrated in figures 4 and 5.4 The scores indicate that regional NHSs are weaker than NMSs, consistent with global trends. In general, NHSs are mandated and managed to a lesser extent than NMSs. The small island states and Madagascar are historically weak in hydrological services but have relatively good NMSs. Comoros and Seychelles rely scarcely on surface water for water supply; thus, surface water hydrology of their NHS is not well developed. In DRC, hydrological services for navigation and electricity are provided by, respectively, the Regies des Voies Fluviales (RVF) and the Société Nationale d'Electricité (SNEL). METTELSAT provides meteorological and hydrological services, but its hydrological services are not well developed, which is concerning from a disaster risk management perspective.

Table 4: Maturity of NMSs and NHSs in SADC member states

	NMS			NHS		
Maturity score	Questions answered (%)	Score	Level	Questions answered (%)	Score	Level
Angola	78%	59%	Essential	68%	38%	Basic
Botswana	73%	50%	Essential	77%	23%	Basic
Comoros	47%	25%	Basic	Not applicable		
DRC	47%	14%	Below Basic	Not assessed		
Eswatini	84%	42%	Essential	79%	23%	Basic
Lesotho	88%	45%	Essential	83%	47%	Essential
Madagascar	77%	62%	Full	42%	9%	Below Basic
Malawi	86%	57%	Essential	79%	36%	Basic
Mauritius	96%	67%	Full	64%	28%	Basic
Mozambique	50%	32%	Basic	60%	53%	Essential
Namibia	94%	43%	Essential	94%	42%	Essential
Seychelles	97%	63%	Full	Not applicable		
South Africa	99%	92%	Advanced	91%	75%	Full
Tanzania	92%	84%	Advanced	83%	38%	Basic
Zambia	91%	50%	Essential	72%	43%	Essential
Zimbabwe	95%	66%	Full	81%	42%	Essential

Note: Not all requirements for a WMO category have been met. NMS maturity score is for the combination of meteorological and climatological services, while the NHS score is for hydrological services only.

[4] Note: Maturity scores for NHSs in Comoros, Democratic Republic of Congo (DRC) and Seychelles were not analyzed for lack of response to the survey.

Figure 4: Map showing maturity of NMSs by SADC member state

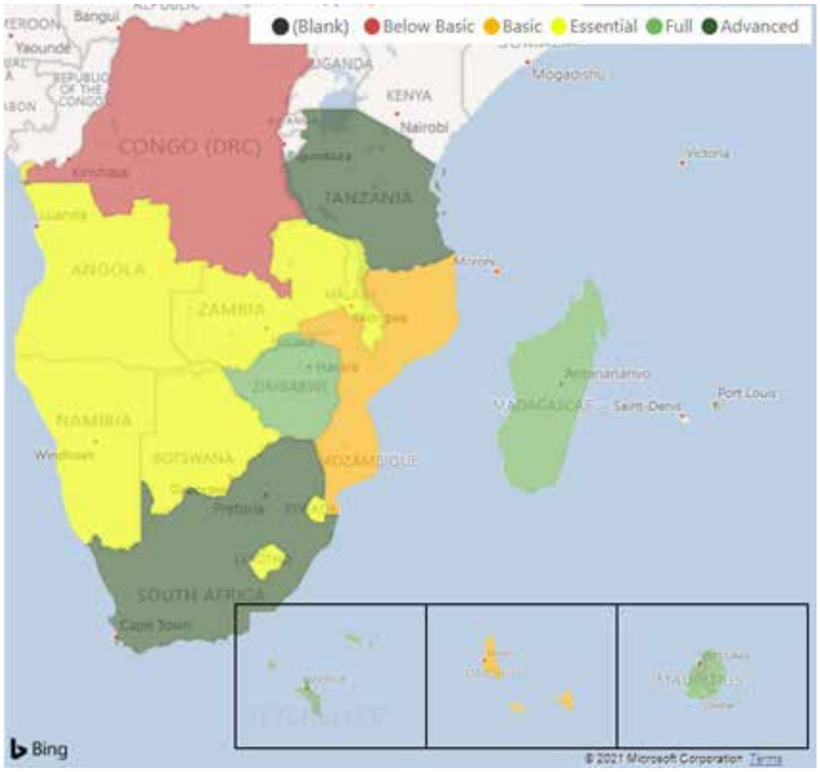
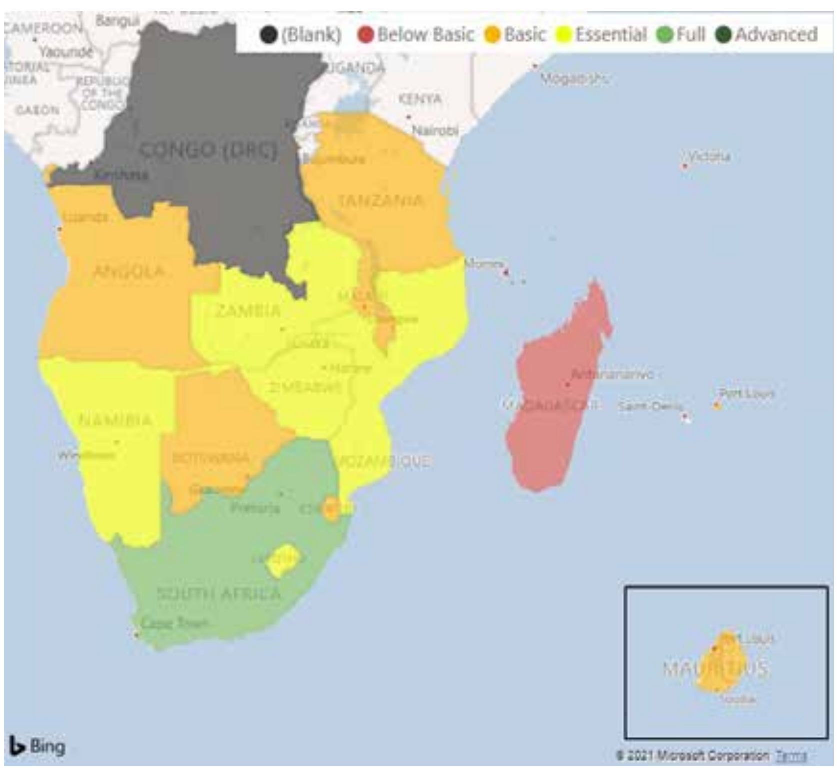


Figure 5: Map showing maturity of NHSs by SADC member state



2.2.1 Enabling factors

The hydromet value chain only functions properly with sufficient enabling factors. Five such factors are: institutional capacity, research & development, education & training, data and information dissemination, and infrastructure. They help determine the feasibility and sustainability of investments.

In looking across the SADC region, mandates, strategic goals, business plans and capacity- building plans are unclear or nonexistent. Mandates tend to be clearer for NMSs than for NHSs, which have fewer staff. NMSs tend to assess their own institutional capacity more positively than NHSs, and all face considerable challenges in attracting qualified and experienced personnel and resources for staff salaries.

The dissemination of data and information is weak. Most countries have challenges with Standard Operating Procedures, such as the exchange of information between NMSs and NHSs. For DRM agencies, serious challenges exist in terms of chosen medium, format type and interpretation of information received from NMHSs. In general, NMHS websites have very limited functionality for disseminating information.

Regional NMSs and NHSs face modernization challenges. In addition to limited financial and human resources, the processes for accessing development financing are often complex and not well understood by these technical agencies. NMHSs also do not always have the capacity to implement such large programs.

In terms of infrastructure, interrupted power supply, poor internet connectivity and/or equipment issues pose substantial challenges and form a bottleneck for implementing region-wide or centralized solutions. These factors also adversely affect communication links between field stations, central offices, and service beneficiaries. In many instances, additional IT expertise and infrastructure will be required prior to investment. Yet, NMHSs are resourceful and try to provide the maximum level of services within their means and (where existent) mandates.

2.2.2 Observation and monitoring network

For most countries, a large proportion of weather, rainfall and river- and reservoir-gauging stations are not operational, and the observation networks are limited (table 5). Most NMHSs are not able to sustainably operate, maintain and calibrate the existing network due to lack of capacity (for example, financial resources, spare parts, transport means or limited capable staff at regional offices). Keeping observation stations functional and providing appropriate maintenance and repair is a challenge due to vandalism, limited availability of spare parts and limited funding for salaries and infrastructure. While current observation networks are not well maintained or are (for other reasons) not operational, most NMSs and NHSs have high ambitions to increase the number of observation stations.

For most NMSs in the region, the frequency of upper air measurements is too low in most countries for proper model initialization. Only four NMSs conduct daily upper-air measurements. About half of the NMSs indicated that lightning detection systems need to be developed or improved. SAWS operates a Vaisala-based lightning detection system consisting of 24 sensors and has apart from including it in the information provided to forecasters also developed sector specific services in this regard. Such a system would be easier to set up than radar, would partly improve the understanding of rainfall, assist in the identification of convective storms and their evolution and would enable services to lightning sensitive sectors. Regional cooperation is important, as the more stations are providing the distance to lightning for a location assessment, the more accurate the location and intensity of thunderstorms can be determined.

The use of weather radar is limited in the region, with only South Africa and Tanzania having radars operational. Many countries have the ambition to deploy this technology. These systems are expensive to acquire and maintain, require specialized mechanical, electrical and ICT skill and extensive supporting infrastructure to ensure reliable power, communication and data processing. Despite being the primary tool for Nowcasting and effective in real-time areal rainfall estimation, only SAWS has largely been successful in operating and using a weather radar network of the past approximate 25 years.

Especially for NHSs, the state of hydrological stations is concerning. In most SADC countries, more than 30 percent of current flow gauges are not operational. While some may be reported as operational, their rating curves need higher accuracy to derive the flows from the measured water levels.

Usage of satellite remote-sensing data products from different providers is common for NMSs. The products from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) are the most widely used, by 11 countries. Building capacity and ongoing training to optimize the use of the vast range of applications available from satellites, such as EUMETSAT, is still important, in particular because of the challenges with ground based observations networks. For NHSs, more than half of the responding NHSs do not use satellite based remote sensing for droughts, and also more than half not for flood monitoring. More in-country expertise is needed on remote sensing for hydrological applications.

Table 5: Key characteristics of observations and monitoring for NMSs and NHSs in SADC Member States

Observations and Monitoring	NMS				NHS					
	Self-assessed qualification of observation network	Weather stations (number)	Rainfall stations (number)	Use of radar	Self-assessed qualification of observation network	Gauging stations in rivers (number)	Gauging stations in reservoirs/ lakes (number)	River gauging stations on telemetry system (%)	Reservoir gauging stations on telemetry system (%)	How often are rating curves updated?
Angola	Essential	10-50	10-50	No	Unanswered	10-50	1-10	1-10%	1-10%	1-5 years
Botswana	Full	10-50	> 200	No	Essential	10-50	10-50	1-10%	0%	Once per year
Comoros	Essential	1-10	10-50	No	Unanswered	None	None	None	None	None
DRC	Unanswered	10-50	0 / Unknown	No	Unanswered	10	> 200 by RVF	Unknown	Unknown	Unknown
Eswatini	Essential	10-50	10-50	No	Unanswered	10-50	1-10	10-30%	1-10%	
Lesotho	Essential	50-200	10-50	No	Essential	10-50	0	10-30%	1-10%	After every major flood
Madagascar	Essential	10-50	1-10	No	Unanswered	10-50	10-50	0%	0%	
Malawi	Full	50-200	50-200	No	Essential	50-200	1-10	1-10%	0%	5-10 years
Mauritius	Full	10-50	50-200	Yes	Basic	10-50	1-10	1-10%	1-10%	
Mozambique	Essential	50-200	0	No	Essential	50-200	10-50	1-10%	1-10%	1-5 years
Namibia	Essential	10-50	50-200	No	Essential	> 200	0	10-30%	0%	
Seychelles	Essential	10-50	10-50	No	Unanswered					
South Africa	Full	50-200	> 200	Yes	Essential	> 200	> 200	30-50%	30-50%	1-5 years planned, but often less frequent
Tanzania	Essential	50-200	50-200	Yes	Essential	> 200	1-10	1-10%	0%	Once per year and after every major flood
Zambia	Essential	50-200	50-200	No	Basic	50-200	50-200	10-30%	10-30%	1-5 years
Zimbabwe	Essential	50-200	50-200	No	Basic	> 200	50-200	1-10%	1-10%	After every major flood

Note: Number of stations are range of stations that currently operational stations managed by the organization itself.

2.2.3 Data processing, analysis and modeling

Digitization

Almost all SADC NMHSs have a database management system for some form of basic data processing, although some rely on spreadsheets. License fees and affordability are a challenge for commercial software. At the same time, many countries have archives of historical data which are only available on paper. Digitization of archived data is therefore important.

Transmission of data to WMO's Global Telecommunication System

NMSs transmit minimal meteorological data to WMO's Global Telecommunication System (GTS). Eight countries transmit less than 50 percent, and Lesotho, Eswatini and Mauritius transmit less than 20 percent. Low transmission rates are caused by outdated software, but poor internet connectivity and interrupted power supply also play a role. Increasing data transmission to WMO's GTS improves initialization and verification (or calibration) of numerical weather prediction and possibly even hydrological models.

Modeling and forecasting capacity

The regional NMSs use forecasting outputs from global production centers, and 10 of the 16 NMSs have a Limited Area Model (LAM). License fees, human capacity and IT infrastructure, however, limit the use of the global production center services. All NMSs, except Zambia, use probabilistic forecasts from ensemble prediction systems of regional or global centers, such as European Center for Medium-Range Weather Forecasts (ECMWF) and National Oceanic and Atmospheric Administration (NOAA). Botswana, Mozambique and Zambia use their own Water Research and Forecasting (WRF) model as a LAM, while the SADC CSC also uses a WRF model. Dynamic or statistical downscaling could be an alternative for using a LAM.

Only eight regional NMSs provide quantitative precipitation forecasts, which are important for hydrological forecasts. Most NHSs focus on monitoring and observations to generate forecasts and have very limited modeling and forecasting capacity. Six NHSs do not conduct hydrological modeling, while 13 NHSs do not use any hydraulic models. Most available models are used for water resources assessments, either as an input for water-use licensing or for assessing the feasibility of infrastructure. Of these models and information services, many are not maintained on a continuous basis to provide input to operational decisions, such as early warning. In practice, NHSs have challenges in obtaining data and forecasts from their NMSs. Table 6 shows the key characteristics of data processing, analysis and modeling for NMSs and NHSs, respectively.

Eight NHSs use Hydstra to manage their hydrological data since this was introduced in a SADC investment programme; four use simple spreadsheets or different programs; and four did not provide information. Eight NHSs do provide some services based on hydrological models, such as rainfall-runoff modeling for strategic decision-making. Only the NHSs of Mozambique, Namibia and South Africa provide services based on hydraulic modeling, as related to flood routing in certain river basins in their country.

Table 6: Key characteristics of data processing, analysis and modeling for NMSs in SADC member states

NMS	What data storage system is used	LAM	Quantitative precipitation forecasts	Ensemble forecasts	Upload to WMO system, % of stations	Self-rated skill of forecasts per forecasting window					Verification capacity
						< 1 days	1 – 5 days	5 – 10 days	> 10 days	Seasonal prediction	
Angola	Not answered	Yes	Yes	Yes	70-90%	Medium	High	High	Medium	Low	Yes
Botswana	Not answered	Yes	No	Yes	-	High	Medium	Low	Low	Medium	Yes
Comoros	Excel and paper	No	Yes	Yes	< 20%	Medium	Medium	Low	Low	Medium	No
DRC	Not answered	No		Yes	-	Medium	Low	Low	Low	Medium	No
Eswatini	METCAP, excel and paper	No	Yes	Yes	< 20%	High	Medium	Low	Low	Medium	Yes
Lesotho	CLIMSOFT and paper	No	No	Yes	-	High	Medium	Low	Low	High	No
Madagascar	Not answered	Yes	Yes	Yes	70-90%	High	Medium	Low	Low	Medium	Yes
Malawi	CLIMSOFT	Yes	No	Yes	50-70%	Medium	Medium	Medium	Low	Low	No
Mauritius	Excel	No	No	Yes	-	High	Medium	Low	Low	Medium	No
Mozambique	Not answered	No	Yes	Yes	20-50%	High	Medium	Low	Low	Medium	No
Namibia	Unspecified and paper	Yes	Yes	Yes	20-50%	High	Medium	Low	Low	Low	Yes
Seychelles	CLIMSOFT	Yes	No	Yes	50-70%	High	Medium	Medium	Medium	Medium	No
South Africa	Unspecified	Yes	Yes	Yes	> 90%	High	High	Medium	Low	Medium	Yes
Tanzania	CLIDATA	Yes	No	Yes	20-50%	High	High	Medium	Medium	Medium	Yes
Zambia	CLIMSOFT and CLICOM	Yes	Yes	No	20-50%	High	Medium	Low	Low	Medium	Yes
Zimbabwe	CLIMSOFT	Yes	No	Yes	70-90%	High	High	Medium	Low	Medium	Qualitative only

2.2.4 Services including early warning

NMHSs provide hydromet services to various sectors and the general public, but very few have staff dedicated to engaging with sectors or end-users. Impact-based forecasting is a known concept for most NMHSs although countries interpret it differently. Countries use different methods for impact-based forecasting and there is scant discussion among DRMs, NMSs and NHSs to develop it. In addition, income streams from service provision are either limited or result mainly from meteorological services for the aviation sector. Services to the aviation and agriculture sectors are common for the NMSs, but the services for the agricultural sector are relatively basic despite it being an important sector for all SADC member states. Many NMSs identified the insurance, energy, agriculture, aviation and water management sectors as feasible for public-private engagements (PPE). NHSs often provide water availability services as a minimum to water managers (11), agriculture (10), energy sector (10), mining (8) and industry (7). Flood early warnings are mostly qualitative and based on observations. Although five NHSs claim to flood forecast for some river basins, this is only confirmed for three NHSs (Shire Basin in Malawi; Zambezi Basin in Mozambique; Orange-Senqu Basin in South Africa). Table 7 shows the hazards for which each NMHS provides early warning.

Table 7: SADC National Meteorological and Hydrological Services for early warning by hazard type

NMS & NHS	Flash/Fluvial flood	River flood	Coastal flood	Meteorological drought	Hydro-logical drought	Tropical cyclones	Extreme Rain	Hail	Frost	Fire hazard	Extreme Wind	Heat	Storm surge
Angola	x	x	--	x	x	--	x	x	--	x	x	--	--
Botswana	x	--	--	x	--	x	x	x	x	x	x	x	--
Comoros	x	--	--	--	--	x	x	--		--	--	--	x
DRC	x	x	--	x	--	--	x	--	--	--	--	--	--
Eswatini	x	x	--	x	x	x	x	x	x	x	x	x	--
Lesotho	x	x	--	x	x	x	x	x	x	--	x	x	--
Madagascar	x	--	--	x	--	x	x	x	x	x	x	x	x
Malawi	x	x	--	x	--	x	x	x	x	--	x	x	--
Mauritius	x	x	--	x	x	x	x	--	--	--	x	--	x
Mozambique	x	x	--	x	x	x	x	x	x	x	x	--	--
Namibia	x	x	--	x	x	x	x	--	x	--	x	x	--
Seychelles	x	x	--	x	--	x	x	--	--	--	x	--	--
South Africa	x	x	x	x	x	x	x	x	x	x	x	x	x
Tanzania	x	--	--	x	--	x	x	--	--	--	x	--	--
Zambia	x	x	--	x	--	x	x	--	--	--	x	x	--
Zimbabwe	x	x	--	x	x	x	x	x	x	x	x	x	--
TOTAL	**16**	**12**	**1**	**15**	**8**	**14**	**16**	**9**	**9**	**7**	**14**	**9**	**4**

2.3 Status of regional services and organizations

All NMHSs in Southern Africa use information from regional centers, river basin organizations or national organizations that have a WMO designated regional role. These organizations support the NMHSs with operational hydromet services and/or with capacity building (table 8 and table 9).

Table 8: Overview of main SADC river basin organizations (RBOs) approached for this study

RBOs	Full name	SADC member states
CICOS*	Commission Internationale du Bassin Congo-Oubangui-Sangha	Angola and DRC sharing with non-SADC member states
LIMCOM	Limpopo River Basin Commission	Botswana, Mozambique and Zimbabwe
OKACOM	Okavango River Basin Commission	Angola, Botswana and Namibia
ORASECOM	Orange-Senqu River Basin Commission	Botswana, Lesotho, Namibia and South Africa
ZAMCOM	Zambezi River Basin Commission	Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe

Note: * CICOS did not participate in the SADC stocktaking as separately stocktaking of hydromet services was done for the Economic Community of Central African States (ECCAS).

Table 9: Overview of SADC regional providers of hydromet services*

Designated role / organization	Designation	Host organization
SADC CSC	Implementing agent for improved hydromet services in SADC. Climate services for all SADC member states. Facilitator of Southern African Regional Climate Outlook Forum (SARCOF)	SADC Secretariat
ICPAC (IGAD Climate Prediction and Applications Center)*	CSC for Eastern Africa, including SADC Member State Tanzania	IGAD
WMO Global Production Centers (GPCs)	For long-range forecasts, coupled ocean-atmosphere global seasonal prediction model, can be consulted by whole globe. .	SAWS
WMO Regional Specialized Meteorological Center (RSMC)	For severe weather forecasts: serves as custodian of the Southern African Regional Flash Flood Guidance System (SARFFGS) for 9 countries and the Southern Africa Severe Weather Forecasting Project	SAWS
	For support on tropical cyclones	Tropical Cyclone Center, La Réunion Météo France
WMO Regional Telecommunications Hub (RTH) & WMO Global Information System Center (GISC)	For collection, distribution and real-time exchange of meteorological data between WMO members or NMSs within the continent and in the other five continents	SAWS; formerly also Zambia Meteorological Department (ZMD) also served as RTH but now is inactive
WMO Regional Training Center (RTC), including Virtual Laboratory (VLab)	For training and education, with additional specialization in Satellite Meteorology (with VLab)	SAWS
WMO Integrated Global Observing System Center (WIGOS)	For improvement and evolution of WMO global observing systems	SAWS

Designated role / organization	Designation	Host organization
WMO RTCs for Lusophone countries	For training and education for lusophone countries	National Institute for Meteorology and Geophysics (Angola) (INAMET)
WMO RTCs for Francophone countries	For training and education for francophone countries	Ecole Nationale d'Enseignement de l'Aéronautique et de la Météorologie (ENEAM) & Ecole Supérieure Polytechnique d'Antananarivo (ESPA) (Madagascar)*
WMO Regional Radiation Center	For international calibration of meteorological radiation standards within the global network and for maintaining the standard instruments for this purpose	National Agency of Meteorology and Teledetection by Satellite (METTELSAT) (DRC NMS)
Hydromet services for Southwest Indian Ocean	For facilitation of Southwest Indian Ocean Climate Forum and as initiator and implementing agent for projects that benefit hydromet services in the SADC island states	Indian Ocean Commission (IOC)
WMO Regional Instrumentation Center (Inactive)	For maintaining relevant calibration standards and assisting members in calibrating their national meteorological and related environmental standards and monitoring instruments	Botswana Department of Meteorological Services*

Note: * Organizations that were not interviewed for their regional role.

SADC CSC assists the region's NMHSs both operationally and strategically. Twice a day it runs the WRF model to create forecasts and it performs remote-sensing assessments. SADC CSC facilitates the seasonal forecast discussions in South African Regional Climate Outlook Forum (SARCOF), provides advisories to NMS directors on extreme weather systems that geographically cover at least two countries and manages the regional NMHS investment programs. It is in the process of becoming a fully designated WMO Climate Services Center and is extending its capacity to provide broader services. For 11 East African countries, ICPAC is the WMO-accredited climate center. Within the SADC region, only Tanzania benefits from the services of ICPAC. The Indian Ocean Commission (IOC) supports regional forecasting and monitoring actions as a coordinator for the Southwest Indian Ocean countries.

Within the SADC region, the following institutions have received official designations by WMO:

- As the WMO RSMC for Severe Weather Forecasts, RSMC Pretoria (that is, SAWS) provides severe weather guidance to SADC countries as part of the WMO Severe Weather Forecasting Project. This information is based on global and in-house models and the responsibility is formally included in the National Forecasting Centre workflow. The information is accessible through a dedicated website and the intention is to provide countries in the region with a heads-up of weather events in the short and medium forecasting timescales. Flash flood early warning guidance, using the Southern Africa Regional Flash Flood Guidance System (SARFFGS) is provided to nine SADC member states, but not yet to Angola, DRC, Tanzania, Madagascar or the island states. As this system is not mature nor well-established, RSMC Pretoria would like to extend the SARFFGS and resuscitate the annual training sessions. The RSMC La Réunion for Tropical Cyclone Forecasts provides guidance information about all tropical low systems for 13 SADC member states. The center's mandate is to track systems in the Indian Ocean, but the center also aims to continue tracking the system after landfall. Close coordination with the RSMC at SAWS is therefore key in that regard. The RSMC in La Réunion is part of Météo France and uses Global Circulation Models for seasonal forecasts as well as the Météo France LAM for more short-term forecasts.

- As a WMO Global Producing Centre for Long-Range Forecasts, one of twelve such centers in the world, SAWS uses its own global numerical model, which involves coupling of both the atmosphere and ocean components to form a fully interactive coupled modelling system, named the SAWS Coupled Model (SCM), and it combines its output to that of the GFDL-SPEAR and COLA-RSMAS-CCSM4 systems (part of the North American Multi-Model Ensemble System) to provide multi-model ensemble forecasts. SAWS makes these seasonal forecasts available through its website, among others, in the form of a "Seasonal Climate Watch". It is unknown to what extent these forecasts are currently being used in the region but these forecasts are provided as input the Southern Africa Regional Climate Outlook Forum.
- The WMO-RTH and WMO-GISC can support the NMSs to increase data transmission of data to the WMO's GTS, but this is currently only happening to a limited extent. As mentioned, improving the transmission is essential for better initialization and calibration of regional and global numerical weather prediction models. Both WMO-RTH and WMO-GISC roles are fulfilled by SAWS. The Zambian Meteorological Department also functioned as an RTH but is currently inactive.
- WMO-WIGOS was launched in February 2021 and can become instrumental in combining NMS' data with data from other sources. It aims to collect metadata of different data sources than the NMSs have which are relevant for climate (change) monitoring. This is another WMO role of SAWS.
- From the WMO regional training center (RTC) in Pretoria there is much training in English, for almost all skills needed with specific recognition by WMO and for the remote-sensing skills. Also, a number of NMHSs staff have been trained in RTCs in other parts of Africa, and/or in another continent. The NMS of Angola National Institute for Meteorology and Geophysics (INAMET) is also designated as WMO RTC for lusophone countries but is currently not operational. Then there are additionally for francophone countries two institutions in Madagascar that function as an RTC but their status of operation was not confirmed during the study.
- The NMS of Botswana is a designated WMO Regional Instrumentation Center but is not operational. The NMS indicates it would like to resuscitate the role, likely with funding from the Botswana government.
- The WMO Regional Radiation Center is in the DRC, but it has not been confirmed if it is operational.

Currently, RSMC Pretoria, RSMC La Réunion and SADC CSC all play a role in providing Member States with short-term weather warnings. RSMC Pretoria provides short-term extreme weather forecasts and flash flood guidance; RSMC La Réunion focuses on the tropical low systems above the sea; and SADC CSC provides advisories based on their WRF modeling. SADC is convening harmonization meetings with Directors of NMHSs and WMO Regional Institutions, but further harmonization needs to be initiated and the mandates between these three organizations need to be clarified. There may be some duplication of tasks that is not cost effective and which will not inform wise future investment decisions, but also there is a risk that several uncoordinated sources of similar information may not be in the interest of society. However, such harmonization needs further discussion, as there are also schools of thought that see the roles differently and see the benefit of having different source of information.

Most organizations with a regional role depend on cost recovery for regional services, either by WMO, Member States and/or project funding. This makes such services very vulnerable to the end of such funding sources.

Overview and Status of river basin organizations

RBOs provide limited operational services. Most of the RBO services pertain to water resources planning and monitoring and to facilitating the data sharing between member states, while there are currently limited operational services. The ZAMCOM has a data exchange system (Zambezi Water Resources Information Systems (ZAMWIS)) but the data is not up to date. It also has an operational model for flow forecasts at key locations. The ORASECOM set up a water information system to enable data exchange. ZAMCOM, OKACOM, and ORASECOM are ahead of LIMCOM in terms of services and institutional set up. Similar database management systems have been introduced in SADC to enhance data sharing within the river basins.

Most RBOs have the ambition to develop hydrological forecasting systems to inform operational decisions. However, the resource constraints of most Member States mean the RBOs depend on grants. A hybrid system combining the efforts of RBOs and NHSs could be more cost efficient, as most NHSs still have to set up modeling capacity. RBOs view that certain Member States, rather than themselves, are better situated to provide certain functions given they are more advanced and have the capacity for maintaining systems.

2.4 Status of private sector engagement and collaboration with universities

Private sector engagement was explored by analyzing survey results and studying the policies and regulatory frameworks of different SADC countries. Additionally, three case studies of potential PPE were explored by facilitating workshops between the private sector and NMSs on crop-specific advice (Madagascar), weather-index-based crop insurance (Malawi) and lightning-detection services (Eswatini).

Among NMHSs, the perceptions of existing relationships with the private sector vary. About 45 percent of the respondents see the relationship as effective or see themselves as a major player. Most NMSs are very positive about the feasibility of setting up PPEs with many segments of the private sector but there is a lack of a unified approach to engage into these relationships that will result in mutual benefits while at the same time favors the outcomes to society. The limited survey results of NHSs precludes generalizations. For NMHSs alike, there is limited co-development of services with the private sector.

As for data policies, NMSs in several SADC countries have provisions in the respective meteorological and water acts that articulate charging for data and services, or not. In several countries, the charges must be published in the government gazette or require ministerial approval. For NHSs, the water acts consulted do not stipulate if fees can be charged for information or stipulate of fees can be charged for water use. These water use charges, however, are not solely dedicated to cost-recovery for hydrological services. Charging for data and services can of course provide financial income for the organizations selling the data, but can also limit the full value of this data on a national and regional level, if charges are so high that they limit the use of the data.

Many SADC countries have public-private partnership acts or policies covering private sector investments in infrastructure. The acts seem to be written for large water management and transport infrastructure, but the procedures described may also be relevant for instances when the private sector invests in monitoring or IT infrastructure.

Apart from opportunities, NMHSs identified challenges in terms of mandates, infrastructure handover, procurement, profit sharing, and regulatory frameworks. The correlation between policy and regulatory framework and the current public-private engagement on the ground was not clear.

The case studies indicate that most NMSs had plans for PPEs but had not yet acted on them. The case studies bear this out: NMSs have limited experience in engaging on potential business models and client-centric service development. During the workshops, the private sector parties identified needs that NMSs appeared to be able to readily fulfil but was not yet aware of.

2.5 Status of collaboration with universities

More than 40 universities are working on topics related to weather, climate, water and disaster risk reduction. Most NMHSs already have existing relationships with universities, mainly in their own countries, for research and development support and as alma maters of their employees. These relationships are in general 'occasionally beneficial' - with a lack of communication being the main reason why challenges are yet to be solved, rather than a lack of capacity at the universities. There is a large dispersion of expertise in the region and only small research units exist at those universities. This makes it more difficult to engage in stimulating a cooperative building of capacity and research profile.

Academic networks exist and have been in place for years. However, these networks do not cover all SADC countries and hydromet services are only part of their scope:

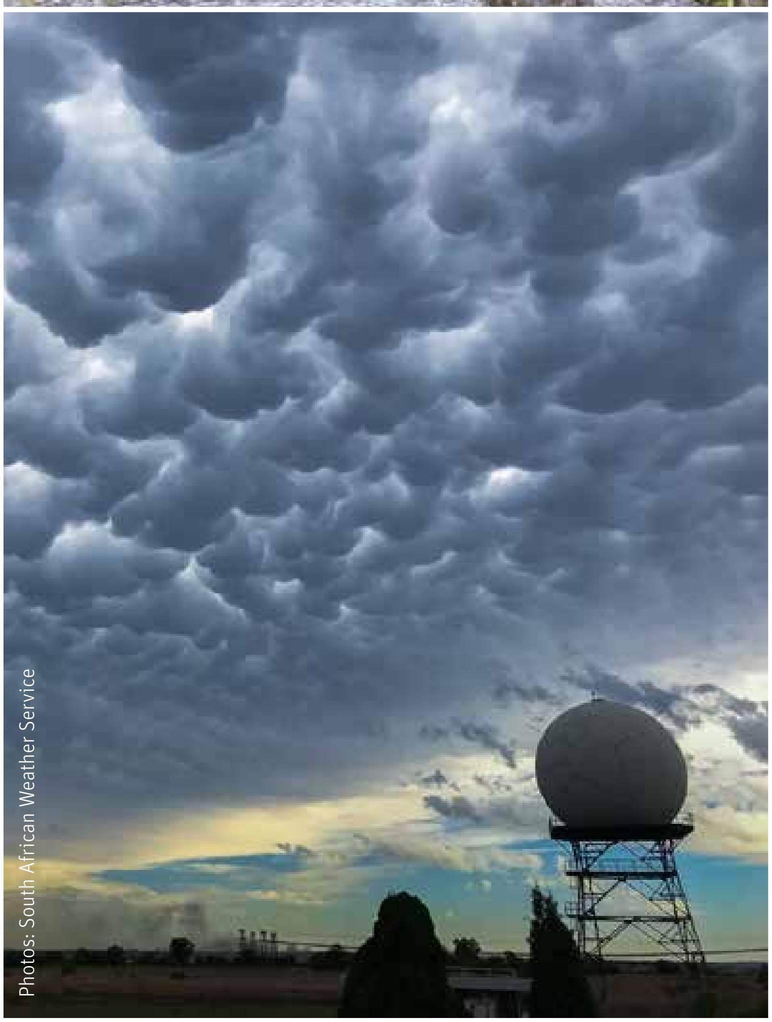
- Partners Enhancing Resilience for People Exposed to Risks (PeriPeriU) mainly focuses on disaster risk management and only touches on hydromet services.
- AUDA-NEPAD SANWATCE focuses on research for water, in general.
- Applied Center for Climate and Earth System Science (ACCESS) is a South African consortium that focuses on earth system sciences.
- WaterNet targets has an official mandate by the SADC to build capacity in integrated water management and is truly regional with many collaborating academic institutions. Within WaterNet, a hydrological program is in place, for which the University of Dar es Salaam coordinates expert inputs from various Southern African universities.

NMHSs, universities and research institutions have different cost-recovery models, inhibiting opportunities for collaboration. To improve research and development for NMHS with the support of universities, one must be aware that many academics focus on teaching rather than on research.

In the networks and in the region, as well as in cooperation with overseas universities and research funds, the South African universities are relatively well represented. It is recommended to also involve other SADC universities in networks for research and capacity building. These universities need support, given their limited staff and financial capacities.

For NHSs, apart from training at the academic level, there is a clear additional need for vocational training, which is not being addressed by the universities. For meteorology, the Regional Training Centers offer vocational training. For NMSs to grow capacity in numerical weather prediction, it is recommended to further build existing collaboration between NMSs and academic institutes around the SADC Cyber-Infrastructure Framework.

Initiatives such as internships, bursary programs, research chairs funded by the NMHSs, involvement of NMHSs staff in lecturing or co-supervision of students are not common in the region. More pilots in this regard are recommended as there are positive experiences with these types of interventions.



Photos: South African Weather Service

The analysis in the previous chapters highlighted the strategic importance of hydromet and early warning services for Southern Africa. The current service levels of the region's NMHSs leave for most countries substantial gaps to respond to the growing demand of adequate services based on sound observations. At the global level, the WMO has launched the Systematic Observations Financing Facility (SOFF) to support countries in generating and exchanging basic observational data based on the Global Basic Observing Network (WMO 2020). In line with these global initiatives, guidance is herewith provided for strengthening hydromet and early warning services in Southern Africa in a programmatic approach. This chapter highlights the programmatic approach for modernizing hydromet services in Southern Africa, defines objectives, outcomes and output and makes recommendations for its implementations.

3.1 Proposed Objectives and Outcomes

The report formulates a comprehensive program addressing the modernization of hydromet services in Southern Africa, ensuring programmatic support along the entire hydromet value chain from observations to improving early warning services and reaching communities. Experience from previous programs and projects shows that hydromet projects should address the entire hydromet value chain, be sizable enough to have a transformative and sustainable impact and support the necessary institutional reforms.

Acknowledging the complexity of large projects and programs, the diversity of the SADC member states in terms of modernization needs and recognizing different opportunities for financing of hydromet services (from the perspective of governments, hydromet services, donors and the private sector), a commonly agreed set of objectives and outcomes, a common framework for monitoring and evaluation and a coherent approach and strategy on policies and regional collaboration have been formulated.

The goal of the proposed action plan is "*to have NMHSs within the SADC region that are capable to (better) provide impact-based early warning services on climate, weather and water hazards*."

The vision is that by 2030 (and, where possible already by 2025) in all SADC member states essential early warning services can be provided and that service levels have improved with this regard. Regional Centers have sustained and modernized their operation, providing adequate services to the countries, communities and businesses in Southern Africa, and support member states in a cascading approach.

Based on the analysis in the stocktaking report, four outcomes were identified to achieve this goal. The different outcomes and related intermediate actions and results/outputs are (figure 6):

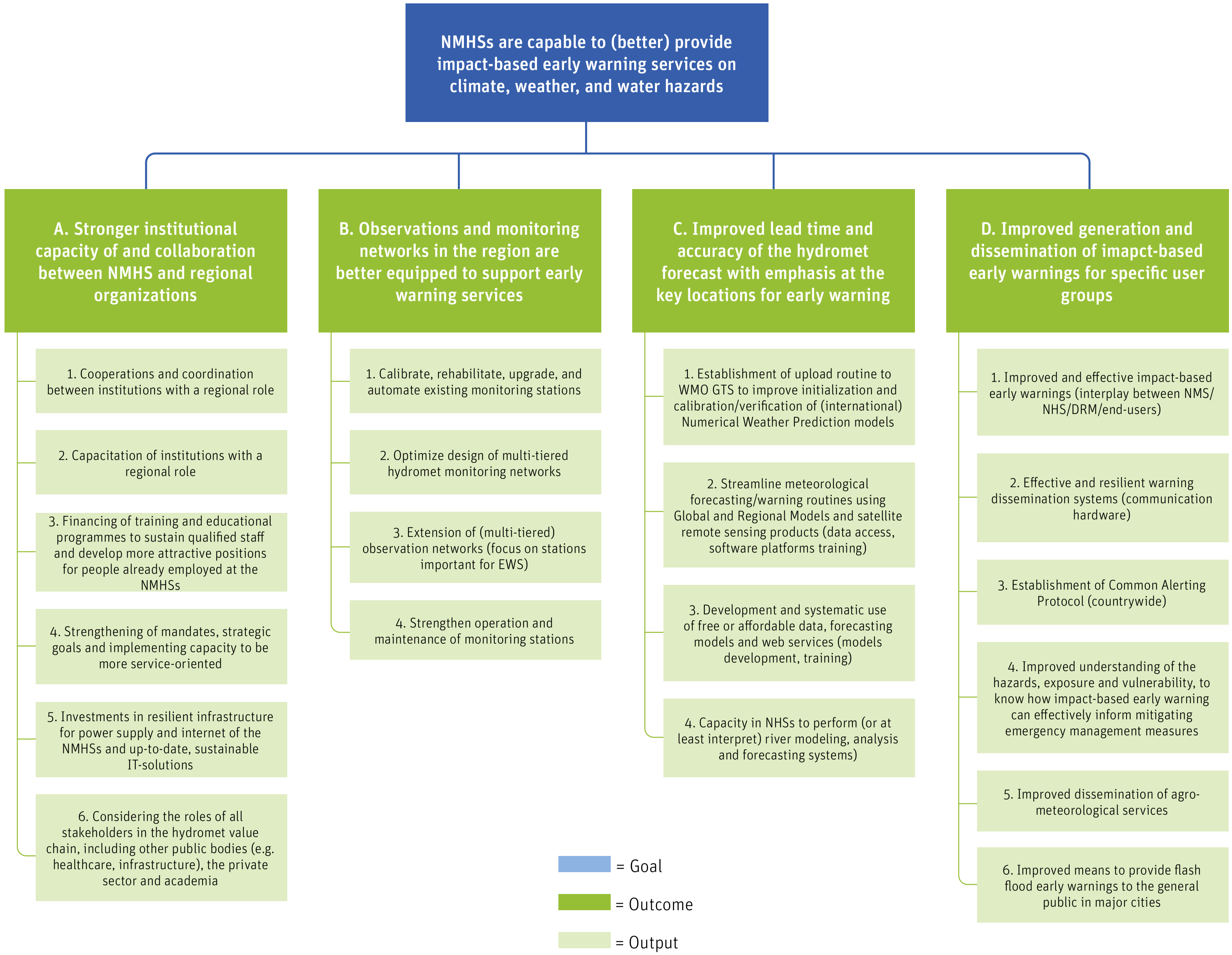
A. Stronger institutional capacity of and collaboration between NMHSs and regional organizations

B. Observations and monitoring networks in the region are better equipped to support early warning services

C. Improved lead time and accuracy of the hydromet forecast with emphasis on the key locations

D. Improved generation and dissemination of impact-based early warnings for specific user groups

Figure 6: Goal, outcomes and outputs of investment framework to modernize hydromet services in the SADC region



3.1.1 Outcome A: Stronger institutional capacity of and collaboration between NMHSs and regional organizations

All NMSs and NHSs in the region have capacity challenges and are relatively small organizations in relation to the enormous tasks they need to fulfil. The WMO recommends a cascading process in which global and regional organizations support NMHSs, but also bilateral cooperation could assist in obtaining 'economies of scale' advantages.

In this outcome, strengthening regional collaboration would start with harmonizing the activities of the regional organizations, notably SADC CSC, RSMC La Réunion and RSMC Pretoria. Activities should lead to a harmonization of early warning messages, updating relevant protocols and harmonizing of activities. In addition to improved coordination, SADC CSC, RSMCs and RTC and NMSs that have other WMO designated roles need further support to implement their genuine activities and mandates. Those activities include, for example, improving and rolling out to additional countries of the flash flood guidance through RSMC Pretoria, training through RTC Pretoria RTC Angola and RTC Madagascar, assistance to NMSs with uploading of weather information to GTS by the GISC and RTH, and calibration of instruments by new or to be resuscitated calibration centres. Also, RBOs need to step up their role to support basin-wide collaboration on flood modelling, forecasting and information dissemination. Stimulating regional collaboration is an underlying but important reason to support the SARCOF process, pre- and post-season meetings within river basins and joint education.

At the national level, NMHSs need support to strengthen their respective management structures. The NMHSs will need to identify what changes in the mandates and in the organization are needed to become more service oriented. In terms of infrastructure, NMHSs most importantly will need adequate support to ensure power supply, internet access and back-up IT capacity.

To facilitate collaboration with academia, universities, and the private sector, the action plan proposes regional funds to support capacity building, academic exchanges, and public-private collaboration. For example, a regional program like a regional bursary program, as was once applied for the water sector, could facilitate innovation by promoting private and academic sector collaboration with NMHSs and promote collaboration among partners in the region.

3.1.2 Outcome B. Observations and monitoring networks in the region are better equipped to support early warning services

Strengthening the observation network and closing critical observation gaps remains an important outcome of any hydromet modernization effort in the region. Before investing in new stations, priority should be given to the calibration, resuscitation, and automation of meteorological, climatological and hydrological observation stations as a large portion of observation stations is not operational and/or not recently calibrated despite the importance of these stations for any early warning system (EWS) and other hydromet services. In particular, river gauging stations need updated rating curves. The current network densities are not sufficient to effectively monitor the most relevant weather and climate phenomena. Before additional stations are added to the observation network, it will be important to consider the additional costs for operating and maintaining the observation network. Operation and maintenance issues are common across all NMHSs and are often driven by a lack of staff, customized and missing spare parts of equipment, lack of resources for field and frequent maintenance visits. It will therefore be important to find a balanced approach between investments in additional observation stations (or reinstalled stations) and the costs for operation and maintenance of the observation network. Actions for maintaining current networks are therefore also included. Priority would be given to enable countries to comply with the Global Basic Observation Network (GBON) requirements, whereas reaching WMO standards for NMSs may still take some time. As part of the observation network, countries may need to establish or extend their upper-air observation network and introduce a lighting detection network and make maximum use from the satellite data and products available through for example EUMETSAT.

3.1.3 Outcome C. Improved lead time and accuracy of the hydromet forecast with emphasis on the key locations for Early Warning

In this outcome, significant emphasis is placed on improving processes for the NMSs to transmit meteorological data globally through the WMO GTS, which is important for the initialization and verification of forecasting models, and on improving reception and interpretation of model forecasts from global and regional models. Furthermore, actions are included to assist in training and provision of data management and modeling solutions that are affordable to maintain for NMHSs. Most NHSs hardly make use of modelling for early warning purposes both for floods (hydrological and hydraulic) and droughts (hydrological), therefore special actions are included to strengthen them. NMHSs should be assisted to in the first place make optimal use of existing model output available and then to set up and implement hydrological and hydraulic models through different means, such as on-the-job training, establishing models with the support of consultants, and peer learning where required. The action plan also has training in interpretation and use of what is available from regional and global centres. It will also be important to strengthen the link between flash flood guidance and early warning at the regional level

3.1.4 Outcome D. Improved generation and dissemination of impact-based early warnings for communities

This outcome aims to reach end-users with timely, impact-based early warnings. Warnings for extreme weather are issued directly from the NMHSs to specific user groups. However, other warnings should be disseminated through DRM organizations and their networks in the country. This investment addresses the warnings as provided by the NMHSs to the user groups and to the DRM. Realistic and useful ways of impact-based forecasting need a thorough consultative process within the countries, as they depend on the hazards, the capacities of NMHSs and DRM organizations and the capacities of the targeted users to receive and interpret warnings and act on them. Actions are included to support such a process, engaging with the DRM organizations and representatives of the end-users of the early warnings. The infrastructure means of communication between NMS, NHS and DRM during disasters and Common Alerting Protocols are also strengthened. The outcome further addresses better organization of spatial information on hazards, exposure, and vulnerability in such a way that it can inform strategic, tactical and operational decisions before and during the occurrence of the hazards. This information will inform many earlier mentioned outputs. For farmers, regional development of warnings dissemination tools and national roll outs of such warning tools is included. This will contribute to optimization of farming and mitigate some of the impacts of mainly droughts but also other weather hazards. Although the SARFFGS is improved in Outcome A, additional budgets are reserved to develop more advanced flash flood guidance systems for metropolitan areas. Such advanced systems require an advanced level of hydromet services and are therefore given low priority for those NMHSs that are not yet at this level.

3.2 Estimating needs for strengthening hydromet and early warning services

The needs for strengthening weather, water, climate, and early warning services in Southern Africa are substantial. This estimation of needs and related costs focuses on those activities, which can be implemented in the next 5 to 10 years and supports actions that would strengthen the existing institutions within their mandate. Only those activities and actions that would directly lead to strengthened early warning and impact-based forecasting and thus not the other relevant priorities of the NMHSs have been considered. All actions would, to the extent possible, be supported by regional actors, institutions, private-sector actors, and universities to strengthen further regional linkages and support the existing institutions in the region with this regard. The estimation of costs is based on general unit costs, needs expressed by the NMHSs, existing infrastructure, country size, relevance of hazards, expert judgement and the maturity level of the NMHSs (see table 4). Where suitable, priority would be given for low-cost technology (for example, in the observation network) and license free or affordable software applications. Only very limited costs are included with regard to building, vehicles and related issues. Operational and maintenance costs are included, apart from staff costs that have been expressed in numbers of staff rather than in costs of salaries.

To strengthen hydromet services for effective early warning, it is estimated that approximately US$ 116 million at current price levels would be needed for all actions to be implemented over the next ten years, excluding the budget for operational and maintenance costs. This cost estimate may increase once other issues that NMHS would require to improve are included in the calculation. This already requires large commitments from the Member States and other partners. Table 10 provides a general overview of costs by proposed outcome. It is estimated that the costs would vary between US$ 3 million and US$ 12 million between Member States depending on their specific needs. About US$ 8.3 million or about 7 percent would be needed for regional actions. This would, for example, also include resources for regional actions, such as a regional scholarship or bursary program. A detailed country assessment would need to follow to draft a detailed country level investment plan, to review the assumptions made for allocation of certain actions to certain NMHSs or organizations with a regional role. The 10 years of operations and maintenance, includes additional training . This period of 10 years for the operational costs was chosen because a longer period would have large technology developments and changing needs of countries, which cannot yet be forecasted. Deliberately, country level needs are not highlighted in this summary report due to the high uncertainty of the estimations.

Table 10: SADC region hydromet investment costs per outcome

	Gross Capital Investments and Actions (in US$ million)				
Outcome	**Works**	**Goods**	**Consultancies**	**Training**	**Total**
Outcome A	0	0.5	3.0	6.7	10.2
Outcome B	4.9	25.2	8.1	8.6	46.8
Outcome C	0	3.8	9.7	18.7	32.2
Outcome D	2.6	2.6	20.4	1.6	27.1
Total	**7.5**	**32.1**	**41.2**	**35.6**	**116.3**

Hydromet services are an important public good function and, in most countries, supported by the government or through public-private partnerships. The proposed investments and actions for strengthening hydromet and early warning services require sufficient operation, maintenance, and personnel. In addition, many of the existing staff in the National Hydromet Services are close to retirement in the coming years, leaving a substantial gap of expertise in some of the countries. It is estimated that to sustain and operate the proposed investments and actions about 277 staff would be required, which would need to be ascertained if it is already available. In some countries it is well possible that some of the current staff cannot fulfil certain tasks due to lack of investments or operational budget. By making clear per action which staff is needed to make the operation and maintenance sustainable, the expectation of investments of Member States is clearer. While financial and technical partners can support, to some extent, the training of forecasters, hydrologists and early warning specialists, the annual salaries would need to be taken up by the respective NMHSs and thus governments. Due to the large differences in salaries and different arrangements in the NMHS about recruiting and involving staff a country specific estimation of the staffing was not conducted. Back of the envelope estimations of staffing expenses over a period of 10 years would add up to US$ 90 million. Collaboration with the private sector or public-private collaboration as well as with universities and research institutes may present an opportunity to attract and sustain talent in the national hydromet community.

The annual operation and maintenance budget in Table 11 is here estimated at about 8 percent of the investment costs for the hydromet observation, vehicles and ICT equipment.

Table 11: SADC region hydromet investment costs per outcome by cost categories

	Operational costs		
Outcome	**Operation and maintenance for 1 year [US$ 1000]**	**Operation and maintenance for 10 year [US$ 1000]**	**Additional staff [number of staff*]**
Outcome A	607	6,065	18
Outcome B	3,254	32,542	60
Outcome C	1,932	19,320	154
Outcome D	3,150	31,500	45
Total	**8,943**	**89,427**	**277**

Note: Cost per outcome = x $1,000 per year. * FTE, Full time employee (equivalent)

At country level estimates of investments and actions range between US$ 3 million (for example for Comoros and Seychelles) and US$ 12.0 millions (for Tanzania) depending on the needs of the member states. While estimations were made at country level and then aggregated, it was agreed to not present country specific estimates due to the large number of country specific factors. It is furthermore important to note that the cost estimations do not include country specific costs, like import duties for goods to be imported or the possibility to source consultancy studies and support locally. Other costs such as the costs for the construction of buildings for NMHS, vehicles and other expenses are neither considered. As such the report the report provides an overview of the key issues to be financed.

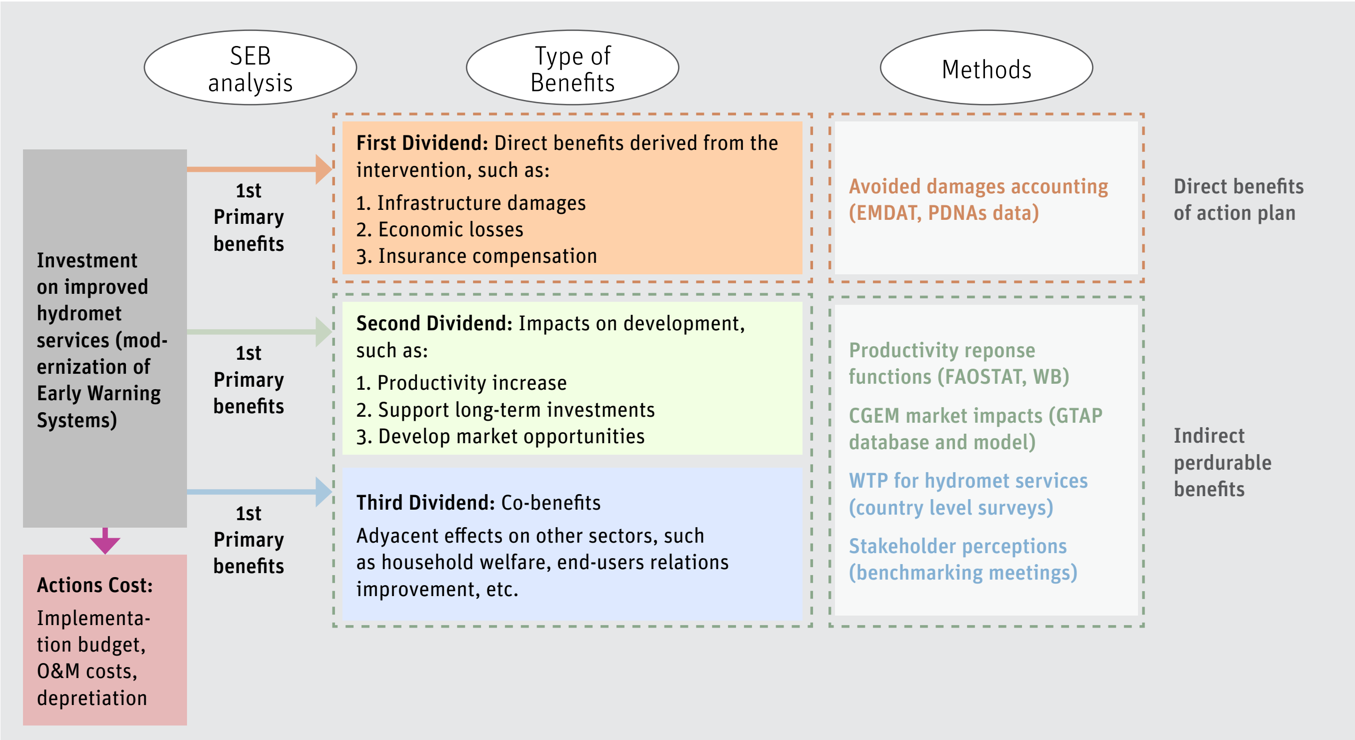
The importance of hydromet and early warning services for the economy and livelihoods in Southern Africa is highlighted at the beginning of the report. In this chapter, the economic benefits from strengthening hydromet and early warning services are identified, with specific attention to the benefits from strengthening early warning information and to a lesser extent benefits to sectors such as agriculture, transport and energy production. The socio-economic benefit analysis aims to quantify the benefits from strengthening and modernizing hydromet services by conducting simulations on the potential benefit and estimating key financial indicators (such as, benefit-cost ratio and net present value). Figure 7 summarizes the proposed framework for the economic analysis, linked to the main affected sectors and some specific impacts.

Since hydrometeorological products and services are public goods, they are generally not marketed in markets. Therefore, there is usually no direct information on their economic value. For this reason, to determine the economic benefits generated by projects to improve hydrometeorological systems, it is necessary to use specific approaches, such as benchmarking, and results transfer methods. In this analysis, the benefits derived for the different economic sectors have been estimated through benefits transfer methods. The analysis follows the general structure of the "Triple Dividend of Resilience" framework.[5] This framework suggests considering the following three resilience dividends when estimating the benefits of a project:

- First dividend: save lives and avoid damages and losses. That is, to what extent an improved system for predicting extreme events and early warning reduces asset losses and prevents deaths.
- Second dividend: unlocking economic potential. Greater awareness of risks and better predictions can increase economic productivity, support long-term investments in productive assets and develop opportunities
- Third dividend: generate the development of co-benefits. Investing in hydrometeorology can serve multiple purposes that go beyond reducing the impact of disasters. For example, improving the quality and timeliness of predictions can produce co-benefits for a significant number of stakeholders, including households.

[5] Tanner et al. (2015).

Figure 7: Triple Dividend Resilience Framework adapted to SEB analysis of the action plan[6]



4.1 Methodology for the socioeconomic analysis

Table 12 outlines the methods proposed to evaluate each of the aspects mentioned in the proposed potential benefits to evaluate. A detailed description of the methods proposed can be found in Quiroga, 2018.[7]

Table 12: Methods and databases for the analysis of the quantitative benefits to improve hydromet services in the SADC region

Potential benefits	Indicators to analyse	Proposed method	Data
Flood losses	Analysis of frequency in the countries, average losses per affected people and loss reduction ratio due to improvements in DRM	Avoided losses	EMDAT, PDNAs
Drought impacts	Drought impacts on crop production	Cost-Loss model (improved drought early warnings)	EMDAT, FAO
Improved economic productivity (agriculture, energy)	Change in production	Impact functions (estimated production response)	FAO, World Bank
Unblocked market benefits	Change in GDP	Computable general equilibrium model	GTAP global database
Household welfare	Change in WTP	Transfer knowledge (similar regions)	Literature review

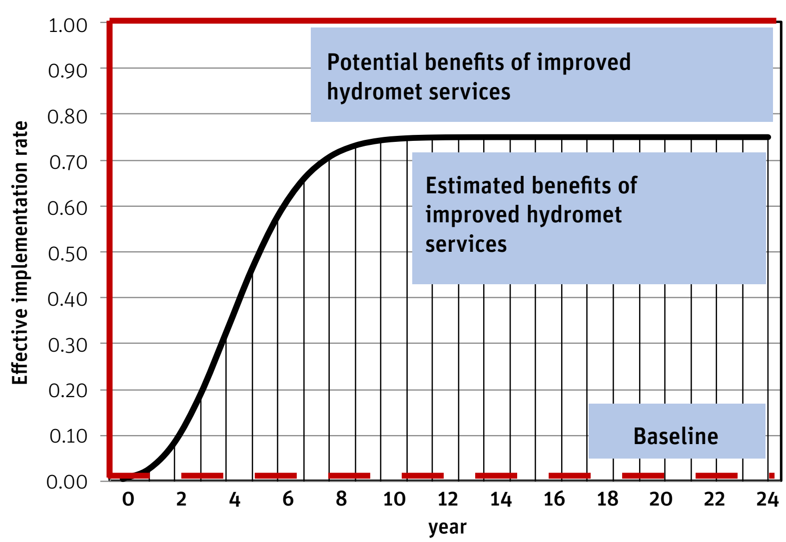
[6] Source: Elaboration based on Tanner et al. (2015).
[7] http://documents.worldbank.org/curated/en/842621563163324249/Socioeconomic-Analysis-of-the-Potential-Benefits-of-Modernizing-Hydrometeorological-Services-in-the-Lao-People-s-Democratic-Republic.

The benefits of the proposed project have been estimated for each resilience dividend. The selection of sector benefits is limited both by the availability of the data and by restrictions of confidence on the same. Therefore, for this analysis, a "conservative"[8] strategy has been taken, so that only the most obvious part of the total benefits of the hydro-meteorological and climatic services have been considered. The total benefits provided are estimated to be reasonably acceptable as a conservative figure compared to their true value. In the analysis, the first dividend considers how predictions and improved early warning systems (EWS) can reduce national losses, both in the face of drought hazards and floods, storms and extreme cold. The second dividend includes how increased awareness of risks and a higher quality of predictions can increase agricultural and energy productivity and the sector's gross domestic product (GDP) through efficiency gains and the impacts of drought and floods avoided (for example, by better understanding of the optimal sowing or harvesting date or improved energy management). The third dividend includes co-benefits for households through a study of Willingness to Pay (WTP) for improved EWS.

Different analysts, countries and agencies have different views on the correct discount rate to use for the cost-benefit analysis. Zhuang et al. (2007) studied discount rates used for public projects around the world and found rates from 2 to 15 percent, with lower rates more common in developed countries and higher rates more common in developing countries. The World Bank provides discount rate guidance in its Handbook on Economic Analysis of Investment Operations (Belli et al. 2001), noting that it has traditionally applied discount rates in the 10 to 12 percent range. Other major multilateral development banks also tend to use rates in this range (Zhuang et al. 2007). WMO (2015a) provides a more detailed discussion of the choice of discount rates. In this analysis, a 12 percent rate of discount as an upper bound and then conduct sensitivity analysis using a lower bound of 3 percent.

The benefits of any such project would presumably last much longer; therefore, a 25-year analysis period was chosen to develop the aggregated estimates. With a higher discount rate (for example, 12 percent), benefits more than a couple decades out have minimal present value. The maximum effectiveness rate of the investments is not achieved in a linear trend, but a path of accumulating improvements has been defined (up to 75 percent at the end of the period). Figure 8 shows the effective implementation rate used in this study, based on a binomial cumulative function.

Figure 8: Effective implementation rate considered in this study



[8] Kull, Mechler and Hochrainer (2013).

4.2 Estimation of Benefits from Hydromet and Early Warning Services

The results of this analysis show that the contribution of hydrological and meteorological information to socio-economic development in Southern Africa is expected to be very high, particularly due to the potential benefits for the increased productivity of the agriculture and energy sectors and their contribution to GDP. Disasters related to water, especially floods, have played an important role in evaluating the improvement of hydrological and meteorological information. This study has not considered the numbers of deaths from an economic perspective, but only in terms of their social impacts. As this report has avoided valuing life in economic terms, the estimates presented can be considered conservative.

Using the 3 percent and 12 percent discount rates as lower and upper bounds, and with the estimated annual benefits, ex ante SEB estimates were established for the EWS modernization in SADC. Table 13 shows the results from the baseline SEB calculations. The present value of benefits is between $1,299 and $4,151 million using a time horizon of 25 years and a 12 percent and 3 percent discount rate, respectively.

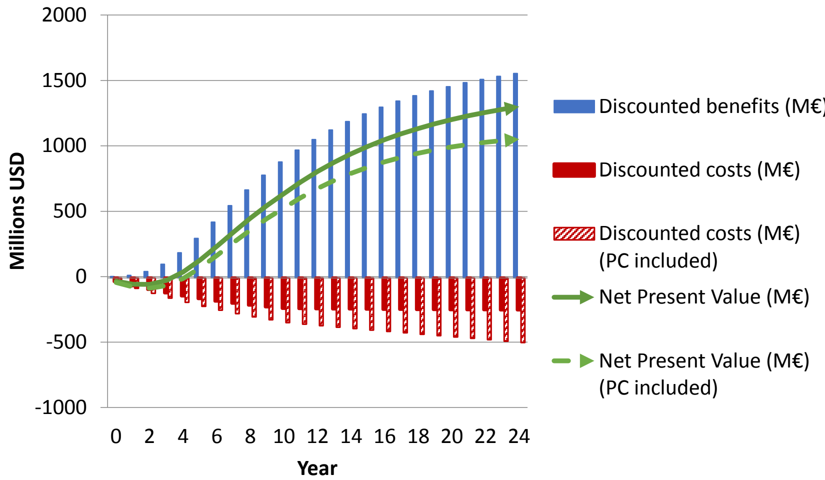
Table 13: Present Value of SEB estimates for the SADC region

Benefit estimates (US$ millions)			
Discount rate (%)	3.0%	7.0%	12.0%
Present value of benefits			
Flood improved response	3,236.2	1,922.4	1,097.9
Drought improved management	925.8	549.9	314.1
GDP unblocked growth (agriculture and energy)	272.7	162.0	92.5
WTP	143.51	84.2	48.6
Present value of SEB	4,578.2	2,719.6	1,553.2
Present value of costs			
Present value of costs	426.6	330.7	253.4
Net present value			
NPV	4,151.6	2,388.9	1,299.7

The report focusses only on hydromet services related to early warning. The estimation of socio-economic benefits is thus also related only to the direct and indirect benefits of early warning services and not for example on agrometeorology. It is however acknowledged that potentially the socio-economic benefits would be higher, but also that substantially more would need to be done to effectively provide different user communities with, such as farmers, with adequate early warning services. The socio-economic benefit analysis highlights the potentially huge benefits, which can be achieved for different sectors of the economy.

The action plan for modernizing early warning systems in the Southern Africa region seems to have a huge potential for socioeconomic benefits in the countries of the region. Figure 9 shows the present value of benefits and costs, and the NPV of the plan for a discount rate of 12 percent in the considered range of 25 years. Personnel costs have been considered separately as sensitivity analysis. It can be observed that the investment may produce substantial benefits.

Figure 9: Net Present Value for the SADC region (actualized 25 years)



An anemometer measuring wind speed and direction. Photo: LasseLund

5 • CONCLUSIONS AND RECOMMENDATIONS

In recent years, many countries in Southern Africa have made substantial progress on the modernization of their hydromet and early warning services. Now, some countries in Southern African are on a critical junction to sustain these services and to improve their delivery for a meaningful impact to communities and the economy. As such, the modernization of the region's hydromet services is feasible and an important contribution for the climate-smart and resilient development. This chapter summarizes the main conclusions and provides some key recommendations for implementation of actions.

5.1 Conclusions on the status of Hydromet and Early Warning Services

The analysis of the status of the NMHSs paints a diverse picture of the status of the national weather, climate, water and early warning services in the 16 SADC member states as well as in the relevant regional organizations.

1. Four countries in the region have "full" NMSs and two have "advanced" NMSs. In general, NHSs are substantially weaker than NMSs, with only one having a "full" NHS and none being "advanced". In general, the NMHSs focus on the technical aspects of observations and monitoring and data processing, analysis, and modeling and less on the service orientation. The following key challenges were observed:
    - For most countries, high percentages of meteorological and hydrological stations are not operational, while the size of the observation networks is already limited and does not meet draft GBON standards. Usage of remote-sensing data products is common for NMSs, but not for NHSs.
    - While the NMSs use GPCs, the transmission of available data to the GTS is limited and therewith limits the calibration and initialization of the models from the GPCs. Most NMSs do not implement the cascading forecasting process to the extent of considering the option not to have their own LAM.
    - NHSs have, in most cases, no or very limited capacity for hydrological or hydraulic modeling to support operational decisions; thus, early warnings for floods and hydrological droughts are mainly based on observations only.
2. Often the weaknesses of the NMHSs are in the enabling factors such as mandates, funding, capacity building and dissemination of information. The availability of stable power supply and basic IT infrastructure (for example, servers and improved internet connectivity) remain a challenge. NMHSs have big challenges attracting and keeping qualified and experienced personnel.
3. Very few NMHSs provide services to climate-sensitive economic sectors, such as agriculture. While general agrometeorological services are available in many countries, few NMHSs are currently providing services for specific agricultural producer groups.
4. Critical gaps remain for last-mile communication and coverage of the early warning systems in major river basins and in urban areas. Instruments such as impact-based forecasting and adapted communication protocols have been tested in pilot projects; however, they are not yet widely rolled out. The division of tasks between DRM agencies and NMHSs is clear, though not necessarily regulated and lacks Standard Operating Procedures for data/information sharing. For DRM agencies, serious challenges exist with the type of information received from the NMS and NHS, in terms of format and way to access, as well as interpretation of data and lead times for floods.
5. Southern Africa benefits organizations with a regional role, including RSMC Pretoria, RSMC La Réunion and SADC Climate Services Centre as well as various other WMO designated roles to na-

tional organizations and a facilitating role of the IOC. There are River Basin Organizations, which facilitate data sharing, but their role in operational services is currently limited. The funding of these centers is precarious, depending largely on project-based funding.

6. As the socioeconomic benefit analysis highlighted, there are substantial benefits from investing in hydromet and early warning services, notably with regard to reduced damages from droughts and floods. Benefits from strengthening hydromet and early warning services, from the perspective of reduced damages from floods and droughts, would be of a factor of US$7 to US$12 for every US$1 invested.

5.2 Recommendations for strengthening hydromet and early warning services in the SADC region

From the analysis on the status of the hydromet services in the region and discussions with stakeholders in the SADC region, notably the NMHSs, recommendations to strengthen and modernize hydromet services include:

Strengthen policies, regional collaboration and data sharing

- Any program for strengthening hydromet and early warning services in the region should be owned and driven by the NMHSs and regional institutions in Southern Africa aimed at sustaining key weather, water, climate and early warning services to the population. Going forward, the implementation of actions needs to be driven by the SADC Member States with sound implementation plans and coordinated actions at the regional level.
- Any regional collaboration on hydromet services should be driven by the effective exchange of hydromet data between Member States, with regional and technical organizations and in compliance with global reporting requirements, such as the Global Basic Observation Network. The existing collaboration between RSMC Pretoria, RSMC La Réunion, SADC CSC and river basin organizations should be strengthened and roles and mandates clarified to ensure a real-time exchange of information, effective use of tools such as the flash flood guidance systems and roll-out of regional climate forecasts, notably supported by the continuation of the SARCOF. To ensure operation of the organizations with a regional role, attention should be given to strengthening the coordination among these regional centers and support to Member States with the use and application of regional products.
- The major river systems in Southern Africa are transboundary. Forecasting and managing river floods should, thus, be considered in a transboundary context and involve the RBOs, in particular because the modelling for early warning services is not very developed in most Member States of such RBOs. Using, for example, common hydrological-hydraulic modeling approaches for flood forecasting, with integration of data and information from up- and downstream parts of the basin, would support integral monitoring and availability of data, information and products at the transboundary level. However, it is acknowledged that for each river basin dependent also on the needs and capacities of the Member States different approaches can be followed.

Invest in sustaining and modernizing the observation and ICT infrastructure, ensure operation and maintenance, and leverage economies of scale in the region

- Rightsizing hydromet investments is crucial. Capital investments in any part of hydromet systems, especially observation networks, require a corresponding increase in operation and maintenance budgets. The focus should be on upgrading and operationalizing the existing network instead of mere enlarging. The modernization of a hydromet and civil protection system is feasible only when governments ensure operation and maintenance of the services, including annual resources for field monitoring and station repairs as well as inhouse services. The reports highlights this clearly: To sustain investments in hydromet and early services about 277 additional people would need to be recruited and operation, maintenance and staffing costs to be estimated at US$ 89.6 million over 10 years.

- Observation infrastructure and high-performance computing facilities are capital intensive, with high costs for engineering, operation and maintenance. They are, thus, mostly out of reach for many SADC countries. Southern Africa has already successfully demonstrated collaboration is possible through for example the Southern Africa Severe Weather Forecasting Project, through investment programs initiated and coordinated by SADC CSC and the Indian Ocean Commission,. Building upon such regional initiatives, SADC Member States can leverage economies of scale to develop infrastructure, continue to promote cascading approaches for forecasting, and establish, promote, institutional, where possible, twinning arrangements between countries to overcome challenges.

Focus on impact and cultivate a hydromet service culture

- 'Science for service' and putting the needs of women, vulnerable groups and other users of hydromet services and early warning systems in the center of the service development will be a critical success factor for any program supporting hydromet and early warning services in the region. So far, only a few NMHSs have actively collaborated with users to jointly develop products and services and to provide impact-based forecasting based on the needs of these users. In this regard, NMHSs are called to step up efforts to actively collaborate with user groups and vulnerable communities and ensure that women are actively involved.
- The coverage of early warning systems for floods, droughts and extreme weather events is still scattered in large parts of Southern Africa and in many cases lacks effective communication with the affected communities. Investing in early warning systems for urban areas (mostly for flash flood) and riverine floods will be important to deliver on avoiding flood losses.
- For droughts, hydrological forecasts on water provision to urban areas and economic sectors and the environment, as well as early warning based on meteorological and hydrological forecasts to provide food security, will be important.

Ensuring sustainability of the investment outcomes

- The private sector and universities can play an important role to complement NMHSs in the provision of specific services. About 40 universities exist in Southern Africa that provide programs and research related to weather, climate, water, early warning, and disaster risk management. As such, Southern Africa is uniquely positioned to facilitate much of the required training within the region. With regard to private sector collaboration, most NMHSs are positive about collaboration but have, so far, little experience in setting up and managing such collaborations. More engagement with private sector parties is needed to understand their needs and become more end-user focused. For the NMHSs to further develop PPEs, it is important to also have internal discussions on how relationships with the private sector are seen now, what would be the purpose of PPE (revenue generation, cost savings and/or better services) and which sectors to prioritize. Such a discussion will need to reflect on the policy and regulatory framework, the capacity of the NMHS to develop services themselves, the need for additional/improved services and the willingness of the private sector and the NMHSs to invest in setting up such a PPE.
- There need to be clear institutional roles, mandates and protocols for the organization and operation of hydromet and early warning services. Technical activities, like meteorological and hydrological obser-

vation and monitoring, meteorological forecasting, hydrological and hydraulic modeling to support forecasting and bathymetric surveys, should be done under the guidance of the institution with the appropriate mandate and technical authority. These institutions should contribute in a cooperative and organized way to develop and implement flood early warning systems and to establish warning systems for different hydroclimatic hazards.

5.3 Recommendations for Implementation

Drawing from the analysis of the status of weather, climate, water and early warning services in the region a set of proposed outcomes and related actions for strengthening hydromet services has been formulated. Building upon the existing strong regional institutions the following recommendations are proposed for the implementation of those actions:

- Strengthening hydromet services in Southern Africa requires substantial investments and concerted efforts from governments, development partners and the private sector. The estimations only for priority actions for strengthening hydromet services and actions related to early warning estimate needs of US$ 116 million. In addition, commitments from governments on operation and maintenance, staffing and training are prerequisite for making the envisioned outcomes of such investment sustainable. These costs can be substantial and are estimated over a period of 10 years at US$ 89.4 million for operation and maintenance and about US$ 90 million for staffing. This calls for maximizing finance, including grants, loans and public-private partnerships, and ensuring that the recovery from the COVID-19 pandemic enables the adequate provision of hydromet services to vulnerable communities. A phased approach, allowing an incremental increase in capacity of NMHSs, may needed to be realistic and provide a durable way forward.
- Regional cooperation between the various role players in the hydromet value chain, of which the NMHSs and disaster management structures are central, is a key success driver for improving hydromet services and EWS in the region.
- Differences in climate, organizational structure, existing hydromet value chain, potential partnerships with the private sector and available financial and human resources all need to be considered for a detailed design of country-level investments and actions.
- The modernization of hydromet and early warning services in Southern Africa should complement and leverage ongoing initiatives, such as the Global Framework for Climate Services, Climate Risks and Early Warning Services (CREWS), WMO's SOFF and specific projects targeted towards hydromet modernization, such as the one Indian Ocean Commission. Notably, the SOFF would be an important program, as it aims to provide finance for bringing observation networks to GBON standards which are prepared for running global weather forecasting models. Table 14 provides an overview of ongoing initiatives in Southern Africa, which support hydromet services in the region.
- A program for modernizing hydromet and early warning services in Southern Africa should be the joint effort of national governments, private sector and development partners and be part of the global programmatic structure, such as GBON. As a next step, the report should be taken forward through the Hydromet Alliance, which is a joint partnership of WMO, other UN organisations and multilateral development Banks, including World Bank. Individual country assessments, with operation, maintenance and staffing plans would need to follow to operationalize the recommendations of the report.

Table 14: Programs and initiatives to improve regional hydromet services in Southern Africa

Acronym	Full name/explanation	Countries
Africa Hydromet Initiative	Partnership of development organizations, implemented by World Bank and GFDRR	DRC, Mozambique, Tanzania
IOC	Hydromet Program of the Indian Ocean Commission supported by GCF, AfD, EU and other partners	Comoros, Madagascar, Mauritius, Seychelles
CREWS	Climate Risk Early Warning Systems	Comoros, DRC, Madagascar, Mauritius, Mozambique, Seychelles
FEWSNET	Food Early Warning System-Net	Countries with food early warnings based on climate forecasts: DRC, Madagascar, Malawi, Mozambique, Zimbabwe
IHP-EWS	International Hydrological Program of UNESCO – EWS development support for Limpopo basin	Focus countries: Botswana, Mozambique, South Africa, Zimbabwe
CIRDA	Climate Information for Resilient Development and Adaptation (United Nations Development Program – UNDP)	Active in all 16 SADC countries.
CLIMSA	Intra-African Caribbean and Pacific Climate Services and Related Applications Program	SADC CSC is coordinating case studies which will be set up in different countries.
ClimDev-Africa Special Fund (CDSF)	CDSF is the investment arm of the ClimDev-Africa program that is jointly implemented by the African Union Commission (AUC), the African Development Bank and the United Nations Economic Commission for Africa (UNECA).	CDSF implemented the Satellite and Weather Information for Disaster Resilience in Africa (SAWIDRA) program that was implemented in Southern Africa via the SADC CSC.
WISER	Weather and Climate Information Services for Africa (https://www.metoffice.gov.uk/wiser)	Tanzania (active in East and West Africa but with intention of developing services for the whole of Africa)
SASSCAL	Southern African Science Service Center for Climate Change and Adaptive Land Management	Countries with observation stations: Angola, Botswana, Namibia, South Africa, Zambia
TAHMO	Trans-African Hydro-Meteorological Observatory	Countries with observation stations: DRC, Lesotho, Madagascar, Malawi, Mozambique, South Africa, Tanzania, Zambia, Zimbabwe.

- Regional investment programs for strengthening hydromet and early warning services in the region should be considered as a framework and open platform for governments, development partners and the private sector to support hydromet services in a coherent program, facilitating an incremental increase to modernize hydromet and early warning services. Enhanced coordination among regional and national partners should be the point of departure.
- Many of the proposed actions are interconnected; thus, it would be important to implement the actions in a coordinated and coherent manner. Coordination among partners would be essential and any regional investment program would not be successful as the effort of a single partner or organization with a large project management structure.

REFERENCES

AfDB. 2021. News: African Development Bank supports development of satellite observations for African early warning systems. https://www.afdb.org/en/news-and-events/african-development-bank-supports-development-satellite-observations-african-early-warning-systems-44824.

Belli P, Anderson JR, Barnum HN, Dixon JA, and JP Tan. 2001. Economic Analysis of investment Operations. World Bank Institute. In Internet: http://documents1.worldbank.org/curated/en/792771468323717830/pdf/298210REPLACEMENT.pdf.

Global Facility for Disaster Reduction and Recovery. 2018. Socioeconomic Analysis of the Potential Benefits of Modernizing Hydrometeorological Services in the Lao People's Democratic Republic. Washington DC: World Bank. https://openknowledge.worldbank.org/handle/10986/32199 License: CC BY 3.0 IGO.

Guha Saphir et al. 2021.

Kull, D., R. Mechler R and S. Hochrainer. 2013. "Probabilistic Cost-Benefit Analysis of Disaster Risk Management in the Context of Development Assistance." *Disasters* 37(3): 374-400.

Lesk, C., P. Rowhani, and N. Ramankutty. 2016. "Influence of Extreme Weather Disasters on Global Crop Production." *Nature* 529, 84-87. https://doi.org/10.1038/nature16467

OCHA (United Nations Office for the Coordination of Humanitarian Affairs). 2019.

Rogers, D., V. Tsirkunov, H. Kootval, A. Soares, D. Kull, A.-M. Bogdanova, and M. Suwa. 2019. Weathering the Change: How to Improve Hydromet Services in Developing Countries. Washington DC: World Bank.

SADC. 2016. Regional Strategic Action Plan on Integrated Water Resources Development and Management Phase IV, RSAP IV. Gaborone, Botswana

Sesolle. 2012.

Tanner, T.M., S. Surminski, E, Wilkinson, R. Reid, J.E. Rentschler, and S. Rajput. 2015. The Triple Dividend of Resilience: Realising Development Goals through the Multiple Benefits of Disaster Risk Management. Washington, D.C. and London: Global Facility for Disaster Reduction and Recovery (GFDRR) at the World Bank and Overseas Development Institute (ODI).

WMO (World Meteorological Organization). 2015. WMO Capacity Development Strategy and Implementation Plan. Geneva: WMO.

WMO (World Meteorological Organization). 2015a. Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services. WMO-No 1153. Geneva. Switzerland.

WMO (World Meteorological Organization). 2020. The gaps in the Global Basic Observing Network (GBON). Systematic Observation Financing Facility. Weather and climate information for the global public good. October 2020. Available online: https://library.wmo.int/doc_num.php?explnum_id=10377.

World Bank. 2019. The Power of Partnership - Public and private engagement in hydromet services. Washington DC.

World Bank. 2021. World Bank Databank: Urban Population (% of Total Population). Washington DC. Accessed: August 2, 2021: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?end=2020&locations=ZG-AO-BW-KM-CD-SZ-LS-MG-MW-MU-MZ-NA-SC-ZA-TZ-ZM-ZW&start=2016

World Bank. 2021a. World Bank Databank: Urban Population Growth (Annual %). Accessed: August 2, 2021: https://data.worldbank.org/indicator/SP.URB.GROW?end=2020&locations=ZG-AO-BW-KM-CD-SZ-LS-MG-MW-MU-MZ-NA-SC-ZA-TZ-ZM-ZW&start=2016

Zhuang et al. 2007. Theory and practice in the choice of social discount rate for cost-benefit analysis: A survey.

Building Disaster Resilience in Sub-Saharan Africa

WORLD BANK GROUP

GFDRR
Global Facility for Disaster Reduction and Recovery

WORLD METEOROLOGICAL ORGANIZATION