DEFRA-JNCC ENVIRONMENTAL POLLUTION PROGRAMME PROJECT SA 2.1

Integrating knowledge systems in flood-risk modelling for sustainable solid waste management and flood resilience in urban informal settlements in South Africa

SITUATIONAL ANALYSIS REPORT

June 2023

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ACRONYMS AND ABBREVIATIONS

CBFEWS	Community Based Flood Early Warning System
CSCM	Coastal, Stormwater and Catchment Management
DEFRA	UK's Department for Environment, Food and Rural Affairs
EPCPD	Environmental Planning and Climate Protection Department
EPP	Environmental Pollution Programme
EWS	eThekwini Municipality's Water and Sanitation
FEWS	Forecast Early Warning System
GFS	Global Forecast System
GIS	Geographical Information System
INR	Institute of Natural Resources
JNCC	Joint Nature Conservation Committee
KZN	KwaZulu-Natal
LID	Low Impact Development
PCRP	Palmiet Catchment Rehabilitation Project
PRG	Pollution Research Group
SAWS	South African Weather Services
SoBEDS	School of Built Environment and Development Studies
SUD	Sustainable Urban Drainage
UKZN	University of KwaZulu-Natal

SUMMARY

This situational analysis report has been prepared as part of the project "*Integrating knowledge systems in flood-risk modelling for sustainable solid waste management and flood resilience in urban informal settlements in South Africa*", funded by the UK's Department for Environment, Food and Rural Affairs (DEFRA) via the Joint Nature Conservation Committee (JNCC) under the 2022-2025 Environmental Pollution Programme (EPP) in South Africa. The immediate objective of the situational analysis is to 'set the scene' vis-à-vis the context in which the project is being conducted; in terms of understanding the following: the geographical location of the case study site (i.e. eThekwini Municipality); the positioning of and livelihoods in urban informal settlements in the municipality, and broader vulnerability factors; climate change and subsequent increases in extreme weather events such as floods; flood risk and the solid waste situation in eThekwini; flood resilience, and knowledge systems informing current understandings of flood risk and flood risk response in urban informal settlements in the area. The report also discusses the potential and benefits of knowledge systems integration in flood response and flood risk modelling in the case study municipality.

The main conclusions following from this situational analysis are as follows:

1. Flood risk in urban informal settlement contexts, including in eThekwini municipality, is multidimensional, as it emanates from both residents' exposures to natural hazards as well as social and political marginalisation.
2. Flood events feed into many other vulnerabilities, and, in the case of eThekwini urban informal settlement areas, flood vulnerability interacts with such vulnerability factors as increasing population, the absence of meaningful flood risk-reducing infrastructures, and illegal dumping, to create a serious solid waste pollution situation.
3. On paper, there are progressive guidelines for flood risk response in eThekwini municipality, emanating from both national and local government policies; however, the practical implementation of these guidelines has generally been lacking.
4. Various actors and knowledge systems holders, including those holding scientific knowledge, practitioner knowledge, and local knowledge are active vis-à-vis flood risk and risk response in eThekwini urban informal settlements; however, they have largely acted in silos – although there are isolated cases where partnerships and knowledge integration are apparent, with clear benefits for flood resilience and sustainable waste management.

5. There is need for a clear framework for integrating knowledge systems towards flood resilience and solid waste management in such contexts as eThekwini urban informal settlement areas. Integrating knowledge systems will: i) assist in making it easier to pinpoint underlying and differential cases of flood risk and in identifying the most vulnerable; ii) ensure the participation of different actors in mapping flood risk thereby creating a sense of ownership and ensuring the uptake of and support for solutions crafted to deal with flood vulnerability; iii) open up opportunities for valuable coordinated support from various actors for a range of decisions around emergency response preparation, infrastructural design, mitigation of flood-mediated solid waste pollution and/or flood waste induced destruction of infrastructure brought about by storm water infrastructure blockages.

1. INTRODUCTION

This situational analysis report has been prepared as part of the project *"Integrating knowledge systems in flood-risk modelling for sustainable solid waste management and flood resilience in urban informal settlements in South Africa".* The report 'sets the scene' vis-à-vis the case study context within which the project is being conducted; in terms of the following: the geographical location of the case study site (i.e. eThekwini Municipality); the positioning of and livelihoods in urban informal settlements in the municipality, and broader vulnerability factors; climate change and subsequent increases in extreme weather events such as floods; flood risk and the solid waste situation in eThekwini; flood resilience, and knowledge systems informing current understandings of flood risk and flood risk response in urban informal settlements in the area. The report also discusses the potential and benefits of knowledge systems integration in flood response and flood risk modelling in the case study municipality.

Flood resilience, which is the major intended outcome of the project under which this analysis is being conducted (together with sustainable waste management), combines social, spatial and structural levels of flood preparedness. Table 1 summarises these different resilience aspects.

Table 1. Different flood resilience aspects

Resilience aspect	Description
Social	The building of robust institutions and governance systems that underpin people and communities' capacity to prepare for and cope with uncertainty, change, and disasters when they occur.
Spatial	The management of land by floodplain zoning, urban greening and management to reduce storm runoff through depression storage and such practices as Sustainable Urban Drainage (SUD's) and Low Impact Development (LID).
Structural	Installation of permanent flood defence structures such as levees, demountable structures that are partially installed, temporary structures that are removable, as well as dry- and wet floodproofing of structures to meet construction standards to deflect or resist pressure without breaking.

Source: NASA/ADS (2012)

Research on resilience has developed rapidly over the past two decades, however, understanding inclusive, proactive municipal strategies for climate resilient action (in the context of emergencies such as floods) is relatively recent. The UK's Department for Environment, Food and Rural Affairs (DEFRA) (2020) notes that the goals of flood resilience should include, a) *Maintaining*: the identity of communities and places; the functions of communities and places; and livelihoods in communities and places, b) *Supporting and encouraging*: the most vulnerable in communities; and the reduction of disadvantage and

inequity in and between communities, c) *Protecting and enhancing*: the health and well-being of communities and places; and the existing wealth and prosperity of communities, and d) *Stimulating*: appropriately high levels of flood risk awareness, memory and knowledge of local environmental changes; consideration of appropriate and timely adaptation; and appropriate adaptive responses.

On the other hand, solid waste management refers to the efficient and effective collection, treatment, and disposal of solid material that is discarded because it has served its purpose or is no longer useful (Nathanson, 2023).

This report is based on a thorough review of both grey and published literature, including journal articles, book chapters, conference and workshop presentations, newspaper review articles, government reports and evaluations, and other policy papers.

2. CONTEXT

2.1. eThekwini Municipality, informal settlements, livelihoods and broader vulnerability factors

eThekwini is one of four coastal metropolitan municipalities in South Africa along with Cape Town, Nelson Mandela and Buffalo City (eThekwini Municipality, 2022). It is situated along the east coast of the province of KwaZulu-Natal (KZN) and has an area of approximately 2 555km^2 (ibid).

Figure 1. Location of eThekwini Municipality in KwaZulu-Natal, South Africa

Source: Marx and Charlton (2003)

eThekwini is the third largest metropolitan municipality in South Africa, following Johannesburg and Cape Town. It has a 98-kilometre stretch of narrow coastal plain, which gives way to major river valleys which originate to the west of the city (Marx and Charlton, 2003). The topography of the area is hilly, with many gorges and ravines. The undulating nature of the topography has influenced urban development which follows a "T" shape as it spreads up and down the coastal plain and inland along the main transport route. The metropolitan area has both an urban and rural character – with 18% being occupied by formal settlements, 5% informal settlements and 10% peri-urban settlements (ibid). Agriculture occupies 22% of the area, with the city being highly fragmented, sprawling and poorly integrated (eThekwini Municipality, 2002). The city has a subtropical/temperate climate and vegetation.

eThekwini has 3.9 million people, accounting for 34.7% of the total population in KZN province (eThekwini Municipality, 2022). Much of the population (63%) are under the age of 35 and almost 30% is under 15. Approximately 8800 households are headed by children and youth younger than 19, with 42.14% of households headed by women (eThekwini Municipality, 2022). According to the Statistics South Africa (Stats SA) Community Survey (2016), 17.1% of the population in eThekwini reported to have no income. Approximately 16.8% of the population has no education, with only 5.8% possessing a higher education qualification. The upper bound poverty line is R 1 227 per person per month, with 2.1 million people falling below the line in eThekwini (ibid). eThekwini is the only Category A metropolitan municipality in KwaZulu–Natal province[1]. Accelerated rural-urban migration and a reduced amount of well-located land have resulted in a multitude of vulnerabilities.

There is a marked increase in informal settlements and informal settlement dwellers in eThekwini. As a matter of fact, eThekwini has the largest number of informal settlements of any municipality in South Africa (UNITAC, 2023). Approximately 314 000 households make up 580 urban informal settlements or a quarter of the city's population (ibid). Due to the challenging topography of eThekwini, urban informal settlements are often found on steep slopes, within floodplains, in close proximity to mine dumps or heavy industrial areas (e.g., in Wentworth, Durban), and even on landfill sites (e.g., along Foreman and Kennedy Road, Durban) (Ngcamu, 2011). Due to the location and nature of informal settlements, they are

[1] This refers to a municipality with a population of more than 1 000 000 people.

vulnerable to natural disasters and man-made hazards (Nzimande, 2019). Precarious and poor-quality housing offers no protection against flooding or extreme temperatures.

Flooding is common in informal settlements due to the close proximity of houses to rivers (closest water resource). In fact, 11 000 households in informal settlements in eThekwini Municipality are within the 1:100-year flood line (Misselhorn, 2022). Fire is also a hazard in situations where electricity is not provided. It can be caused by residents using candles for light or to light paraffin stoves. Furthermore, settlements are more prone to hazards due to the settlement itself, such as collapsing structures, rapidly spreading fire, health risks due to rising dampness and poor indoor air quality (Ngcamu, 2011). The effect on people's health and wellbeing is greater than if they were living in households with air conditioning or adequate insulation and ventilation. Residents of informal settlements often lack access to social security and healthcare systems that provide protection for other city dwellers during climate disasters. Proper sanitation and waste management systems protect against disease transmission and other problems caused by flooding. These systems are not adequate in informal settlements.

3. FLOOD VULNERABILITY AND THE SOLID WASTE SITUATION IN eTHEKWINI

3.1. Flood risk and vulnerability

KwaZulu-Natal province, within which eThekwini Municipality is located, is the wettest province in the country, with an average annual rainfall ranging between 650 mm and 1400 mm, which is higher than the national average (Mucina and Rutherford, 2006; Department of Environmental Affairs, 2019). The peak rainfall period is during the austral summer months (October to March), with the coastline being the region of most intense rainfall (Macfarlane and Bredin, 2017). A coastal municipality like eThekwini is at risk of a combination of both inland and coastal storm surge flooding during an extreme event. Floods caused by heavy rainfall are the most common extreme weather events experienced in eThekwini. Coastal storms and flood events are expected to increase in frequency and intensity due to climate change, putting low-lying areas of the city near the shoreline at risk of flooding and erosion by pounding waves (The Outlier, 2022). It is therefore imperative to understand the current situation in eThekwini and what flood risk responses are in place because the flood risk will increase in the future due to climate change.

Tidal records collected near Durban harbour since 1970 show that sea-level has increased by 2.7mm a year, and scientists project that, because of climate change, the level of the sea could rise by between 0.3m and 1m by 2100 (ibid). The municipality has several rivers and streams, including the Umgeni, Umhlatuzana, uMngeni, and uMlazi rivers. In fact, it has more than 800 kilometres of water streams (Urban Links Africa, 2021). During periods of heavy rainfall, many of the surrounding areas are unavoidably affected by flooding. Many rivers and drainage lines are traversed by bridges to accommodate transport routes and service lines. During extreme flood events, these become blocked with plant debris (mostly alien invasive plants), solid waste (particularly plastic) and sediment, leading to major infrastructure damage and often extremely costly failure (De Winnaar et al., 2020; Graham et al., 2022). Figure 2 shows a timeline of the occurrence of floods (and storms) in eThekwini from 1987 to 2022. The pattern clearly shows a marked increase in flood events in the municipality from 2017 onward.

Figure 2. Timeline of floods and storms in eThekwini 1987 - 2022

Source: The Outlier (2022)

As noted in Section 2, the impacts of flood events in eThekwini, as in most of South Africa, are more pronounced in informal settlements. This is due to:

a) Informal settlements often being built on environmentally fragile locations such as river banks, steep slopes, flood plains and coastal shores which have a high exposure to floods;
b) The high levels of poverty and illiteracy of residents and hence their low capacity to deal with the impacts;
c) The political and institutional marginalisation of these localities emanating from their non-recognition in the broader formal human settlements fabric, often resulting in the absence of meaningful flood risk-reducing infrastructure such as storm water drains, bridges and proper roads (UN Habitat, 2018), and

d) The unplanned nature of physical infrastructure, which somehow leads to degradation of ecological infrastructure – ecological infrastructure which is supposed to confer some level of flood resilience, but which is compromised.

Looking at the four factors listed above, it is clear that flood vulnerability in informal settlements is not only a result of the residents' exposure to natural hazards but also emanates from social and political marginalization. Flood vulnerability in eThekwini is therefore multidimensional and complex, with many facets. Addressing flood vulnerability and building flood resilience in such a context thus requires adequate understanding of the physical, economic, environmental, social and cultural attributes of households and communities.

Box 1. April-May 2022 floods in KwaZulu-Natal

Between 8 April to 12 April record-breaking rains inundated the region around the port city of Durban in KwaZulu-Natal Province, South Africa. Rainfalls of between 304 to 311 mm fell over parts of KZN on a single day, with these rains falling onto already wet to saturated soils from the preceding 2 days' rainfalls of between 66 and 131 mm. This is more than four times the normal average amount for the entire month of April. These rains caused major flooding resulting in damage to roads, mobile network communications as well as electrical and water systems. Over 13,500 houses were damaged or destroyed, approximately 4000 of which were informal dwellings. In addition, over 7250 people were displaced from their homes and moved to shelters, 6250 people were left homeless and 124 schools were damaged, impacting roughly 270 000 learners. Overall, over 450 lives were reportedly lost. The damage to property in eThekwini was estimated at R17 billion and port operations at Africa's busiest harbour in Durban were suspended, and a national disaster was declared (Pinto et al, 2022). A storm in the province on 21 May led to further devastation mainly in districts in eThekwini, King Cetshwayo and Mkhanyakude resulting in further flooding of roads, human settlements, and damage to properties. Some already displaced people where further displaced as their evacuation centres were flooded. The strong low-pressure weather system that gave rise to the floods is not uncommon off the east coast of Southern Africa and have caused localised flooding and large wave events in the autumn previously. In the case of the April 2022 floods, the low-pressure system was enhanced by an influx of low-level moist air feeding in from the southern Indian Ocean. This airflow originated from a warmer sub-tropical climate, increasing the system's capacity to hold moisture. The combined effects of additional heat and moisture fed the system giving rise to more rainfall, far exceeding the expectations of the Southern African meteorological community (Schulze, 2022). The existing high-water table caused by La Nina exacerbated the effects of this excessive rainfall.

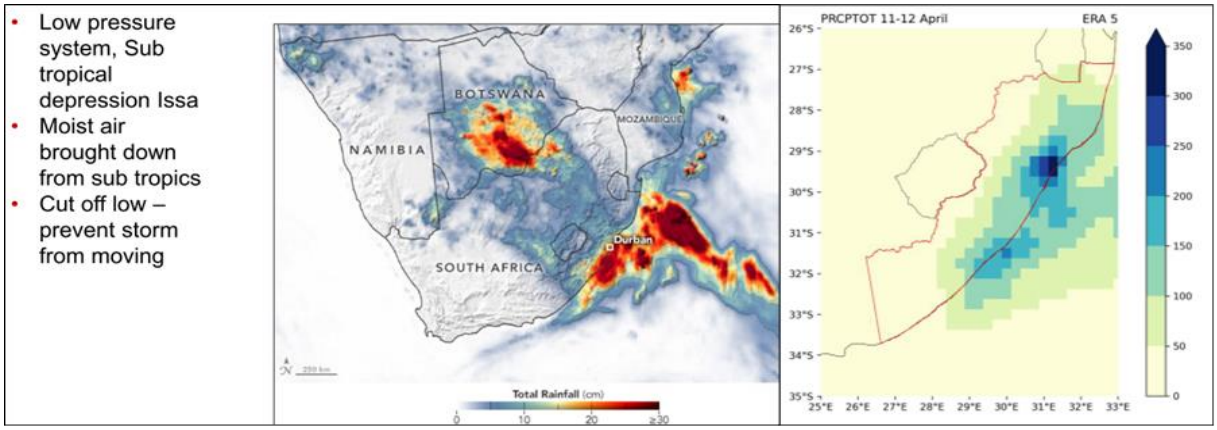

Figure 3. The cut-off low pressure system resulting in the heavy rains in April 2022

Source: Schulze (2022)

3.2. Interaction of flood events with the waste situation in eThekwini

As already noted, flood events feed into many other vulnerability factors within a given locality. In the case of eThekwini urban informal settlement areas, the absence of meaningful flood risk-reducing infrastructure such as storm water drains, bridges and proper roads is one such vulnerability factor. An increase in population, urbanisation and industrialisation has also resulted in the increased production of solid waste. Other factors relating to the increase in solid waste are illegal dumping, littering, the lack of management of municipal staff, the development of peri-urban areas and expansion of informal settlements, and poor service delivery. Planning and risk mitigation measures from the municipality are also typically limited in informal settlements.

The waste management sector itself is vulnerable to floods as a result of the logistical complexity of solid waste removal and disposal systems during and in the aftermath of flood events. Flood events potentially damage municipal waste assets such as waste collection vehicles, landfills and other related infrastructure (road, water and sanitation). In addition, the waste sector has to deal with the debris and waste that remains following floods. Furthermore, flood events undermine the ability of local governments in meeting regulatory requirements such as implementing the waste hierarchy (i.e. to minimise, reuse, recycle, and treat waste) and reducing the volumes of waste going to landfills (Muswema et al, 2018).

It is imperative to note, as highlighted by Urban Links Africa (2021) that eThekwini's solid waste management faces chronic and severe challenges. It is noted that population growth in the metropolitan is resulting in the increased production of solid waste, and its landfill capacity

is reaching its limits with two out of three landfills now refusing general solid waste (ibid). As a result, the city is experiencing an increase in illegal dumping as well as associated congestion from inefficient waste locations, and this is, again, more pronounced in informal settlements (see Figure 4).

Figure 4. Illegal dumping in informal settlements in eThekwini

Poorly managed solid waste contributes to infilling of watercourses (e.g. illegal dumping and waste accumulation) and clogging of stormwater systems, bridges and culverts essentially designed to rapidly convey water away, and thus amplifying the impacts of flooding and causing significant damage to both stormwater and sewage networks (De Winnaar et al., 2020). Lamond et al. (2012) highlight that approaches to improve waste management need to include both large municipal schemes as well as locally based community schemes, and the management of waste needs to be a part of a wide integrated flood management programme. Waste management can be an effective response to flood risk mitigation and management, however, to ensure it is successful, it requires sufficient long-term commitment and engagement.

4. FLOOD RESILIENCE AND SOLID WASTE MANAGEMENT IN eTHEKWINI

4.1. National context of flood response

Flood response in South Africa takes place more broadly within the confines of the Disaster Management (Amendment) Act (No. 16 of 2015). In the event of a flood, the Act mandates the activation of the following:

- An integrated and coordinated approach (between national government and subnational jurisdictions) to disaster management which should focus on reducing risk, mitigating the severity of the disaster, facilitating emergency preparedness, rapid and effective response, as well as post-disaster recovery
- The establishment of national, provincial, and municipal disaster management centres, and
- Disaster management volunteers

A three-phased approach is normally set out as the road-map in dealing with floods at the national level (see Table 2)

Table 2. A 3-phased approach to flood response in South Africa

Phase	Description of Phase	Purpose
1	Immediate humanitarian relief	Ensuring that all affected persons are safe, and their basic needs are met
2	Stabilisation and recovery	Rehousing people who have lost homes and restoring the provision of services
3	Reconstruction and rebuilding	The construction and repair of major infrastructure, the construction of houses in suitably located areas and measures to protect the residents of these areas from such adverse weather events in the future

4.2. Flood response in eThekwini

The eThekwini metropolitan municipality's response to a declared disaster, such as a flood event, is outlined in the municipality's Disaster Management Plan (eThekwini Municipality, 2016) and coordinated by the Municipal Disaster Management Centre. A Disaster Management Advisory Forum is established and chaired by the Municipal Manager whose office coordinates roles and responses of the various line functions and departments included in the response to an emergency. The various departments include (but are not limited to): Metropolitan Police; Fire and Emergency Services; Housing; Parks, Recreation and Culture; and Durban Solid Waste.

In addition, eThekwini's 2019 Climate Action Plan lists what is needed to build flood resilience in terms of anticipation and response. It, for example, lists the need for:

a) An early warning system

b) The one-in-100-year flood line map that, when drawn together with climate projections, should allow for better planning and management in flood-risk areas
c) The establishment of partnerships necessary to restore and conserve ecological infrastructure.

The Plan also lists the actions necessary to keep river corridors healthy and ecological infrastructure working. Elsewhere, the plan also flags the need to move communities out of flood-risk areas and house them appropriately in properly-serviced areas (The Outlier, 2022). As part of operationalising the Climate Action Plan, the Municipality's Coastal, Stormwater and Catchment Management (CSCM) Department came up with an integrated and fully consummated Forecast Early Warning System (FEWS) in 2020 (see Box 1). FEWS was developed over a period of seven years (from 2013-2020), initially designed for flood early warning and gradually evolving to include capacities for other early warnings such as water quality, risk assessments, coastal and real-time data management – hence evolving from a Flood Early Warning System into the Forecast Early Warning System (Ramdass, 2020).

Box 2. eThekwini's FEWS Program

eThekwini's FEWS program is a first of its kind on the African continent. FEWS is a disaster management and data monitoring tool that simulates flood scenarios, environmental water quality, coastal erosion and wave behaviour. Access to reliable weather forecast data enables the system to predict the effects of natural disasters ahead of time, allowing enough time for the information to provide for emergency resources so that the city is better prepared. The operation of the FEWS program can very roughly be broken into 4 phases: a) the data feeds phase, which involves drawing in data and information from various sources, ranging from internal equipment to satellite measurements; b) the data is then imported into the main FEWS, which is a multi-layered process to ensure the validity of the data received; c) the data are then transformed to a format suitable for different models to interpret, which then feeds the results back into the system; d) the results from linked models are then presented in a single interface, streamlining response processes. The FEWS system makes use of the Global Forecast System (GFS), a global numerical weather prediction system containing a global computer model and variational analysis run by the US National Weather Service (NWS). The GFS forecast global model has a 27 km resolution, updates four times per day, offers a forecast for ten days, covers the entire globe and is freely available. Although not a hundred percent all the time, this data is more than sufficient for flood forecasting as initial checks, one week ahead. Any thresholds exceeded can then be monitored as the potential event approaches and updated GFS accuracy and timing improves. Furthermore, the use of radar at real time during storm events can provide the most reliable rainfall intensities and possible storm paths, further improving the localisation of rainfall patterns for the hydraulic models. FEWS data exchange and flow is managed by the FEWS open shell system using the open interface XML format. Essentially XML is the language used for data transfer and standardises the coding. Thus, all inputs/outputs from gauges, models and any other sources are rewritten into XML by automated executables.

Source, AVP, 2021

It is imperative to note that, in the case of the most recent (April/May 2022) floods (see Box 1), whilst the municipality did provide communities with some early warning advisories based on FEWS, it appears the system did not adequately predict the magnitude and the subsequent impact of the flood. This is where we think other knowledge systems will be useful in providing a rounded picture of the anticipated nature, course and impact of such hazards at local levels.

4.3. Solid waste management in the context of flood response in eThekwini

Solid waste management in the context of flood response in eThekwini is also catered for under the Metro's Disaster Management Plan. The following required tasks are stipulated:

a) Compilation of a risk management programme by the relevant Unit
b) Compilation of plans to ensure continuation of solid waste services during emergencies and/or disaster situations such as flood events
c) Providing a (solid-waste) representative at the disaster operations centre when this is activated
d) Creation of facilities for the disposal of hazardous waste
e) Providing refuse bags and/or skips for the collection of debris and waste in and/or from affected areas
f) Maintaining a schedule for waste removal in the affected areas
g) Provision of any other interventions in accordance with statutory obligations and/or the dictates of the circumstances

5. KNOWLEDGE SYSTEMS INFORMING THE UNDERSTANDING OF FLOOD RISK AND FLOOD RESPONSE IN eTHEKWINI URBAN INFORMAL SETTLEMENTS

Knowledge systems can be conceptualised as comprising of agents, practices and institutions that organise the production, transfer and use of knowledge (Cornell et al, 2013). In flood risk and flood response, three forms of knowledge are apparent, and these are: scientific, local/indigenous, and practitioner knowledge systems. Whilst scientific knowledge refers to systematised knowledge that can be replicated and validated by recognised experts through, usually, a series of logical and empirical methods; local/indigenous knowledge refers to place-based experiential knowledge of a community accumulated over generations of living in a particular environment (Eriksen et al, 2005; Roncoli et al, 2012). Practitioner knowledge on the other hand is knowledge held and emanating from practitioners such as resource managers, government bureaucrats, and players in non-governmental, developmental and civil society

organisations (INTASAVE, 2015). From our analysis, all the three knowledge systems are in active use vis-à-vis flood response in eThekwini urban informal settlements.

5.1. Scientific knowledge

Scientific knowledge from academics, scientists and researchers has informed flood response in eThekwini over the years. The FEWS program discussed earlier, for example, is based on weather warning information gleaned from scientific global forecasts and from the South African Weather Services (SAWS). Researchers from the University of KwaZulu-Natal (UKZN) have also been active in specific eThekwini urban informal settlement areas. For example, researchers from the University's School of Built Environment and Development Studies (SoBEDS) have, in the recent past, been observing rainfall and river levels around the Quarry Road West Informal Settlement and transferring the data to municipal officers towards informing flood risk warning in the area. The researchers have also been spearheading the generation of risk maps (together with local communities) towards developing and expanding an understanding into the spatiality of various risks (including flood risk). The University's Pollution Research Group (PRG) also conducts research and generates data on water resources, water reclamation, the impact of effluents, sanitation systems, flood events and other water-related environmental issues in selected eThekwini urban informal settlements.

5.2. Practitioner knowledge

Different civil society and non-governmental organisations have been active in eThekwini's urban informal settlements working on issues related to flood response as well as waste management. For example, Kloof Conservancy, a volunteer organisation which aims to promote environmental awareness, has conducted work on environmental education, flood vulnerability awareness, habitat restoration, sustainable living issues, and invasive alien plant eradication. Coca-Cola South Africa has also led a waste project in some urban informal settlements in recent years (i.e. Project Hlwekisa) aimed at building community awareness about pollution and the value of waste. A non-profit organisation called Green Corridor also provides refuse bags to households in urban informal settlements in the municipality, to enable people to dispose their waste at designated points during and after floods.

5.3. Indigenous knowledge

Urban informal settlement dwellers in eThekwini, as elsewhere, are not 'helpless' victims of floods. They have, over the years, relied on local and experiential knowledge accumulated through oral transmission as well as through past learning and experiences to mitigate and cope

with flood hazards. For instance, using the case of the Quarry Road West informal settlement, in 2022 UKZN scholars identified some of the main local and indigenous indicators used in mapping flood vulnerability in the area. The following came out as prominent:

a) Amount of rainfall – with increasing rains being a sign of high likelihood of flooding
b) Flow velocity – with increasing velocity of water in nearby rivers indicating the likelihood of flooding
c) Nature of soil – with community members able to identify highly erodible soil with a potential to expose one's housing structure to flooding
d) Accumulated waste – which was said to always lead to the blockage of storm drains, compounding flood situations
e) Proximity to main roads – this is because there are no storm drains in the area along the main roads which are close to the informal settlement under focus. Community members highlighted that the major road nearest the settlement appears slightly tilted towards human settlements such that all the run-off from the road which is supposed to find its way to the nearby river ends up in the settlement.
f) Lack of land ownership has also made urban informal settlement dwellers vulnerable to floods and compromised their resilience – this is because they are not allowed to build stronger permanent structures which can withstand (some of the) floods which they experience, as they are considered illegal settlers.

What is remarkable in as far as the listed indicators are concerned is that, whilst some (of the indicators) aligned with what the research team had obtained from key informant interviews and from an initial review of literature, almost half of the indicators had not arisen from those earlier sources but came up directly from engagements with community members, showing a vibrant local/indigenous stream of knowledge in the area.

6. POTENTIAL AND BENEFITS OF KNOWLEDGE SYSTEMS INTEGRATION IN FLOOD RESPONSE AND FLOOD RISK MODELLING IN eTHEKWINI

Many studies have shown the benefits of implementing integrated flood risk and waste management based on a combination of different knowledge systems (e.g. Lamond et al., 2012; APN, 2018; Munyai et al., 2019; Busayo et al., 2022; Membele et al., 2022). In Bangkok, Thailand, APN (2018) documented an urban flood risk reduction strategy which solves urban drainage problems by managing solid debris derived from anthropogenic and natural activities,

through administrative services on sewage and drainage clearing, waste collection, and citizen's cooperation to waste disposal. They developed a public relation and dissemination tool, which is still in use, for residents of vulnerable communities living in flood-prone areas, to share knowledge and consciousness on the environment. This effort was also to encourage proper waste disposal by residents to reduce littering and illegal dumping.

In South Africa, previous initiatives at modelling flood risk have adopted various approaches mostly centred on the scientific mapping of effects of anthropogenic processes, e.g. waste disposal; and/or ecological characteristics of an area such as soil porosity, pervious surfaces, flood plains etc. Such approaches have included the probabilistic modelling approach, neural networks, multi-criteria evaluation, and, in recent years, geographical information systems (GIS) and remote sensing. Although these approaches have improved our understanding of flood risk, including flood hazard extent and evolution, they have not been able to make it easier for flood risk prediction over fine spatial scales (Chikwiramakomo, 2021). Flood hazard maps based on GIS and remote sensing have also generally lacked a useful balance between simplicity and complexity for adequate readability and usability by the lay person (Cea and Costabile, 2022). Consequently, these approaches have not been very effective for risk modelling that is useful to build flood resilience in such localised scales as informal settlements. Proper estimation of flood risk requires careful and holistic consideration of a number of factors, including watershed properties such as size, topography, and land use; the types and characteristics of precipitation which result in flood events; and the location, and types of infrastructure and other assets that could be damaged. Membele et al (2022) note that the changing climate together with the multidimensional nature of flood vulnerability highlights the need for an in-depth consideration of knowledge systems integration in mitigating flood vulnerability in informal settlements.

Bringing together different knowledge systems (such as those discussed in Section 5) in flood risk modelling and understanding flood vulnerability has great potential vis-à-vis various factors important in building flood resilience, such as solid waste management, particularly in urban informal settlement contexts. In the case of eThekwini, there have been fragmented efforts to integrate knowledge systems in an attempt to increase flood resilience and towards realising other environmental benefits. One such effort is the Palmiet Catchment Rehabilitation Project (PCRP), established in 2014, in an attempt to increase adaptive capacity for communities near and around Palmiet River, through an innovative water and climate

governance partnership between eThekwini Municipality, researchers at the University of KwaZulu-Natal and civil society organisations (see Box 3).

Box 3. The Palmiet Catchment Rehabilitation Project

As noted, the Palmiet Catchment Rehabilitation Project (PCRP) involved partnership between eThekwini Municipality, researchers at the University of KwaZulu-Natal (UKZN) and civil society organisations. The initial scope of work of the PCRP, as outlined by eThekwini Municipality's Water and Sanitation (EWS) engineers, focused on finding technical solutions to addressing the risk of flooding and pollution in the lower reaches of the Palmiet River as it flows through Quarry Road West informal settlement into the uMngeni River. The interventions included constructing wetlands, weirs and gabion banks to reduce the impact of the river on both the Quarry Road West informal community and the uMngeni River, and to develop waste management and storm water systems to reduce the impact of the community on the river. Through initial engagements with officials from EWS and the Environmental Planning and Climate Protection Department (EPCPD), UKZN researchers began to shift the focus of the work plan constructed by the municipality, from being top down, technical and managerial, to one that started with the building of relationships between all actors in the catchment around water and climate governance. An actor mapping exercise was undertaken, and new actors were drawn in to the PCRP through the efforts of the UKZN researchers. As a result, a governance arena for building sustainability in the catchment began to be established. EPCPD assumed a leadership role from a climate change perspective in the newly forming PCRP partnership, which by early 2015 comprised of actors from the municipality, the university, community-based organisations (such as River Watch – which is a voluntary community-based organisation located in Westville, a middle to upper income suburb located along the middle reaches of the river, but working across the catchment to report and reduce pollution), and committee members from Quarry Road West informal settlement. One key aspect of the initiative has been to dramatically improve waste collection in the Quarry Road informal settlement, which prevents waste from blocking drains and amplifying the effects of flooding. The project is using social media to better inform residents about flood risks ahead of time, allowing the local community to better prepare for and respond to flood events. The local government came up against several challenges when engaging with the community at Quarry Road informal settlement, but by developing an integrative partnership with UKZN researchers, who had established prior connections in the community, they were able to more successfully bring in the needs and voices of all stakeholders into the project. The city government's initial plans were to construct an artificial wetland to tackle the flood risk in Quarry Road, but after consulting with residents they realised that this approach was inconsistent with the priorities of the local community.

Source: Sutherland et al, 2019; C40, 2017

The PCRP initiative has led to multiple benefits emanating from an integration of different knowledge systems. Among these have been improvements in the appropriate disposal of domestic waste, which (if done inappropriately) can block drainage systems and exacerbate flooding impacts, including the discharge of raw sewage, which poses significant health risks. The PCRP has also inspired the creation of the Community Based Flood Early Warning System (CBFEWS) towards the production of early warnings within the municipality, identifying hotspots for disaster risk reduction and management. Using PCRP platforms, residents within the Quarry Road West informal settlement have also co-produced and ground-truthed risk maps

of their community, and have developed climate adaptation strategies in collaboration with UKZN researchers. As a result, the community now better understands the spatiality of various risks in their settlement.

It is apparent that the integration of knowledge systems leads to multiple resilience benefits. However, it is also clear in the case of eThekwini that whilst knowledge systems integration initiatives have been instituted and are yielding positive results, they are being done in an ad-hoc and isolated manner, without a clear framework of engagement (at city or municipality level). With the convergence of different vulnerabilities in such municipalities as eThekwini around increasing flood risk, increasing urbanization and the attendant challenges around solid waste, there is therefore urgent need for the crafting of models and frameworks for knowledge systems integration towards increased flood resilience and the realization of other environmental benefits e.g., around sustainable waste management.

7. CONCLUSION

This situational analysis report set out to explore key issues and aspects with respect to knowledge systems and knowledge systems integration vis-à-vis flood modelling for flood resilience and sustainable waste management in eThekwini urban informal settlements in South Africa. The report discusses various issues including the geographical location of the case study municipality, livelihoods and broad vulnerability factors, flood risk and the solid-waste situation, flood resilience and knowledge systems informing current understandings of flood risk and risk response in the area. The main message emerging from this situational analysis is that building understandings of flood risk and flood resilience via an integration of different knowledge systems is critical vis-à-vis effectively dealing with flood risk and related environmental challenges like solid waste in such complex vulnerability contexts as urban informal settlements.

In essence, the following observations are made:

a) Flood risk in urban informal settlement areas in such contexts as eThekwini municipality is multidimensional, as it emanates from both residents' exposures to natural hazards as well as social and political marginalisation.
b) Flood events feed into many other vulnerabilities, and, in the case of eThekwini urban informal settlement areas, flood vulnerability interacts with such vulnerability factors

as increasing population, high population density, land-use change, impervious surfaces, the absence of meaningful flood risk-reducing infrastructures, and illegal dumping to create a serious solid waste pollution situation.

c) On paper, there are progressive guidelines for flood risk response in eThekwini municipality emanating from both national and local government policies, (including provisions for partnerships and coordination among different actors); however, the implementation aspect of these guidelines has generally been lacking.

d) Various actors and knowledge systems holders, including those holding scientific knowledge, practitioner knowledge, and local knowledge are active vis-à-vis flood risk and risk response in eThekwini urban informal settlements; however, they have largely acted in silos – although there are isolated cases where partnerships and knowledge integration are apparent, with clear benefits for flood resilience and sustainable waste management.

e) There is need for a clear framework for integrating knowledge systems towards flood resilience and solid waste management in such contexts as eThekwini urban informal settlement areas. Integrating knowledge systems will: i) assist in making it easier to pinpoint underlying and differential cases of flood risk and in identifying the most vulnerable; ii) ensure the participation of different actors in mapping flood risk thereby creating a sense of ownership and ensuring the uptake of and support for solutions crafted to deal with flood vulnerability; iii) open up opportunities for valuable coordinated support from various actors for a range of decisions around emergency response preparation, infrastructural design, mitigation of flood-mediated solid waste pollution and/or flood waste induced destruction of infrastructure brought about by storm water infrastructure blockages.

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