ICAT-A BASIC METHODOLOGY REPORT: SOUTH AFRICA

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TOWARDS A BASIC METHODOLOGY FOR M&E OF FLOOD EARLY WARNING SYSTEMS

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1. Introduction

This report describes the proposed methodology to be adopted in the project to track the effectiveness of flood early warning systems (EWS) in the country through improved monitoring and evaluation (M&E). The focus is specifically on flood EWS, as identified at the inception of the project. South African case studies in the project will focus on tracking the effectiveness of adaptation actions for EWS in support of one of the country's key adaptation priorities: 'Desired Adaptation Outcome (DAO) G3 - Reliable climate information including seasonal predictions and future projections and effective early warning systems for extreme weather and climate-related events'. This adaptation priority (DAO G3) is being implemented through the National Framework for Climate Services by the national Department of Environment, Forestry and Fisheries (DEFF).

The report consists of an outline of existing M&E approaches in South Africa, an overview of South African flood EWS initiatives, the flood forecasting process and gaps that need to be addressed. Potential case studies for testing M&E approaches and a series of potential indicators identified in the context of international frameworks series that could be used in the South African context are described.

2. South Africa’s approach to developing its M&E systems for climate change

South Africa has made substantial progress towards becoming a low carbon and climate resilient society and its responses to climate change seek to address both the country’s development needs as well as climate change obligations. The country is signatory to United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the Paris Agreement. South Africa’s National Climate Change Response Policy (DEA, 2011) called for the establishment of a National Climate Change Response Monitoring and Evaluation (M&E) System, which would ‘evolve with international measuring, reporting and verification (MRV) requirements’. South Africa is developing a comprehensive, integrated National Climate Change Response Monitoring and Evaluation System which includes the current National Climate Change Response Database (NCCRD) and the National Greenhouse Gas Inventory System (NGHGIS) and will serve as a data and information coordination network. The M&E system enables the country to assess, analyse and understand progress made in achieving its climate change commitments and actions, thus tracking the transition to a climate-resilient and lower-carbon society.

The concept of Desired Adaptation Outcomes (DAOs) have been developed to complement the building blocks of the monitoring and evaluation framework and to facilitate and focus the M&E of the country's progress towards resilience. The DAOs aim to provide clear insights into climate change adaptation in South Africa and help capture the country's unique circumstances to aid reporting on adaptation at national and international levels. Nine generic DAOs have been developed, each of which is of cross-cutting, has cross-sectoral relevance and describes, in a general sense, a desired state that will enhance South Africa's transition towards climate resilience and fall into two distinct groups. Six of the nine DAOs (G1–G6) describe the 'inputs' (namely processes, resources and capacities) that need to be in place to enable effective climate change adaptation; and three DAOs (G7–G9) describe the key 'impacts' of adaptation interventions and associated measures (for example, reductions in vulnerability of human and natural systems) (DEA, 2019). The DAOs provide a means of assessing the capacity of 'at risk' sectors and their stakeholders to adapt to climate change and whether the measures being taken are appropriate, efficient and effective.

Table 1. Generic Desired Adaptation Outcomes (DAOs) (DEA, 2019)

	'Inputs' to enable effective adaptation
G1	Robust/integrated plans, policies and actions for effective delivery of climate change adaptation, together with monitoring, evaluation and review over the short, medium and longer-term.
G2	Appropriate resources (including current and past financial investments), capacity and processes (human, legal and regulatory) and support mechanisms (institutional and governance structures) to facilitate climate change adaptation.
G3	Accurate climate information (e.g. historical trend data, seasonal predictions, future projections, and early warning of extreme weather and other climate-related events) provided by existing and new monitoring and forecasting facilities/networks (including their maintenance and enhancement) to inform adaptation planning and disaster risk reduction.
G4	Capacity development, education and awareness programmes (formal and informal) for climate change adaptation (e.g. informed by adaptation research and with tools to utilise data/outputs).
G5	New and adapted technologies/knowledge and other cost-effective measures (e.g. nature-based solutions) used in climate change adaptation.
G6	Climate change risks, impacts and vulnerabilities identified and addressed.
	'Impacts' of adaptation interventions and associated measures
G7	Systems, infrastructure, communities and sectors less vulnerable to climate change impacts (e.g. through effectiveness of adaptation interventions/response measures).
G8	Non-climate pressures and threats to human and natural systems reduced (particularly where these compound climate change impacts).

G9	Secure food, water and energy supplies for all citizens (within the context of sustainable development).

3. Flood early warning systems in SA

3.1. Overview of flood early warning systems in South Africa

The South Africa Weather Service (SAWS) is the legally mandated institution, as per the Weather Service Act (RSA, 2001), responsible for weather and climate forecasting and the issuing of severe weather-related alerts in South Africa. Early warning information systems in South Africa are important tools that are in place to facilitate disaster risk reduction (Figure 1). Several early warning systems are currently in place of which the South African Flash Flood Guidance System (SAFFG) and severe weather events warning system are most relevant to this report. SAWS is primarily responsible for the forecasting of flood producing rainfall. These forecasts are based on mathematical weather models, geostationary satellite images and radar observation stations (Du Plessis 2002). Historically, EWSs for flash floods were issued over a wide geographical area but these warnings were not spatially explicit enough for high-risk areas in small river basins. Consequently, SAWS and the NDMC developed the South African Flash Flood Guidance (SAFFG) system (Coning & Poolman 2010). The SAFFG models the likely hydrologic response of small river basins to rainfall and estimates how much rainfall is needed to cause flooding. This enables the system to issue potential flash flood watches and warnings for floods occurring in the next 6 hours.

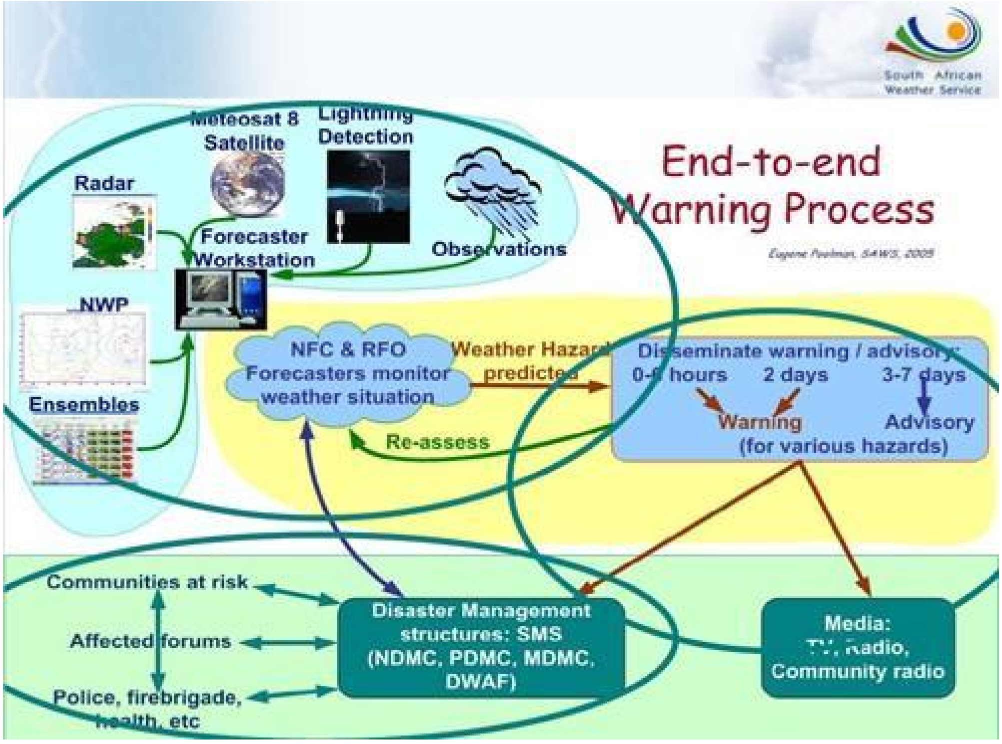

Figure 1. The South African Weather Early Warning System (Poolman, 2009)

Since 2015/16, in close collaboration with the National Disaster Management Centre (NDMC), SAWS have been working on the process of developing and implementing an Impact-Based (ImpB) Severe Weather-Warning System (SWWS) for South Africa (SAWS, 2019). In line with international trends in meteorology and weather forecasting, the impact-based severe weather-warning approach sees a departure from the traditional threshold-based approach and focusses strongly on the socio-economic and physical impact that a severe or extreme-weather system will have on the human population as well as on the environment, including the built environment. In other words, the purpose of the project is to move from “what the weather will be” to “what the weather will do”.

The responsibility for issuing forecasts and warnings for riverine floods in large river basins rests with the Department of Water and Sanitation (DWS). These slowly evolving floods occur during periods dominated by large scale rainfall systems over the country. The Orange-Vaal river system forms the focus of this flood monitoring and warning system (DWS, 2019). A flood office is opened in Pretoria during periods of flooding to co-ordinate dam operations and information dissemination (Du Plessis, 2002).

The South African case studies in this project focus on flash flood EWS as this type of flooding is more frequent, and arguably affects a larger number of people as there are usually no flood control structures in place to minimize flood risks (unlike large riverine floods in the Orange-Vaal system).

3.2. Flood forecasting process from SAWS to municipal level

Flood forecasts and alerts are issued by the forecasting division of SAWS. Usually alerts for potential hazardous weather are produced at different lead times. Depending on the lead-time, the alert would be an advisory, watch or warning as described in Table 2.

Table 2. Alerts issued by SAWS at different lead times

No Alert	***Advisory***	***Watch***	***Warning***
	Be Aware!	Be Prepared!	Take Action!
No hazardous weather expected in next few days	Early warning of *potential* hazardous weather	Weather conditions are *likely to deteriorate* to hazardous levels	Hazard is *already occurring* somewhere or is *about to occur with a very high confidence*
	2 to 6 days period	1 to 3 day period	Next 24 hours, 3 hrs for FF, TS

SAWS adopted the Multi Hazard EWS (MHEWS), which makes use of multiple monitoring systems incorporating meteorological, hydrological, and climate information to prepare and respond to multiple weather- related hazards. MHEWS, which incorporates *inter-alia* flash floods, requires close cooperation with disaster management structures at national, provincial and local level. The information and warnings from these systems are made available on websites and are distributed to provincial, district and local municipalities via SMS and email, for them to incorporate into their own EWSs or to take action. The alerts are also issued directly to the public through the media, internet and cellular phone service providers.

Once the different municipalities receive an advisory, watch or warning, they use this information together with all locally available information on dam levels, river flow, estuary levels and drought conditions to issue more particular warnings at local level. Information on environmental variables such as soil moisture, dam levels etc. is available through existing municipal information systems as well as through partnerships with other organizations and government departments and institutions. For example, the Eden District Municipality works closely with South African National Parks and Cape Nature which have their own monitoring systems and gauges in estuaries and rivers, to help the municipality to improve their EWS.

3.3. Gaps in current EWS in South Africa

Legislative, institutional and mandate issues

- Lack of funding or limited institutional knowledge on how to secure funds, Municipalities do not budget for DRR programmes.
- Effective dissemination of warnings to all levels of society remains a challenge and requires support and participation with the local disaster management structures and the media (SAWS, 2011).
- Lack of communication materials to raise awareness and mainstream disaster risk reduction at the local level.
- There is currently insufficient communication and collaboration between organisations that provide climate services and EWSs.
- Lack of awareness in communities and poor participation of communities and other key stakeholders in disaster management e.g. Fire Protection Associations.

Geographical coverage

- In many areas such as over the Karoo, there is not detailed information to make accurate forecasts. Several floods have taken place in this area and was not properly alerted due to the absence of radar weather data in the area.

Technical issues

- As EWS develop and increase, so do the incidence of false alarms. High incidences of false alarms may affect the credibility and effectiveness of future warnings and cause communities to distrust warnings.

Social issues

- The dissemination and interpretation of warnings in different communities remains a problem because of language, local culture etc.
- Human capacity challenges such as shortage of skills and training. Identified areas of skills shortage include: professional fire-fighting skills, emergency management skills, victim management skills, disaster risk assessment, radio communication, GIS use.

3.4. Examples of EWS good practice in South Africa

Examples of good practice with regard to EWS include the City of Cape Town, Nelson Mandela Bay, Eden District Municipality and eThekwini Municipality. These are described below:

3.4.1. Nelson Mandela Bay (NMB)

The biggest natural risks in NMB are floods, fire, storm surges and drought. NMB has implemented CCTV at remote sites to monitor potential high-risk flooding areas. Some of these are linked to automatic weather stations of the SAWS. Automatic rain stations monitor for flash floods. A few river crossings have alarms to warn of flooding. All weather, rain and water levels are monitored at the Joint Operations Centre and alerts are sent out to affected communities.

3.4.2. Eden District Municipality

The most important natural risks in Eden District are floods, fires and droughts. The area has been declared a disaster area a number of times and suffered significant economic losses. All weather alerts are received from the SAWS, automatic rain stations, and dam level monitors. Eden runs an impact based EWS in association with SAWS. This means that they consider all relevant environmental variables (dam levels, wind speed, soil moisture conditions, estuary levels, river flow etc) when they receive a warning from SAWS. They therefore might adapt a low-risk warning from SAWS to a high-risk warning if all conditions point to higher risk for a potential flood. Alerts are sent out via an LED early warning display system, SMSs to disaster management advisory forums and ward councillors. Since the extreme floods that affected the area in 2006/2007, the Eden area, through their early warning system have managed to significantly lower flood damage and saved many lives in subsequent floods.

3.4.3. City of Cape Town

The Disaster Risk Management Centre (DRMC) is a branch of the City Emergency Services Department which in turn is part of the Safety & Security Directorate of the City of Cape Town. The City of Cape Town is proactive in disaster risk reduction and is working together with neighbouring municipalities, private sector, organs of state and communities through mutual assistance agreements on early warnings, response and recovery. Community members are encouraged to inform authorities of any imminent threats such as blocked drains and storm water systems.

3.4.4. eThekwini Municipality

The Coastal Stormwater and Catchment Management department (CSCM) within the Municipality's Engineering Unit has developed a flood early warning system for the Greater Durban area. This system ingests data from a network of rainfall and streamflow gauges established by the Municipality, together with SAWS weather forecasts and radar data. These data are then applied in high-resolution urban flood models to forecast potential floods. The system also utilizes weather forecasts from other sources and a higher-resolution radar owned by the City (when storms are in close proximity). Special attention is paid to critical locations such as floodplains, informal settlements, key infrastructure sites, low-level bridges and low-lying industrial areas. Different levels of warning are issued depending on the severity of the threat.

During times of potential flooding a joint operations centre is convened. Here, staff from the CSCM, Disaster Management and Emergency Control department and Communications department, meet to monitor and track evolving flood hazards, and issue flood warnings where appropriate. Warnings are disseminated through the media (radio), WhatsApp, SMS and push notifications. From February 2020, more detailed forecast information will also be disseminated online. No formal monitoring and evaluation of the early warning system is currently conducted as the system is still in development. The focus of development at present is on improving the hydraulic modelling and the dissemination of the warnings. However, all measured data and forecasts associated with the system are archived and could in future be utilized to perform a technical evaluation of the forecasting component of the system. Informal feedback from stakeholders on the effectiveness of the system is received and noted by CSCM.

Although the eThekwini flood EWS system utilizes SAWS weather information, it is not part of the SAFFG system. The combination of a dense local monitoring network and calibrated, high-resolution urban flood models run in real time make the eThekwini EWS a powerful tool in alerting the city to potential flood hazards. Information on the eThekwini EWS is shared with the NDMC and PDMC.

3.5. Selected case studies for flood early warning systems for testing and refinement of indicators

The case studies selected for testing and refinement of indicators for M&E of flood early warning systems are:

- Nelson Mandela Bay (NMB) Municipality
- Eden District Municipality
- City of Cape Town

(Note: The eThekwini flood EWS was not selected at this point as a case study area as the system is still in a development phase)

The National Disaster Management Framework (DPLG, 2005) lays out broad requirements for Disaster Risk Management (DRM) which are specified in terms of Key Performance Areas (KPA's). According to the Disaster Management Act (2002), DRM must be implemented by all three spheres of government (national, provincial, local), and the overall responsibility for overseeing DRM lies with the NDMC. The Disaster Management Monitoring and Evaluation Framework (COGTA, 2014) provides detail on what is required in terms of DRM M&E, and clarifies roles, institutional arrangements, norms and standards and critical success factors. The DRM M&E builds on the KPA's specified in the National Disaster Management Framework.

The proposed M&E indicators for flash flood EWS will need to fit within the broader requirements for M&E of DRM but will be specific to the context of flash flooding. DRM encompasses all forms of disasters and is not necessarily related to weather (examples of non-weather-related disasters include exposure to hazardous materials, disease, civil unrest). While the proposed flood indicators are based on the WMO (2018) Multi Hazard EWS check list, many are also found in the National Disaster Management Framework KPA's.

Information related to many of the proposed flash flood indicators will be available through disaster risk assessments that have already been done. For example, a risk assessment for NMB municipality has already generated spatially explicit information on the number of people and dwellings at risk to floods (NMBM, 2010). This risk assessment rated flooding as the highest disaster risk for the Municipality. In NMB Municipality, it has been noted that the most frequent or likely cause of flooding is inadequate stormwater reticulation which has not kept pace with development, rather than due to riverine flooding or dam failures. Thus, it will be appropriate to develop indicator/s that measure the progress in addressing this deficiency.

A disaster risk assessment for the City of Cape Town also rated flooding as the highest potential risk (CCT, 2015). The development of EWS was included in the list of priority actions for disaster risk reduction. The work done on risk assessment and reduction will provide a lot of the information needed for the calculation of M&E indicators.

Since the SAFFG is well established, information on the hazard related indictors (threshold rainfalls, soil moisture index values and quality scores) will already be available. The SAFFG system will be superseded by the Impact-Based (ImpB) Severe Weather-Warning System that is currently being implemented by SAWS (SAWS, 2019). New information may need to be collected to facilitate the determination of indicators that are relevant to the new approach. The identification of indicators has largely been based on desktop review. An important next step is to consult with relevant stakeholders at national and municipal levels to tailor the final set of test indicators to employ in the project case studies to address and support local needs.

3.6. International early warning system M&E approaches

The effectiveness of the SAFFG system can be evaluated through its effects on resilience (adaptation) at the level of local government. There is no commonly applied M&E approach and the literature has emphasized the context of the evaluation of resilience to select the most suitable methodology (Brown et al. 2016). South Africa's DAO system is aligned to a number of international frameworks and programs including the Sendai Framework for Disaster Risk Reduction, UN Habitat New Urban Agenda, Sustainable Development Goals (SDG), United Nations Convention to Combat Desertification and the Paris Agreement and the NDC Adaptation goals. The Paris Agreement gives limited guidance on how to strengthen adaptive capacity, resilience and reduce vulnerability to climate related disasters through its goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change" (Olhoff et al. 2018). It is not clear how the SDG targets, indicator frameworks and indicators which were developed to evaluate development actions at different government tiers of implementation align with each other for the M&E of local disaster risk reduction interventions (Wendling et al. 2018). The Sendai Framework for Disaster Risk Reduction is the most appropriate international framework to inform the M&E of the SAFFG since guidance is provided for local government to incorporate their own targets, indicators and timeframes into the development of disaster management plans (Wendling et al. 2018).

For the M&E of disaster-related EWS such as the SAFFG system, the most commonly referenced overarching framework (Dutta and Basnayake, 2018) is the UNI-ISDR Checklist (UNI-ISDR, 2006) and the four components of community centered EWS: risk knowledge, monitoring and warning device, dissemination and communication, and response capability. A number of literature examples have used the UNI-SDR framework as a foundation to further refine the M&E methodologies applied to evaluate the effectiveness of EWS. In Kafle (2017), the studies which have assessed the EWS for floods, landslides, and Glacial Lake Outburst Floods in Nepal are reviewed. Information about the implementation of EWS in Nepal were collected through surveys of government organizations, non-government organizations and local communities. Dutta and Basnayake (2018) conducted a gap assessment analysis of EWS in South Asian countries and collected information on implementation of these systems through stakeholder meetings and interviews with different tiers of government and communities. Fathani et al. 2016 developed a methodology for a landslide EWS and its application in Java, Indonesia. The collection of information comprised of a mix of quantitative and qualitative indicators and data sources including field surveys and stakeholder group consultations. Flood EWS in Bhutan was assessed from a gender perspective and collected information for the study through literature review, focus group discussions and key informant interviews (Shrestha et al. 2016). In each of these studies, the M&E questions and indicators applied were appropriate for the geographical context of the study. While the selection of a quantitative approach to M&E, is desired, the evaluation of social responses and communication effectiveness of early warnings, requires some consideration of qualitative assessment (de Bruijn et al. 2018). The abundance of indicators available from literature, implies less difficulty for clustering M&E indicators according to the various components of the UNI-ISDR Checklist (UNI-ISDR, 2017).

3.7. Potential indicators for M&E of flood EWS in South Africa

A Flash Flood Disaster M&E Framework was developed for South Africa by adapting the WMO (2018) Multi-hazard Early Warning Systems Checklist. This checklist is a key outcome of the first Multi-hazard Early Warning Conference, which was organized by the International Network for Multi-hazard Early Warning Systems (IN-MHEWS) 2 from 22 to 23 May 2017 in Cancún, Mexico. It updates the original document, Developing Early Warning Systems: A Checklist, which was produced as an outcome of the Third International Conference on Early Warning: From Concept to Action, held from 27 to 29 March 2006 in Bonn, Germany. Through the lens of the Sendai Framework, it incorporates the acknowledged benefits of multi-hazard early warning systems, disaster risk information and enhanced risk assessments. Following the first Multi-hazard Early Warning Conference, a consultation process among the IN-MHEWS partners further refined the checklist, resulting in the present document.

Each checklist is grouped into a series of major themes and includes a simple list of actions /steps/outcomes that, if followed, will provide a solid basis upon which to build or assess an early warning system. The four elements (Figure 2) of efficient, people-centred early warning systems are: (i) disaster risk knowledge based on the systematic collection of data and disaster risk assessments; (ii) detection, monitoring, analysis and forecasting of the hazards and possible consequences; (iii) dissemination and communication, by an official source of authoritative, timely, accurate and actionable warnings and associated information on likelihood and impact; and (iv) preparedness at all levels to respond to the warnings received (WMO, 2018).

Figure 2. Four elements of end-to-end, people-centred early warning systems (WMO, 2018)

The proposed Flash Flood Disaster M&E Framework for South Africa is presented in Table 3. The indicators in the framework were adapted to be suitable as flash flood indicators. The information sources for these indicators were derived from South African research on the South African Flash Flood Guidance System and international literature on flash flood and flood disaster risk and reduction indicators. The list of indicators will be refined and specific indicators shortlisted for testing following stakeholder consultation and analysis of indicators.

Table 3. Proposed Indicators for a Flash Flood M&E Framework to shortlist in consultation with stakeholders

DISASTER RISK KNOWLEDGE: Comprehensive information on all the dimensions of disaster risk, including hazards, exposure, vulnerability and capacity, related to persons, communities, organizations and countries and their assets.	
1. Are key hazards and related threats identified?	
Indicator	**Indicator evaluation**
- SAFFG Basin Rainfall Total - Highest daily soil moisture fraction values, averaged over the relevant period - Lowest daily Flash Flood Guidance 6-hour values, averaged over the relevant period - Maximum flash flood threat 6-hour values over the relevant period - Number of days with a positive flash flood threat 6-hour value over the relevant period - Standardized Soil Moisture Index averaged over SAFFG catchments - False alarm ratio - Hanssen-Kuipers score - Probability of detection - Heidke Skill Score Poolman et al. 2015	Characteristics of key hazards (e.g. geographical extent, magnitude, intensity, disease transmissibility, frequency, probability), including possible cascading hazardous events, are analysed, historical data evaluated and potential future risks assessed
- Flash-flood hazard map Popa et al. 2019	Hazard maps (dynamic and multi-hazard, when possible) are developed that identify the geographical areas/people that could be affected by hazards
2. Are exposure, vulnerabilities, capacities and risks assessed?	
- Map of number of people potentially at-risk - Percentage of houses situated within the inundation footprint - Retirement homes located at flood-prone areas - Bridges located at flood-prone areas - Dwellings with 1 storey above ground level - Education infrastructures (kindergartens, elementary and secondary schools) located at flood-prone areas - Prescribed service lifetime of infrastructure map Aroca-Jimenez et al. 2018; Ali et al. 2017	Assessment and quantification of exposed people, services (e.g. hospitals) and critical infrastructure (e.g. electricity and water-works, quality of building stock) conducted and mapped for all relevant hazards, as well as of any compounding risks, at local level in both rural and urban areas and coastlines

- Integrated social vulnerability Index for Flash Flooding Aroca-Jimenez et al. 2017	Vulnerability factors such as gender, disability, access to infrastructure, economic diversity, societal inequalities and environmental sensitivities considered
- Integrated Economic Vulnerability Index Aroca-Jimenez et al. 2018	Vulnerabilities of key economic sectors at national to local levels assessed
3. Are the roles and responsibilities of stakeholders identified	
- Number of national government agencies involved in risk assessments. - The role of each national government agency to undertake risk assessment.	Key national government agencies involved in risk assessments (including hazard, vulnerability and capacity assessments) are identified and roles defined
- Number of government policies implemented to support the preparation of hazard, vulnerability and capacity assessments for all areas.	Legislation or government policy mandating the preparation of hazard, vulnerability and capacity assessments for all areas are in place
- The national government agency mandated to coordinate hazard identification and risk information (exposure, social and physical vulnerability and capacity).	Responsibility for coordinating hazard identification and risk information (exposure, social and physical vulnerability and capacity) assigned to one national organization with a view to consolidating approaches and monitoring linkages and cascading impacts
- The number of benchmark tests to assess and review the accuracy of risk data and information. - A disaster risk framework developed to support the assessment and review of risk data reliability and accuracy (Yes/No)	Process developed for scientific and technical experts to assess and review the accuracy of risk data and information
- The spatial extent of local hazard and risk assessments undertaken and the number of people who actively engaged in the assessments.	Process developed to actively engage rural and urban communities in local hazard and risk assessments taking into consideration the needs of all people (women, children, older people, people with disabilities, etc.)
4. Is risk information consolidated?	
- Which information systems have been established to store event/disaster and risk information?	Central standardized repository (including but not limited to a Geographic Information System) established to store all event/disaster and risk information
- Sharing standards, protocols and practices for risk information and data have been adopted (Yes/No)	National standards (where possible, following international standards) established for the systematic collection, sharing and assessment of risk information and data related to hazards, exposures, vulnerabilities and capacities
- Has a data collection system or process been established to collect social vulnerability data (Yes/No)?	Standardized vulnerability data and information disaggregated by sex, age and disability
- Is the social vulnerability data collected annually so that risk data is updated (Yes/No)?	Process established to maintain, regularly review, and update risk data, including information on any new or emerging vulnerabilities and hazards,

	with roles and responsibilities of stakeholders identified along with appropriate funding
5. Is risk information properly incorporated into the early warning system?	
- Have safe areas and evacuations zones been defined using spatial analysis (Yes/No)	Information on the geographical extent of hazards used to define safe areas and evacuation zones
- Which factors of social vulnerability were integrated within the analysis of evacuation routes and temporary shelters locations?	Risk information on vulnerable groups (hazard, exposure, differential vulnerability) used to identify and define evacuation routes and location of temporary shelters
- Has up to date municipal built environment vulnerability data and information been integrated within the spatial risk analysis of local government buildings and facilities (Yes/No).	Risk information on different types of assets reviewed to outline procedures to minimize damage or loss of such assets once a warning is issued
- Have standardised procedures, processes or practices been established to integrate updated risk and vulnerability data into the early warning system (Yes/No)	Process established to maintain, regularly review and update risk data, including information on any new or emerging vulnerabilities and hazards, with roles and responsibilities of stakeholders identified along with appropriate funding

DETECTION, MONITORING, ANALYSIS AND FORECASTING OF THE HAZARDS AND POSSIBLE CONSEQUENCES: Multi-hazard monitoring and forecasting services with a sound scientific and technological basis	
1. Are there monitoring systems in place?	
Indicator	**Indicator evaluation**
- Has an observation system been established to monitor flash flood events that occur in South Africa?	Monitoring network established that monitors hazards that impact the country
- Does the SAFFG system include a metadata document for input and modelled parameters (Yes/No)	Measurement parameters and specifications documented for each relevant hazard
- Number of personnel trained to use and maintain SAFFG. Computer hardware and software to use and update SAFFG sufficient (Yes/No)	Technical equipment, suited to local conditions and circumstances, in place and personnel trained in its use and maintenance
- Lead time for rainfall data from SAWS meteorological network. Lead time for SAFFG forecast updates	Monitoring data received, processed and available in an interoperable format in real time or near real time
- Are SAFFG model products routinely curated with quality controls, archived and accessible for verification, research purposes and other applications	Monitoring data and metadata routinely curated with quality controls, archived and accessible for verification, research purposes and other applications
- Percentage of archived SAFFG model outputs available for verification, research purposes and other applications	Monitoring hardware and software maintenance conducted routinely and costs and resources considered from the beginning to ensure optimal operation of the system over time

- Does the technical and personal capacity of the SAFFG system allow for the system to benefit from new data analysis and processing and modelling methodologies, earth observation and in situ data and data exchange platforms (Yes/No)?	The system is able to combine and benefit from new and older technology allowing for exchange of data among countries with different technical capabilities
2. Are there forecasting and warning services in place?	
- Are the scientific and technical methodologies applied for data analysis and processing, modelling, prediction and warning products up to date and are they aligned with international standards and protocols (Yes/No)	Data analysis and processing, modelling, prediction and warning products generated based on accepted scientific and technical methodologies and disseminated within international standards and protocols
- Are forecasting centres operational at all times (24 hours/day, seven days/week) and staffed by trained personnel following appropriate national and international standards (Yes/No)	Warning centres are operational at all times (24 hours/day, seven days/week) and staffed by trained personnel following appropriate national and international standards
- Percentage warning messages from SAWS that are clear, consistent and include risk and impact information.	Warning messages are clear, consistent and include risk and impact information and are designed with consideration for linking threat levels to emergency preparedness and response actions
- Are software and data analysis updates tracked periodically (Yes/No). Do ICT security standards of forecasting centres and the national disaster management centre comply with international ICT security standards and policies (Yes/No)?	Software and data analysis for the received data updated periodically and to high security standards
- Are there standardised procedures in place to continuously monitor flash flood warnings for any data gaps or processing issues (Yes/No)?	The state of the monitoring and data analysis systems continuously monitored for any data gaps, connection issues or processing issues
- Lead time for the SAFFG products by the National Forecasting Centre - Lead time for the dissemination of SAFFG products to Regional Forecasting Office Servers - Lead time for the generation of flash flood alerts by the Regional Forecasting Offices - Lead time for the dissemination of flash flood alerts to Disaster Management Authorities.	Warnings generated and disseminated in an efficient and timely manner for each type of hazard
- Percentage of flash flood alerts validated	Warning system(s) subjected to regular system - wide tests and exercises
- Have standardised procedures been implemented to verify that SAFFG products and alerts have reached principle stakeholders (Yes/No)	Process established to verify that warnings have reached the principal stakeholders and people at risk
- Are there any non-digital mechanisms in place to inform people when the threat and its impacts have ended? Does the communication mechanisms to inform people when the threat and its impacts have ended include fixed and vehicle mounted PAS, digital/electronic display	Mechanisms in place to inform people when the threat and its impacts have ended

screen at select locations, mobile (SMS), web or community radio (Yes/No)	
- Do the standardised procedures applied to evaluate the quality and performance of SAFFG products, supplementary risk and vulnerability data and issued alerts align with international protocols and frameworks (Yes/No)?	Operational processes, including data quality and warning performance, are routinely monitored and evaluated
- Does the South African Weather Services have established fail safe systems and procedures to ensure the continuous operation of the SAFFG system and the issuing of alerts (Yes/No). - Do Disaster Management Authorities have fail safe systems and procedures in place to ensure that the media and local disaster managers receive flash flood alerts within the shortest lead times in the event of power or ICT service failures (Yes/No)?	Fail-safe systems in place, such as power backup, equipment redundancy and on-call personnel systems
- Number of disaster managers training on understanding and using the SAFFG products. Number of training workshops hosted by the South African Weather Services.	Strategies developed to build credibility and trust in warnings (e.g. understanding difference between forecasts and warnings)
- False Alarm Rate SAWS, 2015	False alarms minimized and improvements communicated to maintain trust in the warning system
- Have standardised procedures been established to archive all alerts, forecast, risk and vulnerability data used to formulate warnings by disaster managers?	Warning and forecast archival processes and systems in place
3. Are there institutional mechanisms in place?	
- Are there periodic updates to the Disaster Management Act to improve on institutional mechanisms for disaster risk reduction including monitoring and evaluation (Yes/No)	Standardized process, and roles and responsibilities of all organizations generating and issuing warnings established and mandated by legislation or other authoritative instrument (e.g. memorandum of understanding (MOU), standard operating procedures)

WARNING DISSEMINATION AND COMMUNICATION: Communication and dissemination systems (including the development of last-mile connectivity) ensuring people and communities receive warnings in advance of impending hazard events, and facilitating national and regional coordination and information exchange	
1. Are organizational and decision-making processes in place and operational?	
Indicator	**Indicator evaluation**

- The number of meetings of the interdepartmental disaster management committee for floods per year - The frequency of interdepartmental disaster management committee for floods per month.	Regular coordination, planning and review meetings between the warning issuers, the media and other stakeholders
- The number of professional and volunteer groups that disseminate disaster warnings issued by the national disaster management centre.	Professional and volunteer networks established to receive and disseminate warnings widely
2. Are communication systems and equipment in place and operational?	
- Does the disaster management authority undertake annual surveys to quantify last-mile connectivity to know which population groups can be reached by different services, including mobile-cellular, satellite and radio services (Yes/No)	Understanding of last-mile connectivity to know which population groups can be reached by different services, including mobile-cellular, satellite and radio services
- Penetration rate of flash flood alerts. UN/ISDR, 2008	Warning communication and dissemination systems reach the entire population, including seasonal populations and those in remote locations, through multiple communication channels (e.g. satellite and mobile-cellular networks, social media, flags, sirens, bells, public address systems, door-to-door visits, community meetings)
- Frequency of communication strategy revision for flash flood alert warnings.	Communication strategies evaluated to ensure messages are reaching the population
3. Are impact-based early warnings communicated effectively to prompt action by target groups?	
- Response steps taken following issuing of flash flood alert clearly communicated (Yes/No)	Warning messages provide clear guidance to trigger reactions (e.g. evacuation)
- Impact based flash flood alerts address the different risks and needs of subpopulations, including differential vulnerabilities (Yes/No)	Early warnings should take into account the different risks and needs of subpopulations, including differential vulnerabilities (urban and rural, women and men, older people and youth, people with disabilities, etc.)
- Percentage of the population trained to respond to the hazard risk - Percentage of emergency situations where emergency services responded safely and timely UN/ISDR (2008)	Public and other stakeholders are aware of which authorities issue the warnings and trust their message

PREPAREDNESS AND RESPONSE CAPABILITIES: Institutions and people enabled to act early and respond to a warning through enhanced risk education
1. Are disaster preparedness measures, including response plans, developed and operational?

Indicator	Indicator evaluation
- Public participation processes are adequately followed for the preparation of flash flood response plans.	Disaster preparedness, including plans or standard operating procedures, developed in a participatory manner, disseminated to the community, practiced and underpinned by legislation where appropriate
- The needs of people with different degrees of vulnerability are accounted for in flash flood response plans	Disaster preparedness measures, including plans and standard operating procedures, account for the needs of people with different degrees of vulnerability
- Emergency response networks and plans are regularly updated and tested UN/ISDR (2008)	Protocols established to activate and mobilize last-mile operators (e.g. local police, firefighters, volunteers, health services) who disseminate warnings to the public and decide public measures, including issuing orders for evacuation or sheltering in place
2. Are public awareness and education campaigns conducted?	
- Coverage by grade level and objective of hazard, vulnerability and risk curriculum as part of school curricula. - Number of nationals with advanced degrees related to disaster risk reduction. - Disaster risk reduction programmes identified with professional disciplines, institutes and example courses UN/ISDR (2008)	Ongoing public awareness and education programmes on hazards that could impact the population, vulnerabilities, exposure and how to reduce disaster impacts built into school curricula from primary through university
- Percentage of population implementing response actions C40 and Ramboll Foundation (2019)	Public awareness and education campaigns tailored to the specific needs of vulnerable groups (e.g. women, children, older people and people with disabilities)
3. Is public awareness and response tested and evaluated?	
- Satisfaction level of the relocated persons - Percentage of environment management plan monitoring targets achieved - Annualized flood damage and disaster relief costs - Direct economic losses from floods and waterlogging UN/ISDR (2008)	Previous emergency and disaster events and responses analysed, and lessons learned incorporated into preparedness and response plans and into capacity-building strategies
- Number of public awareness campaigns C40 and Ramboll Foundation (2019)	Public awareness strategies and programmes evaluated regularly and updated as required

4. Way Forward

The indicators proposed in Table 3 will be assessed in stakeholder consultations with national and municipal level stakeholders to agree on the appropriateness of indicators, data availability, systems to support data collection, capacity (and capacity needs) to collect data and utilise the indicators, and in terms of potential financial and policy implications.

Once a shortlist of indicators are agreed on, the indicators will be tested in the case study areas identified in Section 3.5 in collaboration with stakeholders from the relevant municipal level disaster management centres with the view to assess appropriateness of indicators, data gaps, and better understand areas of the flood EWS that need to be strengthened.

Once the indicators are finalised through the consultation process and tested using case studies, additional consultation will be held at a national level to present these indicators to wider range of stakeholders using infographics for each case study to communicate the project outcomes and facilitate uptake of the results.

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