ENVIRONMENTAL DISASTER RISK

Flood hazards in a changing world: Challenges and opportunities in the Garden Route

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In its 2022 Global Risks Report, the World Economic Forum states that environmental concerns dominate the top five long-term risks (in terms of likelihood) with three of them also being among the top five in terms of impact. Biodiversity loss and ecosystem collapse, as well as climate action and adaptation failure and extreme weather are highlighted as the top three environmental risks over the next ten years. Anthropogenic environmental disasters, natural disasters and water crises are expected to have significant impacts on economic stability and social cohesion over the next decade (World Economic Forum (WEF), 2022).

A disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk. Risk is the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between human-induced or natural hazards (i.e., a potentially damaging physical event such as floods, droughts and wildfires) and vulnerable conditions. A hazard can be specified as a potentially damaging physical event, phenomenon, or human activity. Natural hazards can be classified as geological (e.g., earthquake and landslides), hydrometeorological (e.g. floods and wildfires or veldfires) or biological (e.g. epidemic diseases and insect plagues) (Baas et al., 2008; Abbott and Patrick, 1996).

In developing countries like South Africa, natural disasters can have a profound effect on human well-being, the economy, and the natural environment. This vulnerability of developing countries to climate-related disasters is thought to be attributed to poor adaptation strategies (i.e., typically a lack of financing for climate change adaptation) (Nyahunda and Tirivangasi, 2019; Ndaki, 2014). Natural disasters can cause the destruction of property, loss of financial resources, and personal injury or illness. Economic impacts include, for example, the loss of income, reduced tax revenue, loss of infrastructure and the expense of reclamation efforts. Many local communities experience significant economic losses, such that recovery becomes difficult and protracted, if not impossible (Matlakala et al., 2021). However, some communities do find opportunity in the aftermath of a disaster to rebuild better and stronger than before. In addition, ecosystems can be destroyed or suffer severe damage by a single disaster event (e.g., unseasonal wildfires) and may take years to recover.

The information captured across these different sources assists researchers in identifying drivers of impact or change (e.g., change in climate variables or land use change) and to prepare for future events by identifying the strategies needed to reduce these impacts. Anticipating and planning adaptive strategies to deal with risk in future is therefore very important (Hulme, 2005). For example, the lessons learnt following the Knysna veldfires in 2017 include improving disaster preparedness, disaster response times, risk identification, overall hazard reduction and increasing resilience. These fires were arguably the worst wildfire disaster in South Africa's history (Forsyth et al., 2019) with 973 homes destroyed and 560 houses damaged; about 2600 people displaced and roughly 2000 jobs affected. It was reported that the towns of Bitou and Knysna had municipal infrastructure damage of R 66 million while 15 700 ha of pine plantations were destroyed (EDM, 2018). Insurance claims amounted to around R2.5 billion (Forsyth et al., 2019). We should not have to wait for a disaster to occur to have the necessary processes in place to reduce detrimental impacts.

When it comes to flood hazards in South Africa, many rivers are already under stress due to excessive water withdrawal and land development in floodplains. Climate change with its potential to alter rainfall, temperature and runoff patterns will only magnify these existing risks (Palmer et al., 2009). By identifying and prioritising actions that can be taken now to enhance the resilience of urban ecosystems in the face of disturbance we may minimise impacts accompanied by severe flooding in future. To minimise the risks posed by extreme flooding we can take proactive or reactive measures. Proactive measures are actions that, if implemented, will improve the capacity of river systems to absorb disturbances while minimising threats to the environment and human populations. Whereas reactive action involves responding to problems as they are generated by repairing damage or by mitigating ongoing impacts. Currently, we are not adequately prepared to pre-empt the impacts (i.e. respond to floods and their accompanying risks) and are forced to respond to the flood risks reactively. The problem with solely using this approach is that it can be very expensive and may result in species loss, infrastructure damage and loss of human lives. The ideal is to be able to anticipate change and adapt flood management to those changing circumstances, whilst having disaster relief, flood control infrastructure and evacuation plans in place.

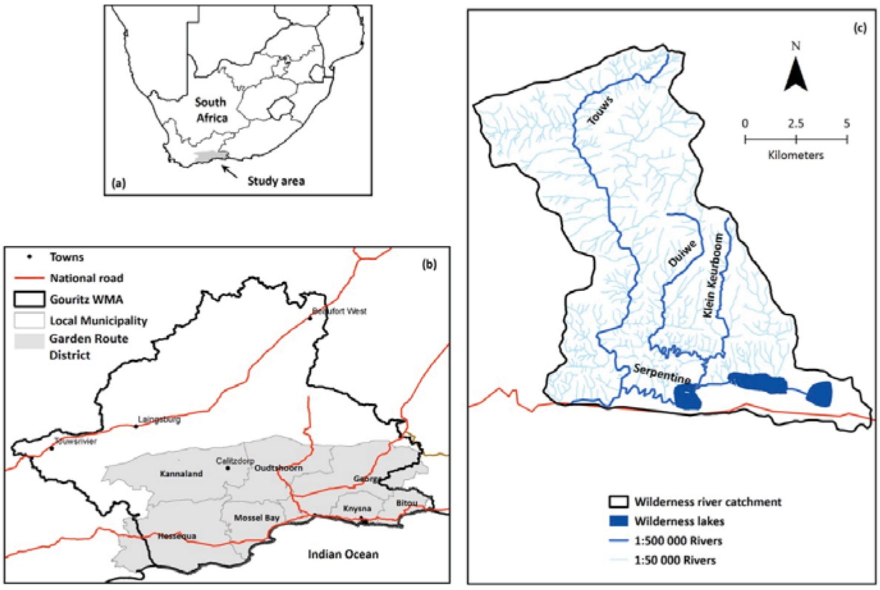
Historical records, hazard modelling, early warning systems and simulations can help to identify areas where disasters are likely to occur and the impact they might have. These hazard or risk maps facilitate planning at all levels of government and society. The Council for Scientific and Industrial Research (CSIR), in partnership with the National Disaster Management Centre, recognised the importance of finding innovative ways to reduce risk. They developed an open access online applied knowledge resource, called the Green Book (visit www.greenbook.co.za). This multi-disciplinary disaster risk profiling and adaptation tool provides a municipal overview of hazard profiles as well as available resources to minimise these hazards. Its goal is to contribute to sustainable, resilient, and liveable human settlements through climate change adaptation. However, such tools are all dependent on having relevant and up-to-date information and people who understand how to use the tools to identify and implement adaptation and mitigation measures.

Using the Garden Route, situated in the Western Cape Province of South Africa, as a case study we highlight how historic and desktop data can be used to identify flood hazards, as well as inform the development of mitigation and adaptation strategies to address such hazards. The research approach involved a combination of modelled, observed, and measured data. Datasets from a wide range of sources were integrated. The analysis in the study focuses on two scales: district level (Garden Route District Municipality) and catchment level. The former involved a flood risk assessment while the latter sought to examine historical rainfall and streamflow changes (i.e., identify extreme flood events) in the Wilderness River Catchment.

Location of the study area

The Garden Route is situated in the Garden Route District Municipality (23 321 km^2), Figure 1b. The District Municipality comprises seven local municipalities (i.e. Bitou, George, Hessequa, Kannaland, Knysna, Mossel Bay and Oudtshoorn) and is well known for its diverse natural areas in the form of nature reserves, national parks and unspoilt coastline (Eden District Municipality (EDM), 2008). Most of the area's vegetation is still unconverted, with 64% consisting of indigenous fynbos and the remainder comprising Succulent Karoo, and Albany Thicket (Mucina and Rutherford, 2006). The Wilderness catchment (178 km^2) forms part of the Garden Route coastal catchments (Middleton and Bailey 2009), Figure 1c. The area is ecologically sensitive and has a rich biodiversity which include the Wilderness Lakes system, a Ramsar site protected in the Garden Route National Park (Cowan and Marneweck 1996; Russell, 2013). This catchment can be divided into two main sub-catchments, the Touws River including the estuary (102 km^2), and the Duiwe River which feeds the lakes (± 73 km^2).

Figure 1: Location of the Garden Route study area within the southern cape region of the Western Cape Province, South Africa (modified from O'Farrell et al., 2015).



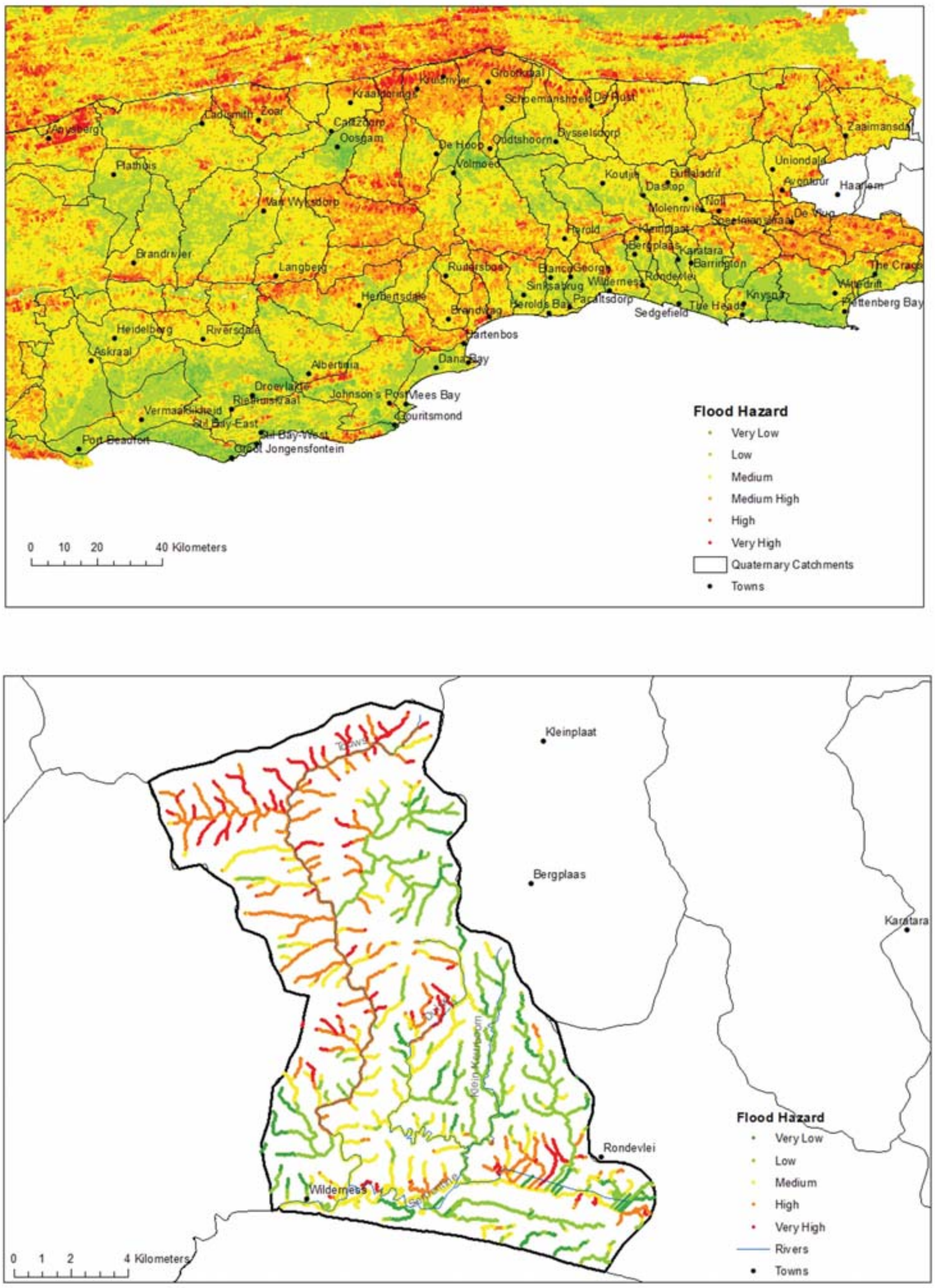
Modelling flood hazard in the Garden Route

Very high or prolonged rainfall (i.e. intense rainfall) events often leads to flood discharges (Smithers and Schulze, 2004; Goudie, 2006). Rainfall in the Garden Route occurs throughout the year, but peaks in March and October (Reyers et al., 2015). Around one in five cut-off low events over Southern Africa typically results in flooding and associated damages to the coastal areas of the district (Holloway et al., 2012), which is often exacerbated by the steep catchments in the coastal areas resulting in high runoff and flash flooding (Nel et al., 2014). Likewise, the shallow soils and limited groundwater storage of the TMG quartzitic sandstones make the river flows highly responsive to rainfall events. Early studies have shown that landscape drivers of run-off can halve the return period of a flood event, and that managing ecological landscapes (e.g., riparian buffer zones) is a key risk management and climate change adaptation mechanism (Le Maitre et al., 2011).

The Sensitive Catchment Integrated Modelling and Analysis Platform (SCIMAP), a decision support tool developed by the Durham and Lancaster Universities along with the British Environment Agency (http://www.scimap.org.uk/) was used to model flood hazard based on the catchment characteristics. Data inputs include a 30 m DEM, national land cover map, design rainfall for a 50-year return period and hydrological soil type data. This model was chosen as it can be applied to catchments with limited data using global, regional, and local datasets. Results of the flood hazard, as based on the SCIMAP model, is shown in Figure 2. The model shows a landscape view of the associated flood hazard which allows for understanding across a catchment and to identify areas that are most likely to generate flood water during a storm event.

According to the model output a band of very-high to medium-high flood hazard can be found along the Langeberg mountains which separate the coastal area from the Klein Karoo and the small coastal catchments of the Garden Route (e.g., Mossel Bay, George and Wilderness). Very-high to medium- high flood hazard areas are also found in the inland area of the Klein Karoo catchments of Oudtshoorn, Calitzdorp, Zoar and Ladismith and Anysberg. The Wilderness Catchment is shown in detail to illustrate the outputs of the model which is represented at a point scale (Figure 3b). In this zoomed in view very-high to high flood hazard zones are displayed along the Touws River, and which is the main river system (240.7 km in length) in the catchment (Figure 1c). High flood hazard is also shown along the tributaries of the upper part of the Duiwe river, as well as the tributaries surrounding the wilderness lakes. Prioritising and targeting these areas for mitigation actions can be an effective way to reduce damages. Understanding the nuances of flood

Figure 2: Flood hazard for (a) the Garden Route District and (b) Wilderness River catchment based on the SCIMAP model.



Understanding the nuances of hazard areas in the Garden Route

Another useful measure of the flood risk is based on the record of observed floods and measured heavy (50 to < 100 mm) to extreme (≥ 100 mm) rainfall events. Spatial data on flood hazard was assessed by examining and interpreting hydrological information (i.e., rainfall intensity and duration as well as flood magnitude and frequency) obtained through historic rainfall (daily measurements from the SAWS and private landowners) and streamflow records (i.e., monthly, and yearly weir gauge measurements from the DWS). Note that < 75% of mean annual rainfall (i.e., dry years) suggests droughts while > 125% of mean annual rainfall (i.e., wet years) suggests floods (after Laing, 1992; Vogel et al., 2000). Existing data gaps were mainly dealt with by combining datasets (i.e., to obtain a complete as possible dataset) were the station data time series overlapped (e.g., Woodville (Bos) and Tura-Kina rainfall stations).

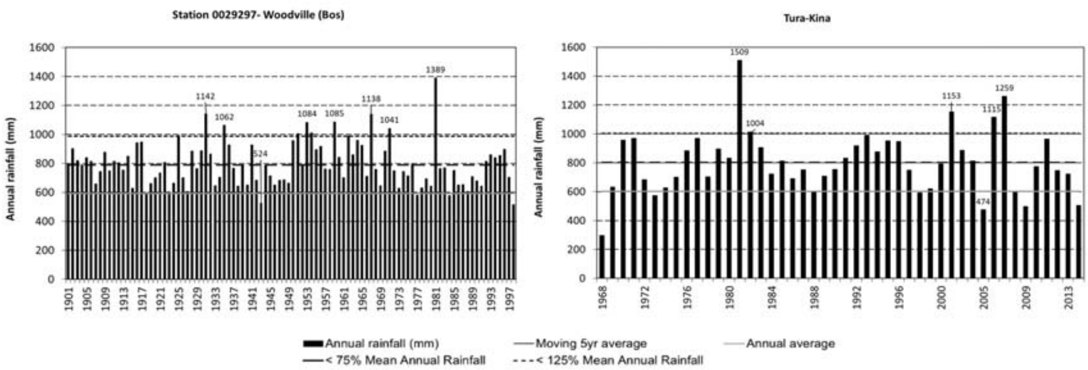
The results showed that the study area is subject to regular floods (Figure 3) related to the drivers of severe weather, land use change and alien plant invasions. In Wilderness extremely wet rainfall years are quite frequent with heavy to extreme rainfall years occurring at least once in every 10 years (e.g., 1959, 1969, 1971 and 1981), Figure 5. The peaks in rainfall often coincide with cut-off low pressure systems which are often associated with extreme weather events (Holloway et al., 2012). Beaumont (1981) reported that the removal of catchment and channel vegetation typically increased large flood events. A case study in a lakeside urban plain found that changes to plantation forestry management altered the 1:100-year flood events to a 1:80-year return period (Nel et al., 2014). Agricultural activities associated with crop cultivation and plantation forestry have transformed 18.6% of the landscape in the Garden Route District. The Klein Keurbooms River channel (27.86 km, location as per Figure 1c).

Figure 3: Flooding in the Duiwe River catchment illustrating channel morphological changes, Wilderness.

The Klein Keurbooms River channel (27.86 km, location as per Figure 1c). before the June 2011 flood (a), the channel during the June 2011 flood (b) and the channel after the June 2011 flood (c). Photographs by Mr Roger Titley (Beyond the Moon Guesthouse, Wilderness).

The remaining areas have been transformed by alien plant invasions (e.g., pine trees and black wattle) and rapid urban expansion that results in land use change seen in increased pressure for housing development and associated infrastructure. Invasive species are important variables key to modifying river flows and affecting sediment erosion and deposition thereby influencing floods of differing magnitude and frequency (Figure 3). These species may alter channel bank resistance and stability, overbank hydraulic roughness and sedimentation and channel morphology (Smith-Adao and Scheepers, 2017). Hence, substantial control and invasion management efforts are required.

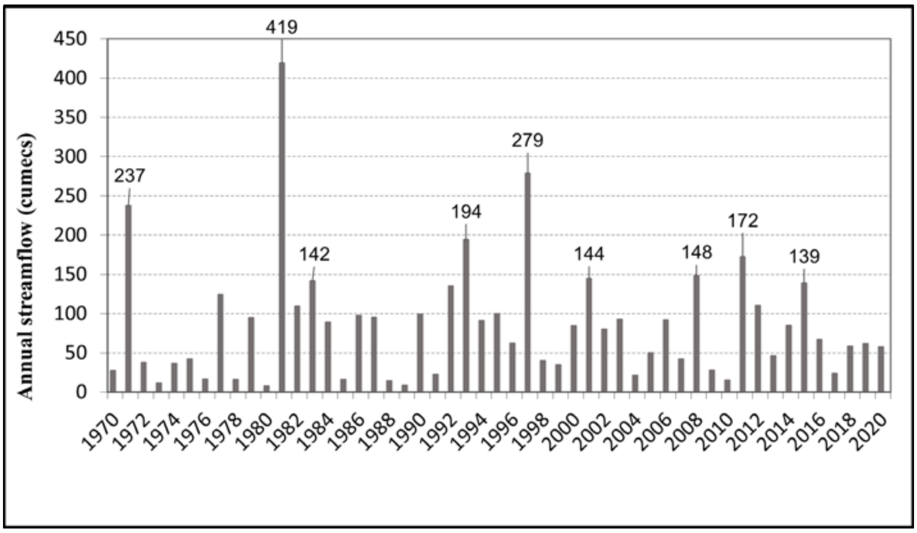
Figure 4: Annual rainfall in Wilderness.



Data sources: The South African Weather Service and private landowner, Mr Karl Reitz (Tura Kina Farm).

Figure 2b indicates that the Touws River has a high flood hazard potential. This river system has no dams or major abstraction points above the gauging weir, and flows are largely natural. However, plantations in the upper catchment influence the flows in the Touws River although large areas have been cleared or burnt in recent years. The river is highly responsive to heavy rainfall with very marked peaks in the months that are particularly wet with much lower flows in most other months. We can see this in the yearly streamflow for the Touws River (Figure 5).

Figure 5: Yearly streamflow for the Touws River, Wilderness.



Data source: The DWS (visit https://www.dws.gov.za/Hydrology/Verified/hymain.aspx).

High magnitude flows (> 130 cubic metres per second [cumecs]) were encountered during the years 1971, 1981, 1983, 1993, 1997, 2001, 2008, 2011 and 2015 (i.e., on average twice a decade). A flood event of 419 cumecs (i.e., similar to the May 1981 flood in this area) can be expected to occur once in 100 years. When data on rainfall, streamflow and major floods in Wilderness were cross-checked, there was a general concurrence. However, not all major rainfall events resulted in flooding (i.e., catchment characteristics such as preceding rainfall and surface hardness play a role). The results from CAELUM database showed no flood records within this catchment over the time period studied. It must be noted that is mostly related to a data quality issue with regards to location accuracy (e.g. place names and accurate coordinates).

Challenges in the Garden Route

Data collection and monitoring

Good progress was made in the assessment of water resources in South Africa over the past 60 years with exponential growth in computational processing power (i.e., high performance computing) and the associated development of highly sophisticated new tools. Two of the primary sources of hydrological data are rainfall and river flow. However, the main worry in recent times has been the serious decline in hydrological monitoring. This includes for example, the low and declining number of weather stations across the country (Foden et al., 2019). This trend can also be seen in the Garden Route where the river systems have very few gauging weirs. Rainfall and steamflow data limitations hampered the identification and verification of extreme events in this study. In general, this speaks to a data gap which is either costly to overcome or indicate that the data is simply not available for the area of interest.

If we examine the number of useful rainfall and flow gauges open, there is a serious cause for concern. Pitman (2011) showed a decline in numbers from a high around 1970 to only about half of that in 2004 (i.e., since 1990 there has been a steady decline), which is roughly the same number of stations as in 1920. Rainfall is the most important and shows the biggest decline in terms of rainfall stations which have closed down. This is a major problem If this trend continues as rainfall is the primary input to any rainfall runoff model. At present there are over 2000 flow-gauging stations in South Africa. However, many are in a state of disrepair, preventing vital flow data from being collected (Job et al., 2019). This deterioration of data makes it harder for hydrologists and water resources practitioners to enter data of the necessary quality into water resource models. It is imperative that this decline be addressed, especially if we are to deal effectively with problems related to natural hazards and climate change adaptation. We also cannot monitor each catchment through in situ measurements, therefore complementary modelling supported by reliable data would be critical.

Funding for monitoring

While South Africa has some robust biodiversity and advanced monitoring programmes, many are dependent on state funding and capacity to execute. Existing monitoring programmes (e.g., National Aquatic Ecosystem Health Monitoring Programme (NAEHMP), which is focussed on rivers) need to be refocused and capacitated. These efforts should be linked with international efforts and should take advantage of new methods and innovative technologies. As critical as ensuring the continuation of the current suite of monitoring programmes, is the need to analyse and incorporate this information into focussed management and implementation plans, which can interpret, respond and adapt to the latest monitoring results as they become available. Monitoring is essential for detecting change and to address uncertainties, particularly with the increased impacts resulting from climate change and the effectiveness of measures taken to minimise the impacts.

Importantly, we need to maintain, enhance and expand time-series monitoring efforts and improve our understanding of change to enable effective adaptation measures. Given the numerous interventions in place and the complexities of implementation, gauging success, failure or impact of any particular intervention requires a broad evaluation protocol.

The protocol should contain a suite of indicators that measure the effectiveness of the interventions against both hazard and socio-economic (e.g. cost efficiencies) objectives. In addition, restoration interventions on rivers for example, that are implemented to manage and conserve these ecosystems, are often not monitored, which makes adaptive management of the activities near impossible. This includes Environmental flows from many public dams. Cooperative governance, research and citizen science are key elements of successful hazard monitoring.

Future change: Natural hazards are increasing
According to regional climate change scenarios, climate change is unlikely to affect South Africa in a uniform manner. 'Hotspots' of concern have been identified in the south-west of the country, the west coast, and, to a lesser extent, the far north of the sub-continent (Dallas and Rivers-Moore, 2014). Warming is expected to be greatest in summer, followed by autumn, winter and then spring (Kruger and Nxumalo 2017). Regionally, the inter-annual variability of rainfall is projected to increase with more irregular events in the southwest. Seasonal rainfall is changing with regards to onset, duration, intensity, dry spell frequencies (Niang et al., 2014). The prediction for South Africa is an increase in between 2°C and 4°C by 2050, and at worse, up to 8.5°C in the interior. Intensification of droughts due to reduction in rainfall and/or increased evapotranspiration are made with medium confidence (Davis-Reddy and Vincent 2017). Shifts in rainfall, air temperature and evaporation will have a direct impact on water availability, both surface and groundwater. The main impacts include changes in runoff patterns such as mean runoff volumes, flow variability, duration and timing and changes in groundwater recharge rates (Dallas and Rivers-Moore, 2014).

In South Africa, these shifts will be exacerbated by the fact that the region has a low conversion rate of rainfall to runoff (9% on average) and groundwater recharge of 55% on average (DEA, 2013), and very high inter-annual climate variability (Stuart-Hill et al., 2012). There has been a general trend of increased frequency of extreme rainfall events (20 mm of rain falling within 24 hours) in the latter half of the 20th and early 21st centuries, but these show no clear spatial coherency (De Waal et al., 2017). Likewise, there is likely to be an increased frequency and intensity of extreme weather events, including very hot days (i.e., > 35°C) (Davis-Reddy and Vincent 2017) and heat waves (Engelbrecht et al., 2015), and other events such as rainstorms (i.e. low confidence and storm surges. Climate-induced shifts in the water cycle will also result in more frequent and intense periods of flooding and drought. Nel et al. (2014) showed that climate change in the Garden Route will increase the frequency of all natural hazard events examined, substantially so in the case of floods, droughts and storm-waves and to a lesser extent for wildfires.

Opportunities in the Garden Route

Natural hazards can be reduced by appropriate land management
Nel et al. (2014) indicated that through appropriate and pro-active land use management, it would be possible to reduce the impacts of natural hazards to a large degree. Clear-felling of timber plantations should ideally be associated with rehabilitation and re-vegetation to avoid increasing the flood hazard. Because the timber plantations (mostly Pinus sp) are similar to dense stands of invasive alien trees, the flood model also supports the clearing of invasive alien trees to reduce the hazard posed by flood events soon after a wildfire. The impacts of climate change can be substantially reduced by clearing invasive alien trees and restoring the indigenous vegetation which is also an effective tool for reducing wildfire and drought hazards. Invasive alien plants (IAPs) are a key threat to rivers and their riparian areas as they alter hydrology as well as nutrient accumulation and cycling. Riparian invasions are also less stable during floods and the debris that is washed down can block infrastructure (O'Farrell et al., 2015). The costs to clear existing invasive alien trees in the Garden Route are much smaller than the estimated losses caused by damaging wildfires to, for example, timber plantations (Nel et al., 2014). We must offer mechanisms and incentives for appropriate land management in these areas providing a stimulus for the implementation of effective integrated catchment management. More importantly, conceptualize and engage with catchments as social-ecological systems.

Similarly, the management of hydrological connectivity is a crucial component of land management activities, notably through the use of buffer zones to protect river systems but also through the flood pulse concept (Junk et al., 1989) which recognises the biophysical benefits that can accrue from maintaining connectivity between the river and its floodplain (i.e. the lateral exchange of water, nutrients and organisms between the main river channel and the connected floodplain). The uncontrolled spread of alien invasive plants in riparian buffer zones poses a significant risk to water-based ecosystem services (i.e. plants reduce overall water yield due to increased evapotranspiration). Lane et al. (2003) using the SCIMAP model investigated the role of upland shallow surface drains, along with observed changes in rainfall patterns, in relation to flood generation and linkage between river and floodplain in relation to flood risk. Localised sources of overbank flow which diffuse across the floodplain were identified. There is a clear spatial variation in inundation depth that is strongly related to extant land use. The model provided a more cost-effective flood defence design through the spatially explicit treatment of the inundation process. Therefore, tools like SCIMAP are required if we are to develop truly integrated approaches to collaborative catchment management that escape the problems of current sectoral concerns. A sectoral approach involves exploring all dimensions of a problem such as flooding in relation to possible causes like land cover and climate change (Lane et al., 2003).

Ecosystem-based adaptation
The incorporation of ecosystem-based management approaches, in tandem with other approaches (e.g., mitigation or engineering responses), into disaster risk reduction and climate change adaptation is crucial, there is a need to build an evidence-base. Disaster Risk Reduction (DRR) is a systematic approach to identifying, assessing and reducing risk. The Garden Route has a relatively well-capacitated Disaster Risk Reduction unit compared to other districts in South Africa. However,

much like in many parts of the world, efforts are still very much focussed on recovery from disaster (e.g. through providing disaster relief funding), or short-term disaster preparedness (e.g. through early warning systems, or ensuring adequate supply of fire engines). Longer term efforts to reduce risk are still lacking (Nel et al., 2014). Disaster risk education is also important. It is essential to integrate DRR into development and education programmes.

The adverse impacts of flooding can be reduced through enhancing and conserving natural ecosystem flood regulation capacity, land use adaptation, and flood resilience strategies (Barbedo et al., 2014). Intact landscapes can capture and store water from rainstorms and slowly release it in a process known as flood regulation, of which the benefits are enhanced safety to human life and human constructions (Millennium Ecosystem Assessment (MA), 2003). Natural ecosystem features and processes can, depending on rainfall intensity, moderate flood impacts or, in some cases, even prevent flooding (Brocca et al., 2008). The capacity of a landscape to store water is dependent on the underlying geological and climatic characteristics, its land use and how those uses are managed (Puigdefábregas, 2005). Strengthening capacity for meaningful active adaptive management needs to be addressed to make progress in this arena and to insure a sustainable future.

Opportunities for disaster management are also related to investments funds (water-food funds). A water fund for example invests in water security (e.g. Greater Cape Town Water Fund). Other funding opportunities include biodiversity stewardships facilitated by, for example, WWF or CapeNature. The latter is an approach to entering into agreements with private and communal landowners to protect and manage land in biodiversity priority areas.

Active citizenship

A new trend globally, as well as in South Africa, is to involve citizen scientists, to complement the state-funded monitoring programmes, however, it is critical that gaps in monitoring sites and variables at key sites are filled. Active citizenship refers to people getting involved in their communities and democracy at all levels from local to national and global. The SAWS for example, to a large extent, relies on ordinary citizens to read their rainfall gauges each morning and send the data to SAWS for processing. After the devastating Bitou and Knysna veldfires in 2017 the Garden Route Rebuild Initiative (GRRI) was established to fast track the rebuild of both these towns with a special focus on doing the rebuild in a "climate smart" way and "building back better" (EDM, 2018). Public-private partnerships between the private and public sectors such as the Garden Route Initiative (GRI) and other forums (e.g., Wilderness Lakes Catchment Management Forum (WLCMF) and Touw River Conservancy) are key. We need to form strong governance alliances between scientists, civil society, land users and decision makers (O'Farrell et al., 2015).

Conclusions

Increases in extreme weather events are expected to lead to increases in the occurrence of floods and fires threatening communities and infrastructure in the Garden Route. People will be more exposed and therefore vulnerable. Social vulnerability and exposure are key determinants of disaster risk and help explain why non-extreme physical events and chronic hazards can also lead to extreme impacts and disasters, while some extreme events do not. Interactions between vulnerability factors in a community are key to understanding risk reduction. The future of disaster risk includes building more resilient and safer cities nested in more resilient landscapes in a changing world. Improving society's capacity to protect itself from disasters includes adapting to changing climates. Reducing disaster risk has to be a critical component of those adaptation strategies. Through pro-active management of key drivers of land cover change, the people in the Garden Route will be able to reduce the impacts of natural hazards such as floods and wildfires. In considering the trade-offs of such ecosystem-based approaches with alternative forms of disaster risk reduction, the multiple co-benefits of land management and restoration need to be considered.

- For the full list of references, contact the Editor.

Acknowledgements

Our study emanates from an internal five-year CSIR project entitled, "Risk to business from biodiversity loss and ecosystem service failures: Developing an Environmental Risk and Opportunities Analysis (EROA) decision support tool" which started in 2020. The aim is to enhance strategic planning, decision-making and reporting capabilities in both the private and public sectors, related to natural hazards. The project developed a draft toolkit through a process of knowledge co-production that provides improved environmental intelligence to support businesses to help manage disaster risk. The decision support tool is based on our understanding of natural capital, the ecosystem services it provides and the links between these services and socio-economic development in South Africa.