Assessment and prediction of flood hazards using standardized precipitation index—A case study of eThekwini metropolitan area

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Abstract
Flood is known to be the leading cause of natural disasters globally leaving disastrous and devastating damages in its wake. Flood risk and their time of occurrence is usually difficult to monitor and predict without appropriate tools for continuous monitoring. Extreme and frequent rainfall is one of the major causes of flood disasters. Assessment of flood hazards and its subsequent analysis using the standardized precipitation index (SPI) is very effective in the prediction of flood risk with the strength of the SPI being the use of rainfall as the only input variable. The SPI is found to be valuable in prediction of meteorological and hydrological floods such as flash floods, groundwater floods and dam burst. The knowledge of the occurrence of these flooding events can be very beneficial in preventing extensive damages to property, infrastructure, agriculture, and loss of life. The aim of this study is to assess flood hazard in eThekwini metropolitan area by examining the trend of flood events from 1985 to 2016 by the use of the SPI and its potential to predict flood risk in the study area. The results show that SPI properly explains the development of the conditions leading up to the occurrence of floods events in the analyzed period. Thus, is indispensable in the assessment of flood risk leading to an accurate prediction. The knowledge of the pattern and trends obtained from the SPI analysis is valuable to decision-makers for efficient flood risk management plans in the promotion of preventive actions for mitigating the impacts of floods.

KEYWORDS
eThekwini metropolitan area, flood, flood risk management, hazard assessment, rainfall, standardized precipitation index

1 | INTRODUCTION
Floods is the leading cause of damages among all the natural disasters bringing annual loses from floods to billions of US dollars and fatalities to thousands of people every year (Hirabayashi et al., 2013). The major factors that cause floods include extreme rainfall and anthropogenic activities such as rapid urbanization and...
deforestation (Kasiviswanathan et al., 2017). Major flood disasters have occurred in urban areas around the world due to heavy rains which are projected to be more frequent with increasing intensity as a result of the impact of climate change (Fatti & Patel, 2013). According to Fatti and Patel (2013), these affected areas are expected to experience more flooding in the future. Southern Africa is likely to show a pattern of increment in extreme rainfall especially in convective precipitation areas (Engelbrecht et al., 2012). Extreme rainfall in the study area causes river, urban, flash, and coastal floods (Davis, 2016). Flash floods are very destructive with devastating and fatal impacts.

Flooding in eThekwini metropolitan area popularly known as Durban, occurs on a yearly basis causing extensive damages to infrastructure, houses, displacements of thousands of people and fatalities. Floods are exacerbated as a result of overpopulation that has led to expanded density of settlements, poor waste management, blocked drains, occupation of flood prone areas and so on causing devastating effects on the people and environment. In July 2016, extreme rainfall caused flash floods, inland flood, and storm surge in Durban with flood damage running into millions of Rands leaving seven dead and thousands displaced (Davis, 2016). Flooding in Durban has continued to be more severe with every year. The flood that hit Durban the Easter weekend of April 2019 was even more severe than the previous year causing damage to approximately 235 homes, washed roads and bridges disrupting traffic making it difficult to get prompt help to victims and at least 5155 cases recorded (News24, 2019). Informal settlements in Durban were the worst hit areas. About 200 homes in Quarry Road were washed away and at least 500 people displaced in Umlazi one of the largest informal settlements in Durban (De-Greef, 2019).

The migration of people from rural to urban areas in search of improved livelihoods, leads to urban expansions and consolidation and construction of houses on flood plains. This changes in demographics within flood plains increases the exposure of the community to flood risk. Other factors include the influence of climate change causing extreme rainfalls, sea level rises and changes in flood behavior as a result of development. The absence of effective flood risk management will increase the level of flood disaster impact on the people, property, and economics in the study area in particular and country at large. Flood risk assessment is very crucial and valuable in cities and communities in order to provide appropriate and efficient flood risk management plans and informed suggestions in flood risks to policy makers for the development of integrated flood risk management.

Flood risk assessment comprises the assessment of hazards, vulnerability, and exposure to estimate the expected consequences of a flood of a certain probability (Norén et al., 2016). Flood risk assessment in urban areas is more complex than in rural areas due to extensive development (Li et al., 2016). Prediction of flood hazards is very important in assessing flood risk. Factors such as type of flood, flood occurrence, flood intensity and other flood parameters are very important to assess the level of risk on the affected people and properties, provide early warnings and design frameworks for potential flood disaster risk reduction and management (Komolafe et al., 2015).

There are different approaches used in flood risk assessment. Most dominant of them is the assessment of hazard, vulnerability and exposure with their results presented on maps (Norén et al., 2016). Other methods outlined by Li et al. (2016) include mathematical statistical methods, dynamic risk evaluation method based on integrated models and index systems method. Lyu et al. (2018) highlights three approaches to evaluate regional floods which include multi-index evaluation systems, historical data-based probability assessment and scenario-based simulation analysis. This study utilizes the historical data-based probability assessment for the assessment and prediction of the flood hazard. The value of historical data in flood risk analysis is longer-term trends and patterns may be explored and reviewed in greater depth.

This study is based on the assessment of flood hazard by examining the trend of flood events in the eThekwini metropolitan municipality during the past 32 years (i.e., for the period of 1985–2016) by the application of the standardized precipitation index (SPI) and the analysis of its potential to predict high flood risk situation in subsequent years. Continuous monitoring of the hydrological conditions in the study area will allow for detection of potential threat of future flood events. The SPI developed for the detection of and monitoring of drought can be used to monitor very wet conditions that lead to flooding due to characteristics of the SPI (Fauzi et al., 2017). Fauzi et al. (2017) used this approach to analyze monthly precipitation data in Terrengganu Malaysia that suffered from three flood events in 2014 during the monsoon season to monitor the extreme wet condition that will eventually lead to flood. The study of Fauzi et al. revealed that short-term wet conditions had enormous fluctuations throughout the period of study. However, long-term were noticeably perceived as to detecting flood periods, which can be applied in water resource management. Applying the same approach in eThekwini metropolitan municipality by monitoring the very wet and extreme wet conditions that led to flood events over the period under study, understanding the pattern and trends and applying the knowledge to prediction of
future flood disasters in the study area can be very useful for developing strategies for mitigation and flood risk management. The results can be validated by the report of the World Meteorological Organization in 2012 on the effectiveness of using the SPI to study historic flood trend and applying the knowledge in decision-making. This study aims to examine flood risk in the selected flood prone area by assessing flood hazards using different time scales of the SPI in predicting flood hazards and strengthening flood risk management in the study area.

2 | LITERATURE REVIEW

Through the decades, floods are visualized as external event affecting societies. This has led to technical solutions being used for flood control. However, with more enlightenment, flood hazards are better understood as a consequence of interaction between the natural phenomenon and the affected society (Norén et al., 2016). There has been a gradual shift from flood control to flood risk management. This is due to the realization that the flood phenomenon should be considered alongside its impact on community and the society (Samuels et al., 2010).

Rafiq et al. (2016) stated that flood risk increases three folds as a result of urbanization thus leading to vulnerability in densely populated areas. Predo (2010) elucidates that climate related disasters as well as climate change induced by humans have been a precursor of massive destructions. Climate change projections indicate a significant increase in the intensity and frequency of floods (Williams et al., 2019). Floods have been known to weaken urban resilience. Doocy et al. (2013) also agree that urbanization as well as land-use changes have increased the vulnerability of people to floods.

Newton and Weichselgartner (2014) considered that Coastal cities are susceptible to river flooding and storm surge leading to an increase in vulnerability. This increase is also due to dense concentration of valuable physical assets, installations of energy, industries, and infrastructures. Durban being a coastal and densely populated area is very prone to these floods. South Africa has 83.3% annual risk to floods due to its geographical locations (Zuma et al., 2012).

To understand how stakeholders respond to disaster risks, it is important to have a combined knowledge of the hazard people experience and their perceptions (Harvatt et al., 2011). Irrespective of the community structure, resilience to disasters can be built through effective decision-making rooted in knowledge via experience and perceptions (Fatti & Patel, 2013). This is authenticated by findings of Yamamura (2010). The efforts of government in Southern African countries to cope with the impact of flooding on communities is often limited and affected by people’s perception of floods which influences response (Musyoki et al., 2016).

All over the world, communities have been facing an increase in the frequency of disasters leading to direct and indirect risks (Haigh & Amaratunga, 2010). It has become very important to reduce the risk from disasters and develop a resilient community. It is important for disaster management practitioners to learn from lessons in order to adapt good practices. This is the case with cyclone Idai that caused floods over Mozambique, Zimbabwe and Malawi resulting in hundreds of death and the KwaZulu-Natal (KZN) flood events soon afterwards causing death and destruction (Bopape et al., 2021). Research conducted by Bopape et al. (2021) showed warnings of the events were given 2 and 1 day respectively and that there were shortcomings in locating the KZN floods indicating that the impacts experienced during the two events could have been minimized if long notices of the event were received. With the gap noticed, this study uses the SPI at different time scales to predict flood hazards. Early prediction of flood hazards is valuable in strengthening flood risk management.

3 | STUDY AREA

eThekwini metropolitan area is home to the Zulu tribe. The bay of Durban which is the largest and busiest harbor in South Africa, gives Durban its Zulu name “eThekwini” (Koopman, 2007). Durban is located in the east coast of South Africa in the KwaZulu-Natal province (Figure 1a). It has a geographical area of approximately 2291 km$^2$ extending from uTongati river in the north through to aMahlongwa river in the south with a diverse topography which is characterized by steep hills, winding river valleys and various gorges and ravines with an average altitude of 50.00 m/177.17 ft (ETH, 2018; NASA, 2021; Turpie et al., 2016) (Figure 1b). eThekwini metropolitan municipality is the third largest city in South Africa with a population of 3.4 million after Cape Town with 3.7 million and Johannesburg with 4.4 million people (Sawe, 2019). eThekwini is home to large cities and is very popular because of its large and busy Durban port. Durban port popularly called Durban harbor is the busiest shipping terminal in sub-Saharan Africa and the largest container terminal in the southern hemisphere (Economist, 2016). eThekwini accounts for 11% of the National GDP and 66% of provincial PDP (Turpie et al., 2016).

South Africa has a weather condition that ranges from subtropical in the Northeast to Mediterranean in the Southwest and temperate in the interior plateau.
South Africa exhibits varying temperature and rainfall patterns. According to the South African Water Research Commission (WRC), rainfall occurs in November to March in some parts of the country, while in the Southwest, rainfall occurs June to August, which is the winter season (SAonline, 2021). Record from South African
Weather from 1999 to 2021 show that there is a considerable variation of rainfall from the west to the east. While in the north, annual rainfall remains at 200 mm, the eastern high veld records 500–900 mm and occasionally, rainfall exceeds 2000 mm. The center of the country receives rainfall of about 400 mm annually (SA-V, 2021).

Durban has a subtropical climate comprising of humid wet and long summers, mildly dry winters with temperature ranging from 16 to 25°C in winter and 23 to 33°C in summer and an annual precipitation of over 1000 mm as a result of the significant amount of rainfall throughout the year (Turpie et al., 2016). June is the driest month with an average precipitation of 11 mm while November has the highest average precipitation of 87 mm. Monthly weather forecast in Durban showed that Durban experienced 320 days of sunshine in 2020, making summer months (December to March) to be very humid and hot with warm and sunny winters. February recorded the warmest month with an average temperature of 24.5°C while July has the lowest average temperature of 16.8°C (Weather-Atlas, 2020).

Durban, located on the coast of the Indian Ocean and the presence of several water bodies, make the metropolitan area very prone to heavy rainfalls and flooding events. The extreme weather conditions experienced in Durban as stated in Weather-Atlas (2020), also contributes to the numerous flooding events experienced in the study area. Hence, there is a need to strengthened flood risk management as the occurrence of the flood hazards is inevitable.

4 DATA AND METHOD

This study focuses on extreme and frequent rainfall in the study area as a cause of floods (Davis, 2017; Fatti & Patel, 2013). Monthly precipitation data sets obtained from metrological data sources archived and made available through satellite from NASA online database is used to study the trend of flood hazards in the study area from 1985 to 2016. This methodology utilizes the application of the SPI. The SPI computation involves fitting the gamma probability density function to a given frequency distribution of precipitation totals for the coordinates. The parameter of the gamma distribution is estimated for eThekwini metropolitan municipality having coordinates of latitude – 29.8120°S and longitude 30.8039°E for the time scale of 3 and 6 months as well as for every month of the year. The cumulative probability of the distribution and each value of precipitation is thereafter transformed to the standard normal random variable having mean and variance of zero and one respectively given the SPI value. Because of the normal distribution of the index, SPI can be used to estimate wet as well as dry periods. Guerreiro et al. (2008) expound that SPI value of zero signifies an absence of deviation from the mean value of rainfall at the chosen timescale for the period analyzed, positive SPI values signify precipitation exceeding the mean value and precipitation below the mean value indicates a negative SPI value. Thus, a wet period is said to be a period during which the SPI stays positive up to a value of +1 or higher for a specified time frame (Table 1).

The SPI technique as purported by Guerreiro et al. (2008) in the study utilizes the Drought indices calculator (DrinC) software for analysis. The analysis of the flood hazard is used to understand the trend of flood hazard in the study area from 1985 to 2016.

The SPI is a very flexible index requiring precipitation variable as the only input used in analyzing wet as well as dry cycles or periods (WMO, 2012). SPI is very useful in the understanding that deficit of precipitation affects soil moisture, groundwater, stream flow, snow pack and reservoir storage. This also is true that excess of precipitation will also have a reverse effect. One of the strengths of the SPI is that it can run with a few missing data without hindering the confidence of the results. This is a very valuable property of SPI especially in developing countries where data is not always comprehensive (WMO, 2012).

The functioning of the SPI is based on the probability of precipitation for different time scales ranging from 1, 3, 6, 9, 12, 24, 48, and 72 months. The use of different SPI time scales allows for the assessment of the impact of precipitation on different components of water resources such as soil moisture, groundwater, stream flow and water storage (Morid et al., 2006). Short-term scales, that is, 1 month standardized precipitation index (SPI-1) is very responsive to soil moisture conditions, whereas a longer time scale (SPI-6) is responsive to precipitation conditions of groundwater, stream flow and water reservoir (WMO, 2012). British geological survey (BGS) explains groundwater flooding as the flooding that occurs

| SPI values      | Classification   |
|-----------------|------------------|
| ≥2              | Extremely wet    |
| 1.5 to 1.99     | Very wet         |
| 1.0 to 1.49     | Moderately wet   |
| −0.99 to 0.99   | Near normal      |
| −1.0 to −1.49   | Moderately dry   |
| −1.5 to −1.99   | Severely dry     |
| ≤−2             | Extremely dry    |
after the ground has become saturated from prolonged heavy rainfall (BGS, 2021). According to Samuels (2013), meteorological flooding (e.g., flash floods) are floods that are usually dramatic and occur following intense and extreme torrential rainfall when the intensity of the rainfall usually exceeds the capacity of the catchment to cope with the amount of water.

5 | RESULTS AND DISCUSSION

Extreme wet and very wet conditions that could cause flooding are examined. The SPI values for time scale of 1 month (SPI-1), 3 months (SPI-3), and 6 months (SPI-6) are represented in Figures 2, 3, and 4, respectively and Table 2. By using the 6, 3, and 1 month SPI, the flood trend becomes clearer and validate recorded flood events in the study area from 1985 to 2016 (Table 3). SPI-1 identifies more wet periods within the time span studied. SPI-1 is more revealing than SPI-3 and SPI-6 in the frequency of precipitation. Thus, for larger time frames, there is a slower response of the SPI. It is evident in the figures that there is always a peak after a well-defined period of wetness. This indicates that humidity of the soil plays a big role in eThekwini metropolitan municipality. The shortest-term scale SPI-1 shows the presence of moisture in the short and medium terms. The longest term scale SPI-6 reveal the evidence of long-term precipitation before the occurrence of a flood (Fauzi et al., 2017; Guerreiro et al., 2008).

SPI-1 analysis is very expressive of the extreme historic flood events and heavy rains leading to extreme and severe floods (Table 3) that occurred in September 1987 (SPI 3.36), March 1988 (SPI 2.47), November 1989 (SPI 2.23), December 1995 (SPI 2.23), December 1999 (SPI 2.56), and September 2012 (SPI 2.48) (Table 2). It is also evident that continuous high SPI-1 levels would trigger extreme flood event in the subsequent month having a lower SPI-1. An example is illustrated in the December 21 and 23 flood event that occurred in 1991 (Table 3) with a very low SPI-1 (−0.39) after high SPI-1 values in October (1.57) and November (0.23) (Figure 2). Thus, SPI-1 is very beneficial in providing early warning of flood and assessment of the severity of the flood. It is also very valuable in agriculture as this is highly dependent on soil moisture. In steep rocky and heavily urbanized regions such as Durban, a relatively small amount of rainfall can trigger flash floods, so a clear understanding of the flood pattern using the SPI-1 will be extremely useful in preventing damages and fatalities that is associated with floods with very short lag time such as flash floods.

With the SPI-3, there are six extremely wet and very wet peaks 1987, 1988, 1996, 2008, 2012 and 2016 and 12 moderately wet peaks. It can also be seen that several moderately wet peaks occurring simultaneously results in a very wet or extremely wet peak (Table 2, Figure 3). This indicates the saturation of the soil. This process produces higher storm flow peaks rapidly than drier soil for the same amount of rainfall on a drier catchment. Also rainfall with lower intensity on saturated soil can produce more run-off and higher peak flows (Pharoah et al., 2016). This also confirms the historic floods recorded in these years as shown on Table 3. The SPI-3 show high SPI values for July 1987 (2.59) and August (2.33) leading to the September (1.55) flood event (Figure 3). The same can also be identified in the SPI-6 values of 1987 for April (2.04), May (2.02), June (1.53), July (1.54), and August (1.35) which are higher than the SPI-6 value for September (1.28) 1987 (Figure 4) when the extreme flood occurred. The September 1987 flood disaster in KwaZulu-Natal was described as the worst natural disaster ever to have occurred in South Africa, causing approximately 332 deaths and recording a precipitation of about 900 mm in 4 days (Badenhorst et al., 1989; Scharf, 2012). SPI-1 value for September 1987 of 3.36 validates the reports of the floods and remains the highest SPI value through the years of analysis (Table 2).

Using the SPI-6, there are two well defined cycles of extremely wet (>2) and very wet peaks (1.5–1.99) in 1987...
and 1988 with major floods associated in 1987 and 1988 (Table 2) as also seen with the SPI-1 and SPI-3.

Major wet and dry periods can be clearly identified in the SPI-6 analysis (Figure 4). It can be seen that there is always a long wet period leading to a peak after an extremely dry period as seen in 1985 (SPI -0.635) and then begins to have wet periods that peaks in 1987 (2.01) and another prominent dry period in 2010 (SPI -1.117).
| Year | Month       | Date      | Geographical area          | Type                      | Source                               |
|------|-------------|-----------|----------------------------|---------------------------|--------------------------------------|
| 1985 | February    | 7, 10     | KZN                        | Extreme flood             | van Bladeren (1992), SAWS (1991)    |
| 1985 | October     | 29        | KZN, South Coast           | Flood                     | van Bladeren (1992)                 |
| 1986 | August      | 28        | South Coast                | Flood                     | Botes (2014)                         |
| 1987 | September   | 27, 28    | KZN                        | Extreme flood             | van Bladeren (1992), SAWS (1991)    |
| 1988 | February    | 8         | KZN                        | Flood                     | SAWS (1991)                          |
| 1988 | March       | 1, 2, 8, 9| KZN                        | Heavy rains/Flooding      | SAWS (1991)                          |
| 1988 | May         | 5         | Durban                     | Heavy Rains/Flooding      | SAWS (1991)                          |
| 1988 | December    | 8         | Durban                     | Flood                     | SAWS (1991)                          |
| 1989 | March       | 14        | South Coast                | Heavy Rains/Flooding      | SAWS (1991)                          |
| 1989 | April       | 14, 15    | KZN South Coast            | Flood                     | SAWS (1991)                          |
| 1989 | November    | 28, 30    | KZN                        | Extreme Flood             | Van Bladeren (1992), SAWS (1991)    |
| 1990 | March       | 24, 25    | KZN                        | Heavy Rains/Flooding      | SAWS (1991)                          |
| 1991 | October     | 26–28     | Durban                     | Heavy rain/Flood          | Brakenridge (2016)                   |
| 1991 | November    | 14        | South Coast                | Flood                     | Botes (2014)                         |
| 1991 | December    | 21–23     | Durban                     | Heavy rain/Flood          | Brakenridge (2016)                   |
| 1993 | October     | 4         | North Coast                | Flood                     | Botes (2014)                         |
| 1993 | December    | 2, 27     | South Coast, North Coast   | Flood                     | Botes (2014)                         |
| 1994 | January     | 10        | Durban                     | Flood                     | Botes (2014)                         |
| 1994 | March       | 9         | Durban                     | Heavy Rains/Flooding      | Botes (2014)                         |
| 1994 | October     | 25        | KZN Coast, Durban Area     | Heavy Rains/Flooding      | Botes (2014)                         |
| 1995 | February    | 12        | Tongaat                   | Flood                     | Botes (2014)                         |
| 1995 | March       | 22, 23    | Durban                     | Heavy Rains/Flooding      | Botes (2014)                         |
| 1995 | December    | 16, 22    | Durban                     | Flood                     | Botes (2014)                         |
| 1997 | March       | 4         | KZN                        | Flood                     | Botes (2014)                         |
| 1997 | July        | 1         | Durban                     | Flood                     | Botes (2014)                         |
| 1999 | February    | 4–7       | KZN                        | Heavy rains/Flood         | Brakenridge (2016)                   |
| 1999 | October     | 26        | KZN                        | Flood                     | Campbell (1999)                      |
| 1999 | December    | 22        | Durban                     | Heavy Rains/Flooding      | Campbell (1999)                      |
| 2000 | February    | 14, 24    | Durban, Tongaat            | Flood                     | Botes (2014)                         |
| 2000 | May         | 23        | Tongaat                   | Flood                     | Botes (2014)                         |
| 2003 | November    | 26        | Durban                     | Flood                     | IOL (2003)                           |
| 2005 | March       | 8         | Verulam, Tongaat           | Heavy rains/flooding      | Chetty and Singh (2005)              |
| 2006 | November    | 13        | KZN                        | Flood                     | Savides et al. (2006)                |
| 2006 | December    | 11, 12    | KZN                        | Flood                     | Savides et al. (2006)                |
| 2007 | March       | 18        | North Coast, South Coast   | Coastal flood             | Nott (2006)                          |
| 2008 | June        | 17, 18    | Durban                     | Flood                     | Savides et al. (2008)                |
| 2010 | February    | 16        | KZN                        | Flood                     | Mbuyazi and Umar (2010)              |
| 2011 | January     | 7         | KZN                        | Flood                     | SAnews (2011)                        |
| 2011 | November    | 28        | Durban South               | Heavy rainfall/flood      | SAPA (2011)                          |
| 2012 | March       | 12        | Durban                     | Flood                     | Sapa (2012)                          |
| 2012 | September   | 6, 7      | Durban                     | Heavy rains/flooding      | SAWDOS (2012)                        |
| 2012 | December    | 11        | Durban                     | Flood                     | (Madlala, 2020)                      |
| 2016 | March       | 16        | Durban Central             | Heavy rains/flood         | Wicks (2016)                         |
| 2016 | May         | 8, 9      | Durban                     | Flood                     | eNCA (2016)                          |
| 2016 | July        | 28        | Durban                     | Flood                     | Davis (2016)                         |

Abbreviations: KZN, KwaZulu-Natal Province; SAWDOS, SA Weather and Disaster Observatory Service; SAWS, South Africa Weather Service.
that peaks in 2012 (SPI 1.5). In 1987 and 2012 occurred historic flood events that are recorded as devastating. These wet and dry periods are even more evident when analyzing SPI-3 as the randomness of precipitation is more revealing and identifies more possible causes of major flood events. Also seen with the SPI-6 (Figure 4) there is a long period of wetness 1995–2009. This period provides good general perspective of the abundance of water resources across the study area. This provides an insight of the possible cause of increased run-off during the major flood event of 2012. Owing to the long-time scale of monitoring rising waters, analysis of floods using the SPI-6 provides more information needed to take proper actions (Lyu et al., 2018) and thus facilitate a lower risk of fatalities. Storage water facilities such as levees and dams can be monitored and failures avoided.

The analysis of the SPI 1, 2 and 6 in Figures 2, 3, and 4, respectively and Figure 5 showing the extremely wet and very wet SPI’s above, validates the historic flood events in eThekwini metropolitan municipality for the period under study (Table 3).

Based on the analysis of the flood in the study area from 1985 to 2016, it is determined using the SPI 1, 3 and 6-time scales (Figures 2, 3, and 4, respectively) that mild, moderate, severe and extreme floods occurred several times in the period under review (32 years) as shown in Figure 5. The figure also shows the intensity of flood events in 100 years.

The historic flood events recorded in Table 3 though not exhaustive shows 27 moderate, 15 severe and three extreme flood disasters shown on the table as flood, heavy rainfall/flooding and extreme flood respectively. The SPI-1 closely depicts the moderate and severe flood events with 28 and 17 respectively and shows 11 extreme events and 109 normal flood events in 32 years (Figure 5). This shows how sensitive the SPI-1 is to soil saturation and surface flooding. The SPI-3 and SPI-6 shows extreme flood events to be two times (Figure 5) against three times of the historic flood events February 1985, September 1987, and November 1989 (Table 3) for the period of study. This shows that using multiple SPI time scales gives a revealing analysis of each flood event and a holistic monitoring leading to a proper prediction.
A 1 in 100 years probability of a flood event occurring is also shown in Figure 7 using the SPI-1, SPI-3 and SPI-6. The probability of exceedance is calculated as the inverse of the return period \( T \) (Volpi et al., 2015).

\[
\text{Probability of exceedance} = \frac{1}{T},
\]

\[
T = \frac{n}{f},
\]

where \( n \) = number of years (100 years); \( f \) = frequency of flood event (32 years data for SPI extrapolated to 100 years).

Return period \( T \) or recurrence interval is used to describe the severity and likelihood of floods (Figure 6). Return period is defined as the expected time interval at which the event of a given magnitude is exceeded for the first time (Volpi et al., 2015). Thus, a 1 in 100 years return period of a flood event occurring means that it has an annual exceeding probability of 1% or 0.01.

It can be seen from Figure 6 that the SPI-1 predicts the severity of the flood events in the short-term, highlighting more on the saturation of the soil and its effectiveness in predicting meteorological floods such as flash floods to enable early warning. The SPI-6 is not sensitive to short-term severity of floods so is not useful in predicting meteorological floods, but is very good in predicting hydrological floods such as groundwater, stream flow and water reservoirs that requires long-term monitoring of rising waters. This enables long planning time for mitigation. SPI-3 is intermediate between the SPI-1 and SPI-6 depending on the characteristics and hydrological factors of the flood such as vegetation cover, soil type, human habitation and antecedent rainfall. In summary, the shorter the SPI, the shorter time it will take to detect the severity of flood events.

Figure 7 shows that the probability of a 1 in 100 years flood decreases linearly as the severity of flood event decreases. This is more prominent with the SPI-1. This makes the SPI-1 more valuable in detecting short-term flood events.

6 | CONCLUSION

The results of SPI analysis indicate the great potential of the SPI to be used in the assessment of flood hazard and its prediction. The incorporation of SPI in an integrated flood risk management framework will be beneficial as part of a comprehensive flood risk management approach. The use of different time scales (1, 3, and 6 months) improves the analysis capacity of the SPI allowing for estimation of different antecedent soil conditions thus, building up to a satisfactory explanation of the development of the circumstances leading up to a flood occurrence. The results of the SPI and its matching historic flood event in eThekwini metropolitan municipality (Durban, KZN) illustrates the practicality of the SPI analysis to decision-makers in making appropriate and definite flood preparedness plans targeted at reducing the loses caused by flood hazards.

In essence, the novelty of this study traverses across different disciplines and community of practices such as engineering, meteorological services, and environmental agencies, just to mention a few. In particular, the generation of valuable scientific information through the application of multiple SPI time scales for implementation by disaster practitioners and functionaries, public officials, managers, and policy makers should be encouraged. The focus and outcomes of the study addresses the local and international dialog on effective flood risk analysis hence, it may be easily adapted and applied within the context of Africa and the world over.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.
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How to cite this article: Olanrewaju, C. C., & Reddy, M. (2022). Assessment and prediction of flood hazards using standardized precipitation index—A case study of eThekwini metropolitan area. Journal of Flood Risk Management, 15(2), e12788. https://doi.org/10.1111/jfr.12788