Initiative for Climate Action Transparency - ICAT

First set of refined tools and methodologies based on lessons learned in pilot testing: Multi-hazard Early Warning Systems Monitoring and Evaluation Framework for South Africa

Deliverable 1.1.a

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UNEP-CCC

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28 February 2023

PREPARED UNDER

The Initiative for Climate Action Transparency (ICAT), supported by Austria, Germany, Italy, the Children's Investment Fund Foundation and the ClimateWorks Foundation.

Supported by:
Federal Foreign Office
on the basis of a decision by the German Bundestag
IKI INTERNATIONAL CLIMATE INITIATIVE
CIFF CHILDREN'S INVESTMENT FUND FOUNDATION
MINISTERO DELL'AMBIENTE E DELLA SICUREZZA ENERGETICA
climateworks FOUNDATION
Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology

The ICAT project is managed by the United Nations Office for Project Services (UNOPS).

UNOPS

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1. Introduction

Early Warning Systems (EWS) are essential tools in adapting to climate change and thereby reducing or even avoiding the damages caused from hazards. However, EWS are only effective and successful in so far as the extent to which they involve the local community through education and awareness, disseminate messages and warnings efficiently and have a sound scientific basis in aspects of risk assessment, data modelling and monitoring. It is therefore not only necessary to have EWS in place, but to also ensure that they can be evaluated against a set of criteria or indicators, in order to ensure its effectiveness.

During Phase 1 of the ICAT project in South Africa, a need (through literature reviews and stakeholder consultation) was established to improve the monitoring and evaluation (M&E) of EWS as an adaptation response to disaster risk reduction. The World Meteorological Organisation (WMO) provides a list of generic indicators (WMO, 2018) against which EWS can be evaluated. These WMO indicators are useful as an entry point to develop a country specific framework of M&E indicators and were thus used as a starting point to develop an M&E framework for multiple hazard EWS in South Africa.

The indicators were prioritised in terms of appropriateness to the South African context, data availability, systems for data collection, costs of collection, and capacity needed. These indicators were thus adjusted and refined through iterative consultation with relevant stakeholders (both interested and affected). Moreover, this framework of indicators aligns with existing policy and legislation regarding disaster risk, climate change adaptation and existing M&E systems or instruments.

The different elements of the framework have been integrated into a Microsoft Excel Tool format, to produce an M&E guidance tool. The M&E guidance tool is aimed at key stakeholders involved in disaster risk reduction to routinely assess the effectiveness and success of their MH-EWS. It is expected that the tool can be scaled up or down across government levels and geographical scales.

This document reports on the existing policy environment and context for EWS in the country. The progress that was made in developing a tool to monitor and evaluate Multi Hazard Early Warning Systems (MH-EWS) in South Africa and the results for the application of the framework in two case study areas, namely the Garden Route District Municipality and the eThekwini Municipality is presented.

2. South Africa’s policy environment and M&E of EWS

2.1 South Africa’s existing approach to developing its M&E systems for climate change

South Africa’s National Climate Change Response Policy (DEA, 2011) called for the establishment of a National Climate Change Response 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 National Climate Change Response M&E System Framework was published in 2015 (DEA, 2015b) to provide high-level guidance on information requirements and assessment methodologies.

The concept of Desired Adaptation Outcomes (DAOs) has been developed to complement the building blocks of the M&E framework and to facilitate and focus the M&E of the country’s progress towards resilience. The approach used to M&E progress on achieving individual DAOs involves the use of traffic light colours as a basis of a scoring system to summarise progress as follows:

- Red indicates that no or only preliminary work has begun towards the strategic outcome
- Amber indicates that significant progress is being made towards the strategic outcome
- Green indicates that work on the strategic outcome is in an ideal state

Nine generic DAOs have been developed, each of which is of cross-cutting, cross-sectoral relevance and describes, in a general sense, a desired state that will enhance South Africa’s transition towards climate resilience. Of particular relevance to this project is the DAO that focuses on the need for “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.” The only indicator that is currently used for this DOA is the number of municipal EWS in the country. Gaps remain in terms of M&E that need to be addressed, particularly at a municipal level with respect to the M&E of MH-EWS.

o 2.2 Overview of Early Warning Systems in South Africa

The mitigation of disaster risk[1] in South Africa is managed through the country’s Disaster Management Act (2002), Disaster Management Framework of 2004 and the National Disaster Amendment Act of 2015. The issuing of advisories, through the application of EWS, so that precautionary measures can be taken timeously in the event of threats due to natural hazards, technological accidents or environmental degradation is a key requirement of the Disaster Management Framework of 2004.

[1] Disaster risk is defined in the South African National Disaster Management Framework of 2004 as the likelihood of harm or loss due to the action of hazards or other external threats on vulnerable structures, services, areas, communities and households.

The South African Weather Service (SAWS) is the legally mandated institution, as per the Weather Service Act (Republic of South Africa (RSA), 2001), responsible for weather and climate forecasting and the issuing of severe weather-related alerts in South Africa. SAWS is primarily responsible for all weather forecasting; these forecasts are based on mathematical weather models, geostationary satellite images and radar observation stations (Du Plessis, 2002). SAWS has an observation network in place across the country that monitors meteorological, terrestrial and hydrological variables for threats such as floods, fires, damaging winds etc. This observational network includes:

- 20 Regional weather offices
- 130 Automatic Weather Stations
- 112 Climate Stations
- 1512 Rainfall Stations
- Radar network
- Lightning Detection Network
- Air Quality Monitoring

The system provides weather warnings in a user-friendly language that is intended to be understood by everyone. The system works by collecting information from these automatic weather and rain systems, satellites and radars which helps weather forecasters to make accurate forecasts. SAWS monitor relevant hazards and issue warnings to national, provincial and relevant municipal disaster management structures. These warnings are also issued to the public via several media platforms while the disaster management units have the responsibility to relay warning to the local communities at risk.

EWS in South Africa are important tools that are in place to facilitate disaster risk reduction, with particular progress made with developing EWS for flooding. Historically, EWS 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 National Disaster Management Centre (NDMC) developed the South African Flash Flood Guidance (SAFFG) system (Coning & Poolman, 2010). The SAFFG system is a hydro-meteorological modelling system, combining real-time meteorological information such as quantitative rainfall estimation from weather radars, satellite, and rain gauges, with hydrological modelling of the soil moisture conditions and the flash flood potential in 5 366 small river basins (on average 50 km^2) in five flash flood prone regions over South Africa (including the Garden Route). 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.

There are however gaps that have been noted in the EWS in South Africa that present challenges with the operation, uptake and M&E of the EWS. From an institutional perspective, funding for disaster risk reduction programmes presents a challenge to effective dissemination of warnings and results in poor participation of stakeholders in disaster management. The low level of geographical coverage of weather monitoring stations in certain areas prevents accurate forecasting, and lead to false alarms of EWS that affect the credibility of future warnings. Given the diverse number of languages (11 official languages) spoken in South Africa, dissemination and interpretation of the warnings also presents a challenge. Human capacity challenges include: professional fire-fighting skills, emergency management skills, victim management skills, disaster risk assessment, radio communication and GIS use.

The National Disaster Management Framework of 2004 (DPLG, 2005) lays out broad requirements for Disaster Risk Management (DRM) which are specified in terms of Key Performance Areas (KPAs). 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 KPAs specified in the National Disaster Management Framework. 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 and civil unrest).

3. Development of the M&E framework for Multi-Hazard Early Warning Systems for South Africa

3.1 Elements and indicators of the framework

During Phase 1 of the project, in consultation with the Department of Forestry, Fisheries and the Environment (DFFE), it was initially decided to focus on flooding, so that the development of the municipal level indicators could feed into the national system. During the process of stakeholder consultations, it was found that M&E for a single hazard with numerous, detailed indicators was considered too comprehensive at a municipal level and would be unlikely to be implemented. The alternative, in line with the approach selected for the second focus area, was to consider a multi-hazard approach and use flooding, or more broadly hydro-meteorological events, as an example in the case studies.

A Multi-Hazard Early Warning System (MH-EWS) M&E framework was thus developed for South Africa by adapting the WMO (2018) M-H EWS Checklist. This checklist, in combination with other international literature sources referencing EWS were used to develop a comprehensive list of indicators that could be used in the framework, which address monitoring, observation and forecasting of hazards. The WMO (2018) provides for indicators that typically focus on the accuracy/credibility of the forecast, human resources/capacity of people that operate the system, the technical feasibility of the system and the ability of the system to adapt. The indicators support the evaluation of an EWS from the perspective of authenticity, effectiveness and accuracy.

Each checklist of WMO (2018) 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 EWS. The four elements (Figure 1) 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).

The WMO (2018) checklist of indicators thus provides a useful overview of what is required internationally to operate a good EWS. However, in South Africa and at a municipal level, this comprehensive list of indicators may not always be practical in terms of reporting on all the indicators in terms of data availability, and may therefore be difficult to implement. A comparative assessment was undertaken to identify linkages between the types of indicators contained in the WMO (2018) checklist and existing reporting requirements in South Africa. Key performance indicators (KPAs) from the National Disaster Management Framework of 2004, the implementation indicators of the National Climate Change Adaptation Strategy and the checklist criteria in the Multi-Hazard EWS Checklist for disaster risk were analysed. While the proposed indicators are based on the WMO (2018) Multi-Hazard EWS check list, many are also found in South Africa's National Disaster Management Framework KPAs. This ensures that the proposed M&E indicators for MH-EWS fit within the broader requirements for M&E of Disaster Risk Management.

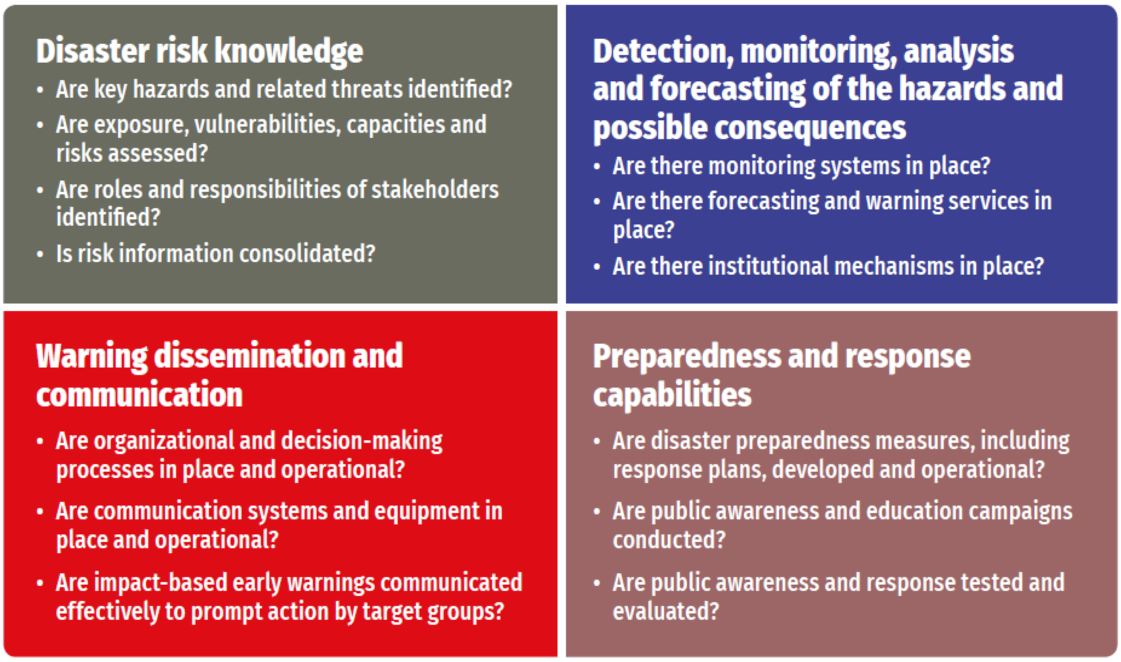


Figure 1. Four elements of end-to-end, people-centred early warning systems (WMO, 2018).

Furthermore, the indicators were revised by reviewing the capabilities of local municipalities to implement and execute some of these suggested components of monitoring, evaluation and forecasting. This involved consulting local literature sources, municipal policies, papers and any other documents and stakeholders that provided insight into how municipalities contribute to and operate EWS. Indicators were therefore reduced and refined to better match the circumstances at local municipal level in South Africa.

The process of refinement further included a series of engagements with key stakeholders within the DFFE and testing of the indicators through the case studies (presented in Section 4 of this report). These stakeholder engagements were iterative, as the feedback received was used to further refine the approach and indicators used to develop the framework.

The indicators were also refined to consider on-going processes for developing municipal level indicators. An example is the updating of national Circular 88 list of indicators to include environmental considerations. The link of indicators used in existing reporting requirements for municipalities, as mandated by current policies, was also included such that the information captured could be used to 1) inform other reporting needs and 2) provide an indication of the gaps in capturing information required.

The stakeholders further highlighted the growing need for the country to understand the effectiveness of EWS in reducing the impacts of hazard events on people and infrastructure. In this context, the WMO (2018) checklists do not provide indicators for the evaluation of such impacts, and thus the indicators of the Sendai Framework were incorporated into the framework. The majority of WMO (2018) indicators are further geared toward evaluating the effectiveness of the processes, plans and preparedness of EWS on an annual basis, whereas the impact-related indicators focus on a particular hazard event. Thus, it emerged that the framework would need to have elements that could be evaluated for a particular hazard event and more broadly also have elements that evaluate the level of planning and implementation thereof within the year the hazard event occurred.

The indicators were thus grouped according to the following three elements:

- ‘Efficiency of processes’,
- ‘Reliability’, and
- ‘Impacts’

The general description of the type of information that is meant to be captured within these elements is shown in Table 1 below.

The first element, ‘*Efficiency of processes’,* provide an indication of the extent to which a municipality have the systems, processes, plans, and tools in place to effectively prepare for a disaster, alert the affected community of the risk and to mobilize a response. Due to the number of indicators within this element of the framework, these were grouped into sub-elements that cover the core elements of the WHO (2018) guidelines of disaster risk knowledge, detection, warning and dissemination and preparedness and response. Such indicators are linked to the planning cycles and advancement in relevant policies in the municipality. Over time these efficiency indicators would track the progress or lack thereof toward efficiency in preparing for, and mobilizing a response to disasters.

The second element were defined as ‘*Reliability*. The purpose of the indicators associated with this element is to report on the reliability and accuracy of the forecasts, whether the warnings are released timeously and whether the warnings provide clear guidance that triggers reactions in response to the warning issued. This set of indicators may indicate the success or failure of the EWS in a particular year and in relation to a particular disaster event, track progress to enable further developing/ refining the EWS over time and identify areas of improvement.

The third element of effectiveness is gauged through evidence of ‘*Impact*’, measuring the reduction in (or avoidance of) lives lost, damage to infrastructure and injuries. Quantifying disaster losses is a crucial step towards tracking progress of implementing measures and investments to reduce risk (UNDRR, 2013). According to the Sendai framework the impacts (loss and damage) after a flood event can be quantified by the following indicators:

1. assessing the number of people affected, injured, displaced, and killed in a disaster,
2. assessing the economic costs of damage to assets and infrastructure.

These impacts are, however, also mediated by other factors such as the location, intensity, and duration of the flood event, the degree to which adaptation measures have been implemented, as well as the vulnerability of the communities subject to the flood event. As such direct comparisons of the indicators of “Impact” over multiple years or hazard events would not be advised. However, the information would be useful to track over time how the municipality is affected by hazards and in combination with the indicators “Efficiency of processes”, and “Reliability” enables a municipality to assess what additional measures or improvements are needed within the EWS to better understand, plan, prepare and implement measures to reduce potential impacts.

Table 1: Summary of three elements of the M&E framework for the effectiveness of MH-EWS in South Africa.

Efficiency of processes	**Disaster risk information**	The systematic collection of data and disaster risk assessments for the development of disaster risk knowledge is important for efficient, people-centred early warning systems. Disaster risk knowledge in the context of EWS can be defined as the likelihood of harm or loss due to the action of hazards or other external threats on vulnerable structures, services, areas, communities and households anticipated in the future which can be synthesized for the purpose of issuing of advisories about the potential adverse impacts of physical hazards and the precautionary measures which can be taken timeously to mitigate potential threats. While risk and vulnerability information may not have geospatial attributes when integrated into a decision support system for EWS, it is in the best interests for the local disaster management authorities to manage such risk information within a geospatial data repository so that decision makers can appraise vulnerable populations, buildings and infrastructure in a timely and efficient manner.
	Detection and monitoring	Monitoring of climate/weather related variables lie at the core of an EWS. They underpin the scientific basis of forecasting hazards/disasters. There are three crucial elements of monitoring: observation, measurement and prediction. Observation consists of an environmental behaviour that anyone can see. Measurement is something expressed in numerical form, for example, the water level in a river. Prediction involves an analysis of measurements to predict future consequences. This will provide users with the information needed for effective planning and operations to respond to climate hazards.
	Warning and dissemination	Provision of warnings to those at risk is a key activity in preparation for a disaster or as part of a disaster response to ensure that people and communities receive warnings in advance of impending hazard events. Effective dissemination of severe weather early warnings needs to be included as part of the disaster management information management system for the relevant area. Municipal Disaster Management Plans describe the arrangements for managing disaster risks and for preparing for and responding to disasters within Municipality as required by the Disaster Management Act.
	Preparedness and response	It is key to assess and track over time the preparedness of the municipality to actively involve the communities at risk, such that public education and awareness of the potential risk is raised and that there is a constant state of preparedness. A further objective is to assess how well equipped the municipality is to enable a quick and effective response through the testing and evaluation of the level of awareness and response. Protocols to activate and mobilize emergency response services (e.g. local police, firefighters, health care workers, etc.) need to be established and implemented. Knowledge and awareness campaign programmes also need to be undertaken and processes need to be in place to ensure the level of the response and awareness activities are tested and evaluated in terms of their effectiveness.
Reliability	**Reach of warning and clarity and lead time**	These indicators are meant to provide a measure of how reliable or accurate forecasts are and whether or not the warnings reach the affected areas. Also assesses if the warnings had clear messages to prompt stakeholder response and were released in a timely manner. These indicators provide a measure of the success or failure of the EWS for a particular event/ period.
Impact (loss and damage)	**Impact on people and property**	These indicators are used to assess the impact of flooding events on people's lives and livelihoods. They include the number of lives lost, damage to property and the number of people that were displaced. These indicators provide a measure of the impact (loss and damage) of a particular extreme event/period.

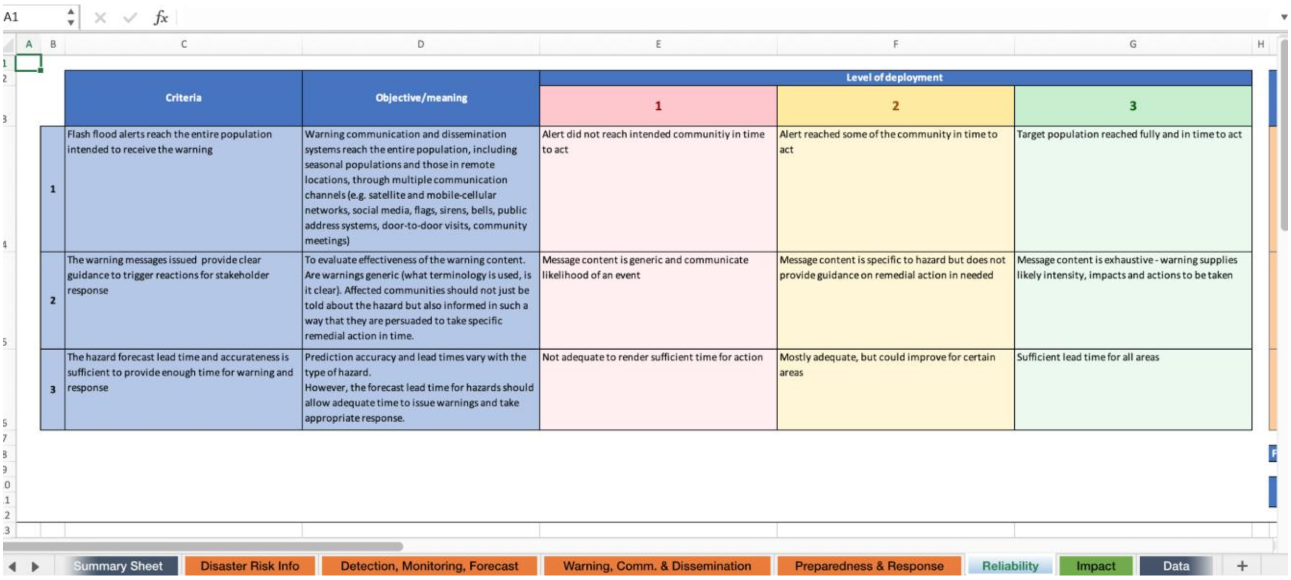
3.2 Approach to scoring and ranking of indicators

Existing methods and approaches to scoring EWS indicators with respect to the evaluation of flood forecasting, warning and response systems were reviewed and included frameworks developed for the European Union and the United Nations reports on EWS. Current relevant research papers were also reviewed, these included Agyei et al. (2020), which presented a case study in the Philippines of multi-criteria analysis of EWS for flood reduction in the Philippines, and Tarchiani et al. (2020) which presented a case study for an EWS in Niger.

This review of literature was used to guide the approach of scoring of the indicators such that the level of deployment could be assessed where a:

- Score of 1 indicates a low level of deployment and most critical factors are not met
- Score of 2 indicates some level of deployment, but some critical factors are not met
- Score of 3: indicates a high level of deployment and all key factors are met

Thus, the literature was used to guide how each indicator within the framework could be scored. For example, if a flash flood alert reached the entire community it was intended for, a score of 3 would be assigned, whereas a score of 2 is used if the alert only reached some of the community and a score of 1 is given if the alert did not reach the target community (Figure 2a).



	Criteria	Objective/meaning	Level of deployment		
			1	2	3
1	Flash flood alerts reach the entire population intended to receive the warning	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)	Alert did not reach intended communitiy in time to act	Alert reached some of the community in time to act	Target population reached fully and in time to act
2	The warning messages issued provide clear guidance to trigger reactions for stakeholder response	To evaluate effectiveness of the warning content. Are warnings generic (what terminology is used, is it clear). Affected communities should not just be told about the hazard but also informed in such a way that they are persuaded to take specific remedial action in time.	Message content is generic and communicate likelihood of an event	Message content is specific to hazard but does not provide guidance on remedial action in needed	Message content is exhaustive - warning supplies likely intensity, impacts and actions to be taken
3	The hazard forecast lead time and accurateness is sufficient to provide enough time for warning and response	Prediction accuracy and lead times vary with the type of hazard. However, the forecast lead time for hazards should allow adequate time to issue warnings and take appropriate response.	Not adequate to render sufficient time for action	Mostly adequate, but could improve for certain areas	Sufficient lead time for all areas

Figure 2a: Example of the 'Reliability' element of the framework showing the indicators and definitions for the level of deployment in the M&E tool

The scoring would further need to be supported by data/information and referencing to sources thereof as shown in Figure 2b below.

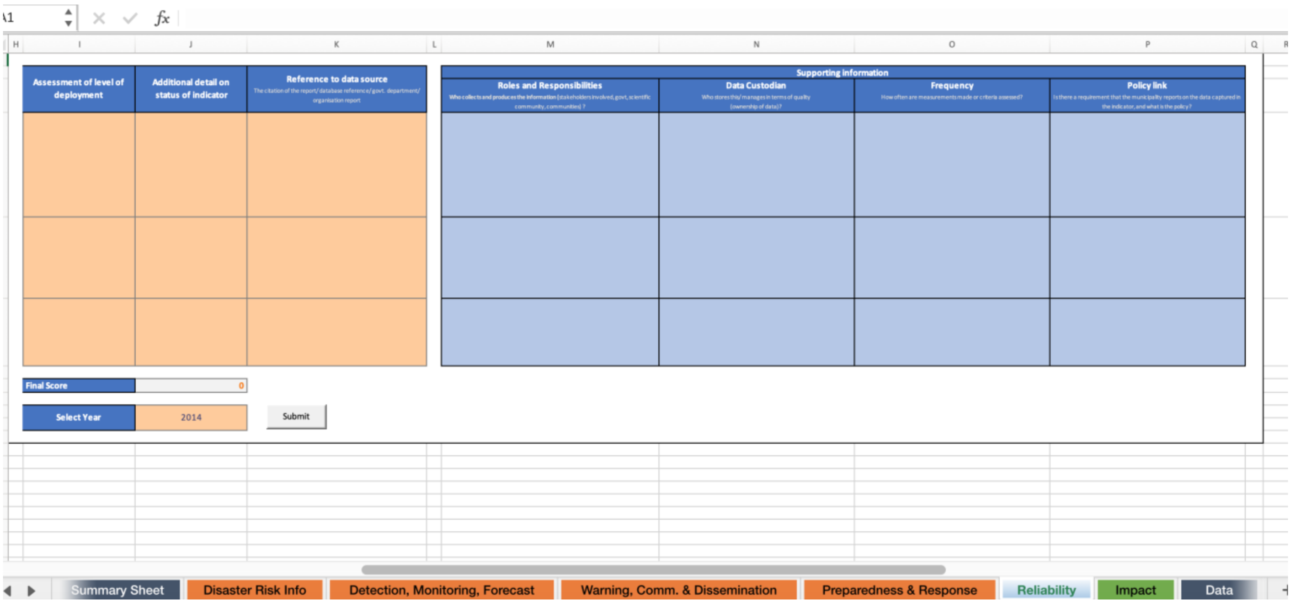


Figure 2b: Example of the 'Reliability' element of the framework showing the columns for scores and supporting information in the M&E tool

Equal weightings were assigned to each element of the framework (guided by best practice) and within each element of the framework the individual criteria were also equally weighted.

The individual scores within each element of the framework produce a weighted score such that the final weighted scores of the different elements of the framework can be classified according to the ranges displayed in Table 2. The colour coding (robot system) used in the classification scheme allows for integration within the reporting framework of the DAOs. With the MH-EWS framework in place, the country will thus be able to expand its reporting from only listing the number of EWS to now also reporting on the effectiveness thereof.

Table 2: Robot system for M&E of MH-EWS for South Africa

Range	Classification
0 -0.2	Not effective
>0.2-0.4	Slightly effective
0.4-0.6	Moderately effective
0.6-0.8	Very effective
>0.8-1.0	Extremely effective

The elements of the framework, related indicators, weightings, and assessment criteria for the levels of deployment were put together within a Microsoft Excel spreadsheet to provide a simple format to calculate the scoring and serve as a database over time. The information is collected per element of the framework, capturing information per indicator or sets of indicators as shown in Table 1 above, while Table 3 below shows an example of how the weighted scores per element of the framework can be extracted within the tool.

Table 3: Example of table used in framework to aggregate indicators within elements of the framework

Tracking reliability	Weighted score	
	Hazard Event 1	Hazard Event 2
Warnings reach intended stakeholders		
Clarity of warning message		
Warning lead time		
Average score for reliability		

By expanding on the elements contained within the WHO (2018), this framework allows for a tailored approach to M&E of MH-EWS in South Africa. The elements of the framework and the indicators therein may be used by local municipalities to monitor whether the necessary elements of their EWS are in place and further understanding of where there are gaps (information, capacity, infrastructure, plans, etc.), thereby allowing them to understand the effectiveness of their EWS. In so doing, this can guide the development and revision of policies, plans and interventions at a local level, to reduce the impacts of hazards events now and into the future under a changing climate.

A tool for M&E of MH-EWS of local municipalities in South Africa has been developed in Microsoft Excel. This M&E tool is based on the framework presented in this report and is a self-contained, automated tool, such that the user will only have to enter scores and the supporting into the tool to obtain the results. Please refer to the M&E tool and its related guidance document for further information.

3.3 Linking the municipal M&E framework for MH-EWS to national priorities

In Section 2.2 of this report, the gap in the country's DAO that focuses on EWS has been laid out. It was stated that the only indicator that is currently used for this DOA is the number of municipal EWS in the country (orange blocks in Figure 3). The implementation of the M&E framework for MH-EWS will allow expansion of this reporting process by capturing additional information that evaluates the effectiveness of EWS (blue boxes in Figure 3). This information can feed into the national reporting system, whereby it can support the DAOs through the three elements of effectiveness, and the average score can be ranked according to the robot system described in the section above. Climate change considerations are not always sufficiently integrated into disaster risk planning. The indicators incorporated in this framework may thus help to bridge the gap between disaster risk reduction and climate change adaptation, by expanding on the WHO (2018) guidelines and including further elements of reliability and impact.

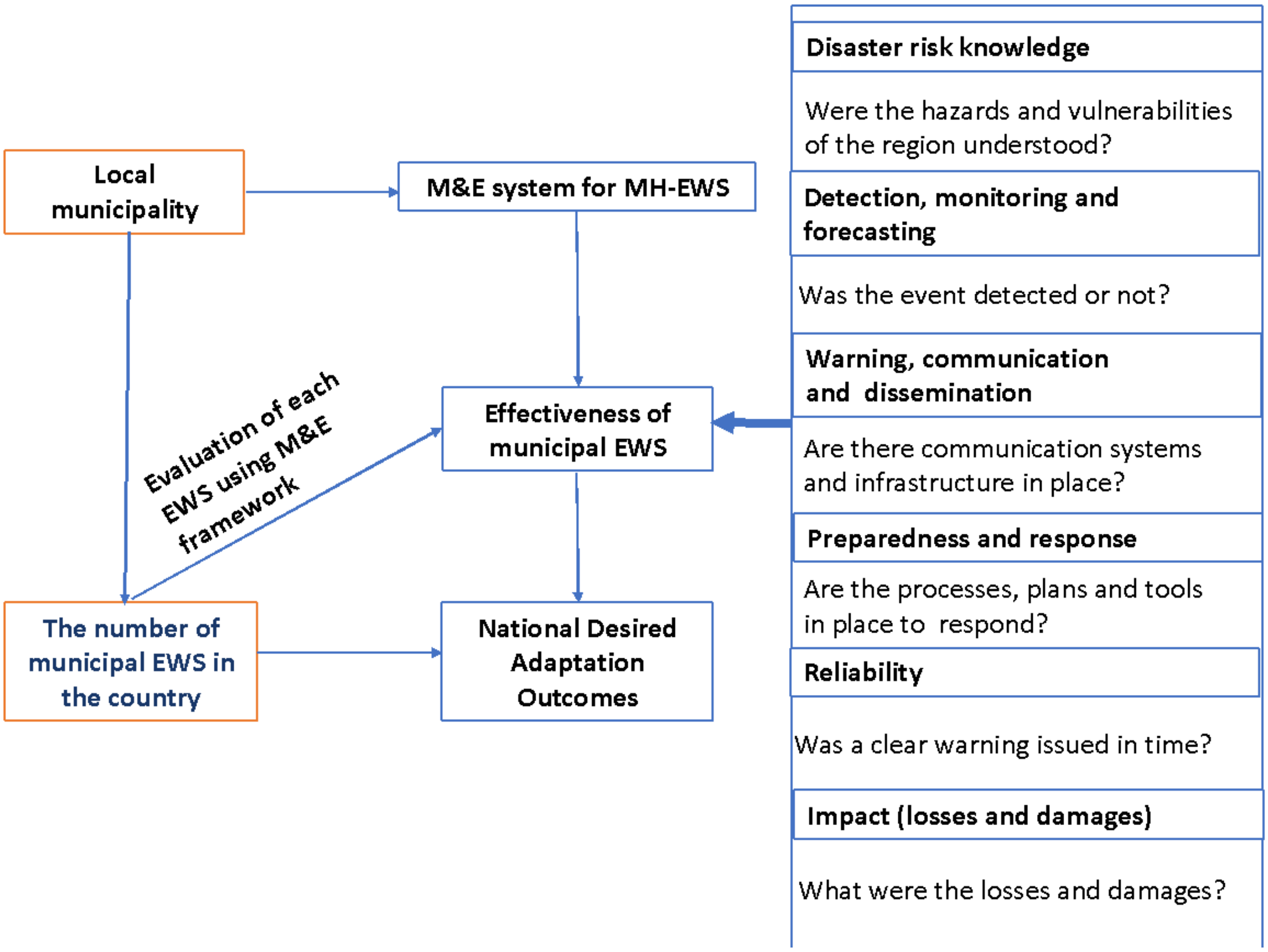


Figure 3: Overview of the linkages of the EWS M&E system within the broader context of the national DAOs.

The information collected through this framework will also help support other climate change, sustainable development and disaster management objectives of the country, that include:

- SDGs Goal 1 (Indicator 1.5), Goal 11 (Indicators 11.5 and 11 B); Goal 13 (Indicator 13.1)
- Sendai Framework for Disaster Risk Reduction (Targets A-D)

Review and update of information in Municipal Disaster Management Plans (as required by the Disaster Management Act, 2002).

4. Testing of the draft indicator framework through case studies

The draft framework was applied to two case study areas in South Africa in order to further refine the indicators and test the utility of the framework, which is presented in the section below. The case study areas were chosen from coastal areas of the country that are prone to flooding and have documented evidence related to flood related disasters. The scoring of the indicators was an iterative process that also contributed to the refining of the indicators within the framework as discussed above. The feedback from the stakeholders was also key to identifying the sources of information and understanding the potential for any municipality in the country to have access to the types of information relevant to the indicators and highlighting where potential gaps may lie. The results presented here provide a summary of the key findings that informed the framework and the finalised outcomes of the indicator testing within the case study areas.

4.1 Case study of the Garden Route District Municipality (previously the Eden District Municipality)

Through a process of literature review and consultation with the branch Oceans and Coasts of the DFFE in Cape Town, the Eden District Municipality (renamed to Garden Route District Municipality in 2018) was selected as the first case study to apply the indicators in the different elements of the framework. The Garden Route District (Figure 4) is a major provincial growth node, with tourism, agriculture, and related industries as its primary sources of economic growth and employment. The district municipality was chosen as a case study since the area has been impacted by numerous extreme events such as flooding, wildfires and droughts and it is likely that these risks will increase as the climate changes. Disaster and climate risk management are critical prerequisites for sustainable growth in the area which has been declared a disaster area many times, resulting in significant financial losses to the province. Consequently, there are documented impacts (data and reports) available on previous disasters, which makes it a suitable area to test the indicators of the MH-EWS M&E framework. The CSIR has been working with the municipality on several previous projects relating to natural disasters and therefore has an established research relationship with key personnel within the region.

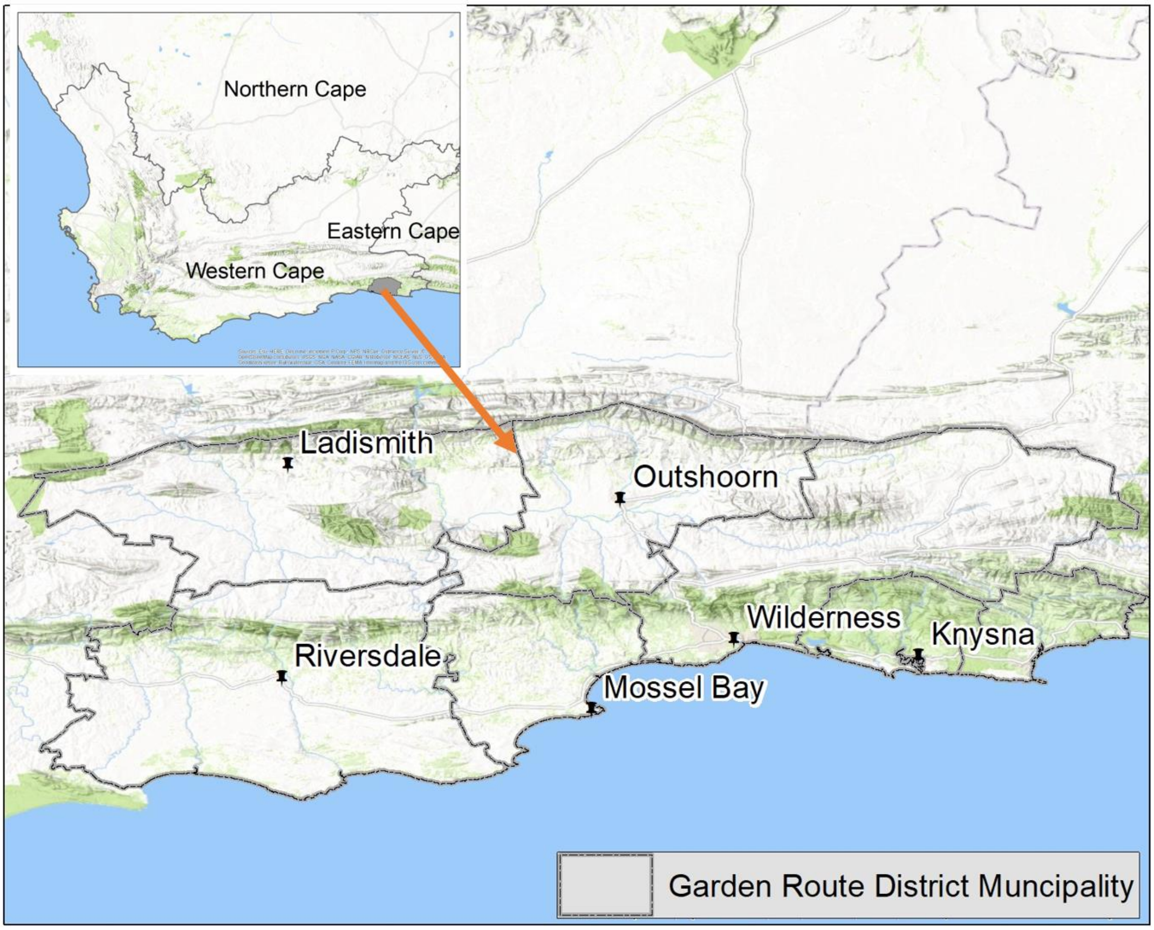


Figure 4: Locality map of the Garden Route District Municipality within the Western Cape of South Africa

For the testing of the M&E framework for this area, flooding events in 2006 and 2012 were selected. The events occurred in July/August 2006 and in July/August 2012. In both instances there was a declaration of a local disaster. The ‘August 2006 floods’ is referred to as a compound disaster due to two cut-off lows spaced three weeks apart, the first of which occurred from 31 July–4 August 2006 and the second from 21–24 August 2006 (Holloway et al., 2010). This compound disaster highlighted the Garden Route District’s exposure to climate hazards and drew attention to the on-the-ground risk factors that increase the likelihood of flood and storm damage. The July-August 2012 event consisted of a cut-off low combined with a low-level cold front in July (13-14 July 2012) resulting in heavy snow in Eden and the Central Karoo, and a cut-off low in August (7-11 August 2012) with flooding in the Cape Winelands and Eden (Pharoah et al., 2016).

Across each of the elements of the framework, the case study area was used to test if the information/data required by the indicators selected were measured or not. If information on the indicator did exist, further information was then sought on how often the information was collected, where it was stored, where this information would be found, and what the data gaps are (in the case of indicators that were needed but which had limited information). In instances where no data are currently collected, reference was made to the legislative requirement or benefits to start collecting the data.

The following sub-sections provide further details on the revised indicators of the framework in the context of the case study.

4.1.1 Efficiency of processes

This element of the framework consists of four sets of indicators as described earlier in the report. In the evaluation of the two years within which the hazard events occurred, overall, there was an improvement from the EWS being slightly effective to becoming moderately effective (see Table 4). This change was primarily due to improvements with respect to disaster risk information, detection and monitoring, and in the preparedness and response, as described below in more detail.

Table 4: Summary of results for indicators in the ‘Efficiency of processes’ element of framework

	2006	**2012**
Disaster risk information	0.39	0.78
Detection	0.42	0.58
Warning and dissemination	0.38	0.38
Preparedness and response	0.25	0.45
Efficiency of the EWS (average)	**0.34**	**0.5**
	Slightly effective	Moderately effective

Disaster risk information:

For 2006 it was found that although GRDM did review on an annual basis, the risks posed by hazards to communities, municipal assets and infrastructure, no geospatial risk data was generated in the assessments. This can contribute to the effectiveness of an impact-based early warning system. Prior to 2010, risk data were not integrated into the GRDM disaster management plan, thus the scoring improved in 2013 once this was a mandated requirement. Consequently, some of the risk assessments outputs that were mapped were incorporated into the district GIS database. The disaster risk and vulnerability information were also incorporated into the regional spatial development framework.

The municipality does track some climate-related hazards based on the early warning alerts issued by SAWS and the calls logged at the DMC. Disaster risk reduction initiatives are reported and tracked with the district's internal information management system. This system is currently being upgraded so that it is seamlessly connected with provincial and national information management systems. As such there is some progress by the district towards improving disaster risk for an effective impact-based EWS. During the period 2006 – 2012, neither district authorities nor the province was combining local and indigenous risk and vulnerability knowledge with findings from scientific assessments which can increase the acceptance of early warnings (DEA, 2016). Whilst these retrospective studies do highlight challenges to the effective use of disaster risk information in 2006 and 2012, it should be noted that significant improvements have since been made with the implementation of the latest Integrated Development Plans (GRDM, 2019, GRDM, 2020).

Detection, monitoring, analysis and forecasting

The responsibility to monitor lies with SAWS and other entities, and not municipalities. The improved score in 2012 compared to 2006 for detection was attributed to the implementation of the SAFFG in 2010 as well as capacity building (personnel and equipment) in EWS at the GRD municipality. While the GRDM has established networks to receive and disseminate warnings widely, they were not fully utilized and there was room for improvement across both years assessed. Rainfall forecasting is one of the most difficult tasks in weather prediction due to the variability and complexity of the physical processes related to rainfall and the need for accurate prediction of other variables it depends on. The implementation of the SAFFG system from 2010 onwards contributed to the provision of better information to disaster managers on flash flood potential in the Garden Route region.

The hazard forecast lead time and accurateness is a function of the skill and accuracy of the SAFFG implemented by the SAWS. Disaster managers typically require more than 6 hours lead-time to prepare and react appropriately to threatening disasters. This is a field of existing research and continuous efforts are made to increase lead times without sacrificing accuracy.

Warning and dissemination

There is regular coordination, planning and review meetings between the warning issuers, the media and other stakeholders in the GRDM. The Garden Route Disaster Management Centre consults regularly at various platforms with other government departments. The GRDM has a fully functional District Disaster Management Advisory Forum (DMAF) as well as a Safety and Security Cluster Joints structure that meets on a quarterly basis with B-Municipalities and other stakeholders. These meetings are followed up with quarterly attendance of both the heads of disaster centre (HOC) as well as the Provincial Advisory Forum (PDMAF) and Provincial JOC meetings (GRDM, 2020).

Warnings are disseminated through the district municipality disaster management centre and ward councillors disseminate warnings through WhatsApp groups, social media and loud hailers. While the district municipality has volunteers registered, it is not their role to disseminate warnings. In 2006, the local radio station was not operating during the flood event because it possessed a temporary licence, thus it could not be used as a channel for public warning. A report on the severe weather compound disaster in August 2006 in the Southern Cape (Benjamin et al., 2007) recommended to SAWS that, for events above a certain level of risk, it may be more effective to communicate weather warnings directly by telephone to key officials. While the SMS system is a very effective and rapid means of communication, phone calls are less easily disregarded and provide opportunity for questions of clarification. In 2012, there was still room for improvement in terms of warning dissemination with a recommendation that municipal authorities should explore dissemination mechanisms that more effectively target populations in areas exposed to flooding (Pharoah, 2016). Specifically, in the GRDM this should include communities living along the Keurbooms River and tourists and others likely to travel through flooding hotspots such as Meiringspoort.

The GRDM has developed an inventory of specific vulnerable groups based on previous incidents and communities affected and have addresses and contact details for these groups. There are currently no surveys in the GRDMC to quantify last mile connectivity to know which population groups can be reached and how. This represents a gap that needs to be addressed. A 24/7 emergency call centre has been established adjacent to the GRDM. The 24/7 call centre is operated in conjunction with the provincial Emergency and Medical Services (EMS) and renders an emergency call-taking and dispatch platform servicing the whole district . Records are kept of emails or SMSs sent out, undelivered emails or SMSs are recorded, and the list is continuously updated. According to the GRDM 20/21 IDP (GRDM, 2020), a future sub-project is to "Commission a reliable early warning system (linked to radio stations, community leaders and social media) to alert communities and industries on the possible occurrences of storm events." This has commenced and an individual in the communications department at the GRDMC has been assigned to monitor feedback for early warnings sent on media and social media platforms. The DM-DMC has also funded radio stations to reach some rural areas and areas that may have been missed.

Preparedness and response

Much of the information needed to evaluate the framework indicators are readily available in disaster management plans and outreach strategies. Existing reports produced, post-2010, as a legislative requirement for planning and reporting on disasters contain the information required. These include flood damage assessments and data on verified losses due to the disaster. Thus, there was an improvement from 2006 to 2012 once these plans and reporting were in place. The level at which these plans are implemented, reviewed, and updated presented opportunities for improvement.

The case study also highlighted that, for 2012 onwards, there is mention of activities around communication materials (knowledge and awareness of the disaster management plan – within the community and other key stakeholders) in reports. However, data on these are not readily available online. Through communication with stakeholders in the GRDM it was found that on-going training events are held to respond to disasters. Additionally, incident command training and related training events are also activities that take place at a local municipal level and often feed into the broader district municipality or provincial schedule of disaster management response planning. However, the frequency of these events and other specifics are not centrally documented within the municipality. The framework and related tool would thus present a platform to capture data and maintain a database of this information.

4.1.2 Reliability

Overall, it was found that the reliability of the EWS did not change significantly between the hazard events that occurred in 2006 and 2012 (Table 5). While forecast lead times have improved, there were challenges with respect to the warnings reaching the communities and the clarity of those warnings, as described further below.

Table 5: Summary of results for the Reliability indicators within the framework

	2006	2012
Warnings reach entire population through multiple channels	0.67	0.67
Clarity of warning message to trigger stakeholder response	0.33	0.33
Hazard forecast lead time for warning and response	0.33	0.67
Reliability of the EWS (average)	**0.44**	**0.55**
	Moderately effective	

For the 2006 severe weather compound hazard, the flood alert did not reach the entire community in the GRDM. The Cape Town Weather Office released warnings to three Cape Town-based daily newspapers, warnings were posted on the SAWS website and their telephonic forecast. Knysna and Oudtshoorn municipalities reported they did not receive any early warnings. Furthermore, the warning in Oudtshoorn was reportedly only received 'the day after' the rain started. Virtually all the warnings were issued the morning that the weather event occurred, while most of the advisories were issued a day in advance (Benjamin, 2007).

In 2012, SAWS weather alerts reached most governmental role players involved in responding to flooding. However, this information did not always reach populations in high-risk areas. More could be done to reach members of the public and tourists regarding flooding in high-risk locations. Avenues for disseminating information could include radio, television and social media, as well as the distribution of SMSs, warnings to accommodation providers and Tourist Bureaus (Pharoah et al., 2016).

Very few of the warnings issued for the 2006 severe weather compound hazard included a description of the possible impacts of the weather event they describe, such as the possibility of flooding, wind damage, etc. (Benjamin et al., 2007). In 2012, the generalised nature of warnings was also reported as a challenge where the information does not always reach those exposed to flooding. Disaster managers noted that alerts lacked the precision needed for effective decision-making, particularly in areas with high levels of meteorological variability (Pharoah et al., 2016).

4.1.3 Impact

The Garden Route is a good example of an area where flooding has had severe impacts on people and environment. As a result, several institutions received funding to conduct research on flood events and other disasters. Hence, there is substantial information available on flood related impacts in the Garden Route. This information is critical in monitoring impacts of flood disasters. However, this might not be the case in other district municipalities. The trends in direct damage costs and population affected by disasters are shown in Figures 5 and 6 below.

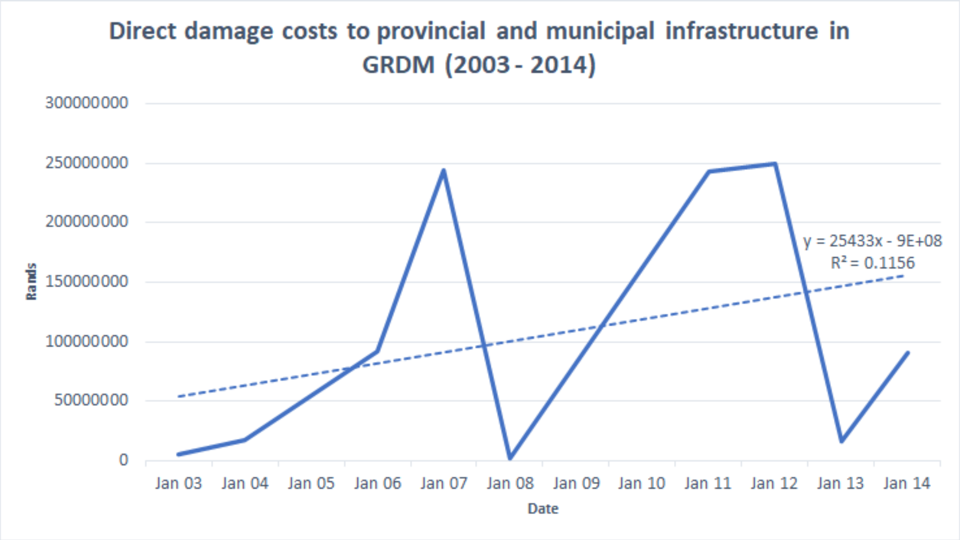


Figure 5: Direct damage costs to provincial and municipal infrastructure in the Garden Route District Municipality for the years 2003 -2014.

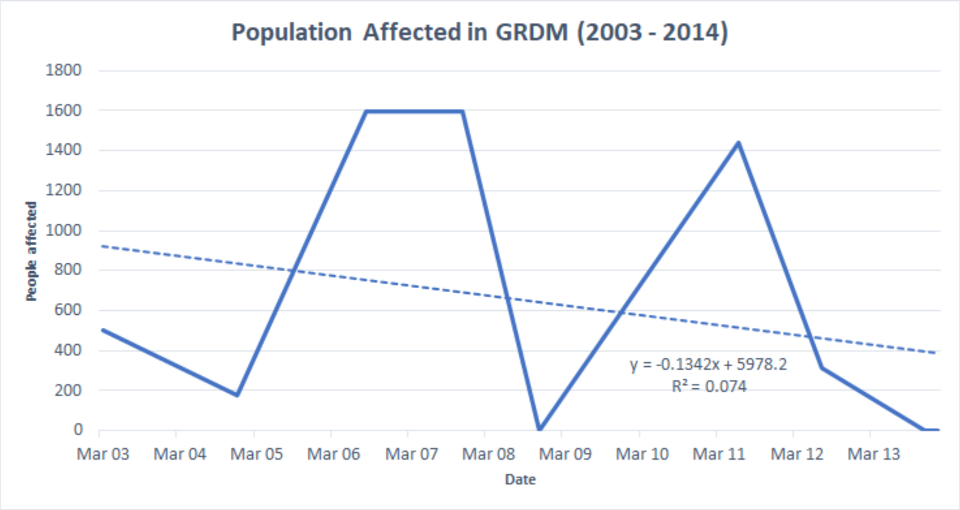


Figure 6: The number of the population affected in the Garden Route District Municipality for the years 2003 to 2014 (Source: Pharoah et al., 2016).

This information has been used to populate the framework with the results shown in Table 6 below. The only score to have improved was the indicator on the number of people displaced, which is indicates a decrease in the number of people whose destroyed/damaged dwellings were attributed to flood disasters.

Table 6: Summary of impact indicators for 2006 and 2012

	2006	**2012**
Deaths avoided	0.33	0.33
Property damage avoided	0.33	0.33
People displaced	0.33	1
Impact - loss and damage (average)	**0.33**	**0.55**

Changes in economic losses and data on the number of fatalities, people displaced, and property damage should be carefully interpreted and not automatically attributed to improved EWS or climate risk management. Interpretation of loss and damage data are subjected to the following limitations:

- Each flood event has its own magnitude and density leading to different impacts in different areas of the municipality. It is therefore not possible to directly compare between different flood events.
- The impact of flood events on loss and damage are mediated by several other factors apart from EWS, such as progress made in terms of Ecosystem Based Adaptation measures in catchments, Estuary management and breaching protocols, improved land use planning etc.
- Loss and damage verification methods has changed over the course of years and not all sectors and departments have reported damage or are reflected in the damage assessments.

4.1.4 Overall findings and key lessons learnt

This case study highlights the utility of the framework as it captures the improvement of the EWS (Table 7) due to the implementation of the Disaster Management Act and the related requirement for disaster plans to be developed and implemented.

Table 7: Summary of the effectiveness of the EWS

Summary of overall effectiveness	**2006**	**2012**
Efficiency of processes	0,33	0,50
Reliability	0,44	0,55
Average scores	0,39	0,53

The case study also highlighted a number of challenges to effective EWS which can be used by the municipality and others, to make improvements to EWS over time. These include:

- There is a challenge for the integration of combined disaster risk and climate change risk and vulnerability data into spatial development plans. This is an issue for both population and infrastructure risk and vulnerability. Furthermore there is no guideline provided for the integration of geospatial risk and vulnerability information. The implications for alignment to spatial development plans are vague. The SAWS need up to date geospatial risk and vulnerability data for the production of impact based early warning alerts.

- Sufficient, accurate and quality checked climate/weather data lie at the core of an effective EWS. However, it also needs flexibility to enable interaction and adaptation to local conditions. Understanding local contexts (social, political, cultural and economic) can help make effective use of appropriate technologies and participatory methods to provide warnings and educate populations so that responses to warnings are effective. While flood warnings are issued by SAWS, local communities, conservation monitors and volunteers can make additional contributions in assisting disaster management centres by providing more information on environmental conditions to support impact based warnings at local level. Local officials have a better insight into environmental conditions (e.g. soil water saturation) preceding warning of heavy rainfall.

- A significant challenge in municipalities that cover a large geographical area is the lack of higher resolution weather/climate data. Warnings are often issued for an entire region, but in reality these warnings are often only applicable to specific areas within a region. This may lead to warnings being inaccurate with growing mistrust in future warnings.

- SAWS should explore available means of refining forecasts to provide finer-scale information that captures meteorological variability between areas.

4.2 Case study of the eThekwini Municipality (Durban)

The eThekwini Municipality (Durban) is a coastal city located in the province of KwaZulu-Natal (Figure 7). Flooding is regarded on one of the top ten risks facing the municipality with 9 flood related disasters declared in the period 2008 to 2019. The municipality developed its Disaster Management Plan in 2009 and operates a Forecast Early Warning System (FEWS) since 2019 (officially launched in 2020).

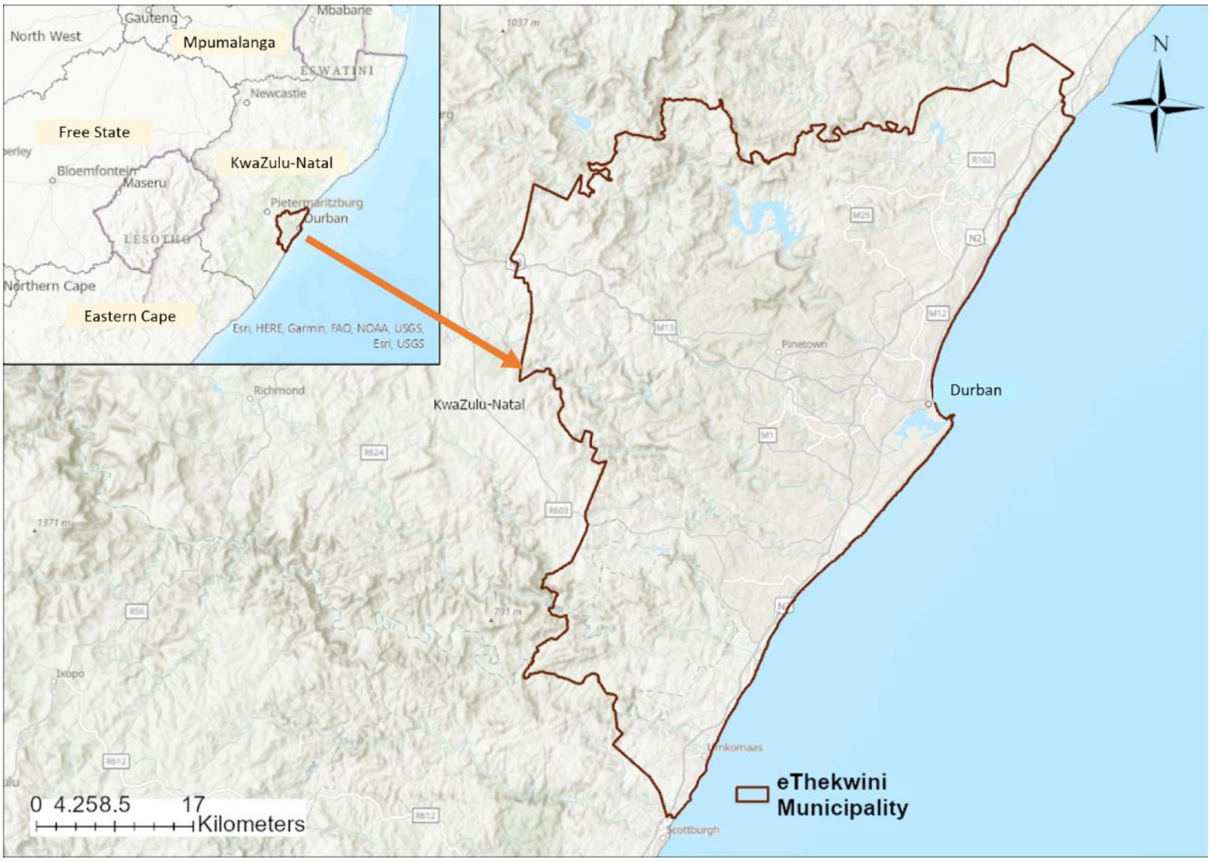


Figure 7: Map of the eThekwini Municipality

Two flooding events were selected to test the framework, namely:

- 17-18 June 2008: Torrential downpours wrought havoc in KwaZulu-Natal. The floods killed at least 10 people, left about 1 000 homeless and caused damage estimated at tens of millions of Rands.

- 18 -22 April 2019: Experienced heavy torrential rainfall which resulted in flash flooding over a period of five days, causing damage and destruction to residences.

The approach used in the GDRM case study discussed above was applied to this case study.

4.2.1 Efficiency of Processes

The level of planning and the implementation thereof within the EWS showed improvement over the 2 years (Table 8), due to improvements that were made on disaster risk information, detection and monitoring and preparedness, as described further below.

Table 8: **Summary of results for the Efficiency of Processes indicators within the framework**

	2008	**2019**
Disaster risk information	0.33	0.72
Detection	0.42	0.63
Warning and dissemination	0.38	0.38
Preparedness and response	0.25	0.5
Efficiency of the EWS (average)	**0.32**	**0.52**
	Slightly effective	Moderately effective

Disaster Risk Information

In 2008 it was noted that the information systems used in various government departments did not have the capabilities to generate GIS based risk profiles, with no risk assessments completed and no functionality to integrate risk profiles into province and national information systems. The scores for this set of indicators improved in 2019 due to the implementation of the disaster management centre information system. This system provides eThekwini's geospatial risk and vulnerability data, which facilitated the high-level risk assessments completed for the disaster management plan.

Detection, monitoring, analysis and forecasting of the hazards and possible consequences

A forecast EWS driven by an open-source data management platform was developed from 2008/9 onwards for eThekwini. The Coastal Stormwater and Catchment Management (CSCM) department of eThekwini started to use this in 2011. After the initial implementation of the system, the municipality realised there were many components of the system that needed improvement. So, they engaged the land use planning and GIS departments to provide better supporting information to improve the accuracy of the system by end of 2015. After 2015 they acquired yet more funding and IT support to further improve the system. The CSCM department only started to communicate and engage with the eThekwini Disaster Management Unit around 2017 to enable them to also work with, and use the system. Up to then the FEWS system was not integrated with the Disaster Management Unit. The system appears to be very advanced but other components such as communication, preparedness etc. are not well integrated and aligned. The FEWS was officially launched in 2020.

In 2008, SAWS forecasts did not include radar data yet and relied heavily upon the rain gauge network to fill in gaps. Relatively little funding was spent on infrastructure, improvement and capacity building for EWS. Training of personnel was also not a high priority because of the absence of a proper functioning EWS. During the flood event in 2008 most of the EWS communication between models and the community were still manual.

There was no evidence of additional monitoring equipment installation is available before 2011 although SAWS has had good quality control measures in place to ensure that radars, AWS etc. are maintained. However, after 2011 significant progress was made to supplement the rain gauge network. eThekwini also procured and commissioned an X-band rain radar with a 50 km radius coverage. The radar is located along the coast in a position that is central enough to cover all of eThekwini and areas off the coast. After 2008 a significant effort was also made to install additional monitoring equipment to improve the city's EWS through the development of its FEWS capability. FEWS uses rain gauges, radar in catchment areas to monitor rain and seawater levels and more than 200 hot spots can be monitored. eThekwini now has a vast network of monitoring equipment.

In addition to the monitoring and maintenance done by SAWS , the municipality also has very good quality control measures in place. After the 2008 flood event significant progress was made in automating the process of information dissemination between models, interpretation and communities. The FEWS progressed to a forecast early warning system that included an operational flood hydraulic model. Upon implementation of the more advanced FEWS, a concerted effort was made to train and capacitate EWS personnel. To address the identified skills gaps, FEWS team members attended focused training and international workshops. This equipped the team to develop and manage the processes required for the data management platform. More funding, and investment into capacity building and software have since been invested, contributing to the improved score in 2019.

Warning dissemination and communication

The municipal disaster management centre has documented procedures for assessing, interpreting and disseminating early warnings for rapid and slow on-set disasters. Communication during a disaster is between the FEWS team, SAWS and the city's disaster management practitioners. During the disaster event, all three spheres meet and communicate directly at eThekwini Municipality's Disaster Operations Centre. The KZN Weather Services, local and community radio stations, newspapers, departments and municipal notifications and announcements serve as very strategic tools of communication, that of 'informer to a receiver.' The primary means of communication with the public currently through local radio stations. Information is disseminated to the public through the internet, direct mailing and word-based community Disaster Management Committees.

There has been improvement between 2008 and 2019 flood events in terms of the municipality's networks in place to disseminate flash flood alerts. While the flood warnings for eThekwini are issued by SAWS, the FEWS team is an active contributor to the 'impact-based' warnings for the region and translates each warning to a local level. FEWS produces impacts for specific locations within the region and therefore is able to supplement the warnings issued by SAWS without contravening the South African Weather Service Act of 2001. Since the flood event in October 2017, there has been an agreement in place between the FEWS and SAWS teams. The municipality can issue impact-based warnings based on SAWS issuing of a hazard on their system and the FEWS team and a SAWS meteorologist then meet and agree on the additional information needed.

Preparedness and response capabilities

The council also approved a Municipal Disaster Management Framework in 2009 and in August 2013 adopted a Municipal Disaster Management Plan that is reviewed annually, thus resulting in the improvement noted in 2019. The Disaster Management and Emergency Control Unit was formed in 2011 to provide rapid response and disaster prevention (Masabo, 2019), which is meant to operate 24 hours, 7 days a week emergency service and is fully functional with a state-of-the art CISCO call centre system, The unit comprises of Disaster Management, Emergency Mobilizing and Communication Centre (EMACC), CCTV Control Room, Technical and Specialised Services and Administration department. Furthermore, a Disaster Management Advisory Forum chaired by the City Manager meets on a quarterly basis.

4.2.2 Reliability

This element is linked to the ability of the SAWS to predict severe weather events with accuracy and skill. The SAFFG was only implemented at the SAWS in 2010. Hence before 2010, the ability of SAWS to forecast flash flood events was not as well developed.

In 2008, media reports stated that there were no warnings sent. In 2019, the alert reached some of the targeted community but there was concern about available capacity of the disaster call center. The municipality’s interim storm damage report stated that only 171 to 200 calls reached its call centre, while 1 264 people could not get through. Concerns were thus raised about the capacity in the disaster call centre with only six staff members taking calls during the flooding.

In 2019, there was an improvement in terms of the content of warnings issued. This is linked to the improvement in the warning dissemination and communication indicators (discussed in Section 4.2.1) where the FEWS team translates warnings issued by the SAWS to a local level and produces impacts for specific locations within the region.

Table 9: Summary of results for the Reliability indicators within the framework.

	2008	**2019**
Warnings reach entire population through multiple channels	0.33	0.67
Clarity of warning message to trigger stakeholder response	0.33	1
Hazard forecast lead time for warning and response	0.33	0.67
Reliability of the EWS (average)	0.33	0.77
	Slightly effective	**Very effective**

4.2.3 Impact

The floods caused both significant human loss and economic damages over the affected areas. More than a 1000 people were affected and 70 people were reported to have lost their lives in 2019.

Communities needed immediate disaster relief funds to rebuild their homes and get access to adequate shelter.

Building infrastructure damage following the flooding were estimated at a repair cost of over R650 000 000. Damages for water and sanitation infrastructure such as storm water pipes, walls and culverts were estimated at R248 400 000. Electricity related costs were at R19 530 000 with repairs to 11 substations to be undertaken. The city's health unit estimated costs to be R3 000 000 with the roofs of clinics in several areas damaged as well as consultation rooms, which were also flooded.

Unlike the GRDM where there is extensive data on flood related loss and damages, this was not the case in the eThekwini Municipality, which limited a more detailed analysis of the impacts of the two hazard events assessed. It is expected that the tool on Loss and Damages in South Africa (developed as part of the ICAT project) will help to improve the collection of impact (loss and damages) related data which in turn would feed into the tool for the M&E of MH-EWS.

4.2.4 Reflections on the April 2022 floods in the eThekwini Municipality

Between 09-12 April 2022, the eThekwini municipal area and surrounds experienced devastating floods. The event was caused by a cut-off low (COL) that diverged from the mid-latitude westerly wave and tracked across the east coast and interior of South Africa (Singh et al., 2022). Several weather stations around the eThekwini Municipality recorded 300 mm or more rainfall within a 24-hour period. These heavy rains led to localised floods which resulted in loss of lives and many people displaced, while others were left homeless and unable to have access to basic amenities. Various sectors including Human Settlements, Education, Infrastructure, Agriculture, Health, etc. were affected.

The socio-economic losses associated with this event were significant in terms of lives lost, casualties and damage to infrastructure. Over 40 000 people were impacts by the rainfall and subsequent floods, with 435 deaths reported, 55 injured and 54 people missing (Government of South Africa, 2022a). There was significant damage to infrastructure with 13 500 homes damaged or destroyed; 630 schools affected in the KZN province in the areas that were impacted, and 124 schools were damaged (Government of South Africa, 2022b).

Critical infrastructure was affected which included damage to bridges and roads, two major highways, mobile phone infrastructure (400 towers impacted due to power outages flooded fibre conduiting), and damage to water and electricity infrastructure which impacted large parts of Durban for days due to damage to water treatment and power plant stations (IFRC, 2022; Tech Central, 2022). The severity and magnitude of these floods in the province prompted the initial classification of a provincial disaster on 13 April 2022, in terms of the Disaster Management Act, 2002 (57 of 2002) (DMA). However, the negative impacts of the floods in terms of severity and magnitude also became evident in the Eastern Cape, Northern Cape and North-West provinces which necessitated the reclassification of the disaster to a national disaster. The Minister of Cooperative Governance and Traditional Affairs, subsequent to consulting responsible Cabinet Members, declared a national state of disaster in terms Section 27 of DMA. A notice to this effect was published in Government Gazette No. 46247 – R. 2029 of 18 April 2022 (COGTA, 2022).

4.2.5 Overall findings and key lessons learnt

The high-level disaster risk and vulnerability assessment completed in 2016 informed the location of risk zones in the municipality, and this information is used by the municipality to supplement the early warning alerts issued by SAWS to produce risk zone specific impact-based early warning alerts. However, this risk and vulnerability data has not been shared with either SAWS or NDMC. Also, the disaster risk and vulnerability assessments undertaken do not incorporate analysis of climate data or a climate change risk and vulnerability assessment approach (this could contribute to the production of local impact-based early warning alerts). The development of disaster risk assessment and disaster risk plans improved the City's preparedness. The 2019 and to a greater extent the 2022 floods indicate that even though the municipality has a reliable EWS, that it still suffered severe losses and damages that was linked to the nature of the flooding events and the legacy of poor spatial planning that exacerbated the extent of the losses experienced.

5. Key considerations for the implementation of the M&E framework for MH-EWS in South Africa

The existing legislation and policies around climate change and disaster management create an enabling framework for promoting the adoption of the framework developed in this project. The case studies used in this project to test the framework are relatively well capacitated compared to other municipalities in the country and have established EWS. As such, a key facet for the successful implementation of the framework and tool is linked to broader processes that need to occur in the country to better capacitate municipalities to use and implement EWS and disaster risk management plans.

Another learning point has been the importance of viewing the M&E of MH-EWS and the outcomes thereof within the broader context of adaptation and gaps that may still exist in a country's climate change response. The 2022 floods in the eThekwini Municipality for example demonstrated that weather and climate-related impacts experienced are mediated by many factors, highlighting that MH-EWS and the M&E thereof is just one of the key elements needed in an effective disaster risk and climate change adaptation response. Specifically, a municipality might have an effective EWS that produces reliable warnings that are disseminated to the public; yet the impacts experienced are modified by other factors such as the intensity and duration of the hazard event. This highlights the importance of simultaneously working on aspects around loss and damages and the need for M&E of adaptation actions and resilience planning. Taken together, work undertaken to strengthen EWS and understand loss and damages is needed to provide an improved response to weather and climate-related disasters.

6. Conclusion

South Africa has established the need to improve the M&E of EWS as an adaptation response to disaster risk reduction. It is therefore not only necessary to have EWS in place, but to also ensure that these EWS can be evaluated against a set of criteria or indicators. The WMO (2018) indicators for assessing EWS were used as an entry point to develop a framework of indicators that can assess the effectiveness of EWS in South Africa. These indicators were adjusted and refined through iterative consultation with relevant stakeholders to ensure that the framework aligns with existing policy and legislation regarding disaster risk, climate change adaptation and existing M&E systems or instruments in the country. The M&E guidance tool is aimed at key stakeholders involved in disaster risk reduction to routinely assess the effectiveness and success of their MH-EWS. It is expected that the tool can be scaled up or down across government levels and geographical scales. The framework was tested for two case studies, both coastal cities that are prone to flooding. These case studies highlight opportunities to improve the efficiency of processes and the reliability of the EWS and in doing so help protect the most vulnerable people and infrastructure. The indicators of the framework can thus be used across the three elements to provide pointers to refine plans, policies and procedures to reduce losses and damages from climate related disasters and ultimately increase resilience of exposed receptors.

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