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# THESIS FOR QUALIFICATION OF MASTERS OF ENGINEERING (MENG) DEGREE IN CIVIL ENGINEERING FLASH FLOOD RISK MANAGEMENT IN A SOUTH AFRICAN TOWNSHIP: A CASE STUDY OF ALEXANDRA

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**DECLARATION**

I, A.O. FADUPIN declare that this research project on: "FLASH FLOOD RISK MANAGEMENT IN A SOUTH AFRICAN TOWNSHIP: A CASE STUDY OF ALEXANDRA is my work and that all sources I have used or quoted have been indicated and acknowledged through complete references.

**Signature**

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**Date**

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# ABSTRACT

Several studies have been carried out on improvement of flood risk assessment and management in South Africa. Despite all these studies, the problem of Flash Flood (FF) persists. This study was designed to determine the most appropriate Flash flood inundation model that could be applied in flash flood risks management in a South Africa Township: a case study of Alexandra. Alexandra Township being a FF-prone area was chosen for this study from where a sample of 30 respondents was purposively selected.

A survey (Questionnaire) and document search were used to collect relevant quantitative data and qualitatively based secondary information from the sample population respectively. Also, data were collected through in-depth interviews of senior officials in the Disaster Management Services for more well-rounded information. Content analytical method was used to process the qualitative information. The study adopted complementary analytical tools, namely, R- programming and appropriately selected tools from the Statistical Package for Social Sciences (SPSS version 21.0) to analyze the quantitative data and to determine the most appropriate Flash Flood Inundation Model. In search of mitigating the risk of the FF in Alexandra Township, a FF inundation model was determined. People were educated on FF not to build shacks along Juskei River and were trained to prepare for and manage FF. Early Warning messages were sent and community volunteers were trained on managing risks related to FF. The main observed risk factors of FF where building of shacks without abiding by the rules and regulation, blocking of drainage system by illegal dumping of solid waste and growth in population. The major risk factors the respondents agreed to cause FF where annual rainfall intensity (70.0%), poor drainage (56.7%) and human settlement (50.0%). The three Principal Components identified to be contributing to FF in Alexandra Township were terrain, soil texture and poor drainage system. This factors contributed 82.0% of FF risk factors in Alexandra Township. The model revealed that appropriate solid waste disposal, construction of sewers, dredging of Jukskei River, and construction of Gabions along Jukskei River will mitigate flash flood risk and related hazards in Alexandra Township.

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# CHAPTER ONE

# INTRODUCTION

## 1.0 Introduction: Flash flood in brief perspective

World meteorological organization (WMO) defines flash floods as a rapid onset flood of short duration with relatively high peak discharge. The American meteorological society also defines flash floods as a flood that rises and falls quite rapidly with little or no warning usually as a result of intense rainfall over a relatively small area. A detailed definition of flash floods is employed by the U.S. National Weather Service. They defined flash floods as the rapid and extreme flow of high water into a normally dry area, or a rapid rise in water level in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam) (WMO,2007). According to the World Meteorological Organization (WMO), flashfloods are the most lethal form of natural disasters (based upon the ratio of fatalities to people affected) which causes millions of dollars in property damage per year (WMO, 2007).

Flash floods are dangerous and destructive in almost any part of the world including South Africa. They occur as a result of short-lasting severe rainfalls which causes substantial structural and social impacts (e.g., loss of human life, damage to property, and disruption of services).The collapse of dams and dykes, overloading of drainage systems contribute to flash floods. Flashfloods often have an impact on the poorer population in remote areas. Flashfloods are expected to increase due to urbanization in flood-prone areas (Nirupama and Simonvic, 2007) and global climate change (IPCC, 2001), which will cause an increase in frequency and intensity of extreme rainfall and sea-level rise. The elevated probable risk associated with flash floods and flow of debris is connected to the broad dispersion of the areas which has the likelihood of been affected and the swift occurrence with very brief intervals between the generating storm and the ensuing flood and sediment response.

As opposed to large river floods, such lead times often do not allow warning of the affected communities promptly and to establish effective risk management (Creutin *et al*., 2013).
From the year 1999-2010, over 300,000 reported flood disasters have occurred, resulting in consequential damage including an estimated 3 billion people being made homeless in the world and the death of over 200,000 people (Smith, 2013). It is affirmed by UNESCO generally that approximately 200 million people in more than 90 countries are exposed to destructive flood events yearly, and it is expected to rise in the future due to climate change and urbanization (UNESCO, 2008).

Flood risk is assumed as the probability of hazard (Climatic change), the exposure and vulnerability of elements at risk. Hooijer *et al.*, (2004:343) defined flood risk as a function of the probability of flood hazard and the potential damage. In the next three decades, temperatures in South Africa are expected to rise, and rainfall in Eastern Africa is expected to increase (including the Horn of Africa). Global sea- mean- level is expected to rise from 18 to 59 cm (according to different temperature change scenarios) over the next 100 years (IPCC, 2007:45).

A crucial concern for the world’s natural hazards is the combination of efforts, strategies, policies, and programs of the global government at various levels to reduce flood occurrences. The persistent incidence of flood events besides the measures undertaken reveals the inability of flood control measures to adequately control floods.

The magnitude of flooding which has been occurring recently has been groundbreaking with approximately 70 million people all over the world being exposed to floods yearly and an estimate of over 800 million individuals living in places that are prone to floods level, speedy growth in population and urbanization, the degree of development on the flood plains, the level of awareness of risks associated with flooding and the ineffectiveness of handling floods in various regions (Raaijmakers *et a*l., 2008).

The main concern all over the world with natural disasters especially flooding are change in climate with heavy rainfall intensity, rise in sea level, speedy growth in population and urbanization, the degree of development on the flood plains, the level of awareness of risks associated with flooding and the ineffectiveness of handling floods in various regions (Raaijmakers *et al,. 2008)*

One of the cornerstones of flood risk management is the information of people at risk and the authorities and agencies responsible for flood risk management. The basis for effective and efficient measures for reducing risks related to flooding are risk analyses which will take into account the different aspects of flood risk, for instance, hydrological, economic, social, and ecological aspects (Berz *et al*., 2001).

The seasonal rainfall forecast of the Southern African Regional Climate Outlook Forum (SARCOF), predicted average rainfall for the region except for central and Southern Mozambique and South-west South Africa. La Nina which causes lower than normal temperature in the eastern equatorial area of the Pacific Ocean caused above normal rainfall raised concerns that the region could experience severe rainfall in 2011 (UN,2010). According to the report issued by the Regional Office for Southern and Eastern Africa (ROSEA) on Southern and Eastern African Floods and Cyclones, heavy rains early in the season affected Mozambique, South Africa and Lesotho. South Africa which was not usually affected by flooding experienced large scale devastation that year (UN, 2011).

Historically, rainfall increased during January to February in South Africa. Heavy rainfall in December 2010 and January 2011 caused severe flooding across South Africa and experienced large scale devastation. By 21st January 2011, South African Government declared a national state of disaster and established an Inter-Ministerial Committee to support the planning of the response efforts against the disaster. A Government report of 1st of February 2011, estimated that a total of 13,043 houses were damaged, 91 people died and 321people had been injured as a result of flooding and storms across South Africa. The cost of the damage was estimated at over a billion Rands. The Johannesburg flood of November 2016 was the biggest natural hazard in South Africa. The storm and flash flood caused significant damage to the township of Alexandra.

The current method for mitigating flash flood hazards to lives and properties in South Africa is the use of an early warning system. In established terms, the project on early warning systems in South Africa could be categorized as being in its early stages of development hence not mature enough to evaluate the effectiveness of an early warning system. However, the project plans to evaluate the impacts of improved forecast and early warning systems on flash floods (Guha *et al*., 2016).

A sustainable flash flood risk management requires a flood risk assessment to identify forces and factors causing flashflood risks. Literature highlights various available options to manage flood channels which include structural methods such as, dyke, dams, reservoirs, and relief channels. For instance, Sultana *et al.* (2007:35) asserted that structural measures like embankments could protect against flooding. Given the persistence in flood occurrences, there is a need to explore more options to manage flood channels. These could include preventive options such as the operation and maintenance of flood channels through community education and litter disposal among others.

## 1.1 Problem statement

Flash floods have been recognized as one of the major natural hazards in South Africa due to the country's semi-arid to arid climate. It has been discovered from the world meteorological organization country-level survey in 2008 that out of 139 countries 105 have indicated that flash floods were among the top two most important hazards around the world and it requires special attention (WMO, 2008). In line with the center of research on Epidemiology, it has been reported that about 72% of natural disasters in South African regions are as a result of harsh weather conditions which are hydro-meteorological (e.g., floods, flash floods, storms, drought, and extreme weather) (Guha *et al*., 2016).

Since December 2010, it has been reported that the region of South Africa has been experiencing rainfall that has been above average and this has caused flood havoc on a level that has never been experienced (DREF Operation, 20ll). According to the report, due to this occurrence, 200,000 people have been affected by floods, and an estimate of 40 people have died. In 2011, some areas were continuously reported as being prone to floods (DREF operation, 20ll). These storms and flash floods caused significant damage to some residential areas including townships. Some suburbs were declared as areas prone to flood disasters. Recently in 2016, the province of Gauteng experienced another occurrence of flooding attributed to heavy rainfall which caused some rivers to burst their banks and affected major infrastructure like bridges (Aurelie, 2016). This damage to infrastructure as a result of flood hazards are estimated to be in millions of Rands. Government and civil society have made intensive efforts to address the incidence of flood hazards in South Africa. Several studies have been carried out on the improvement of flood risk assessment and disaster risk management in South Africa (Musungu, Motala &Smith, 2012; Pyle & Jacobs, 2012; Fatti & Patel, 2013; Balica *et al*., 2013: Musyoki *et al*., 2016, Omere, 2011). Despite all these studies, the problem of flooding persists. Musyoki *et al*., (2016) examined the impact of flooding and communities perception towards responses to flooding. The risk associated with flash floods were analyzed in an informal settlement in Cape town graveyard by Musungu, and Smith (2013) using a multi- criteria evaluation and GIS (Geographical Information System) and

Omere (2011) focused on the geographical patterns and disaster management in the Township of Alexandra. These studies dwelt on the effects of flash floods on the communities including their perception without highlighting the elements of risk reduction and long-term adaptation strategies in dealing with flash floods in areas they studied in South Africa with particular reference to Alexandra Township. Government and respective agencies have been reactive by providing palliative measures such as alternative shelters and evacuation of affected people. However, activities that will engage more proactive measures have not been put in place due to a lack of design or a reliable forecast to do so. This study attempts to engage in the analysis of the present situation to provide an estimate for community risk reduction and long-term adaptation strategies to flash floods and also determine the most appropriate flood inundation model that could be applied in the management of flash floods in Alexandra Township.

## 1.2 Aim of the study

This study aims to determine the most appropriate flood inundation model that could be applied in the management of flash flood risks and related hazards in a selected flash flood-prone area in Alexandra Township, which is recognized as a flood-prone area in South Africa.

## 1.3 Specific objectives

The specific objectives of the study are**:**

i. To determine the possible forces and flash flood risk factors and assessment on the extent of flash flood hazards in the selected area of study;

ii. To determine appropriate, effective, and efficient measures to mitigate flash flood hazard to life and property;

iii. To develop an applicable flood inundation model that will manage flash flood risk and related hazards in the selected area.

## 1.4 Motivation of the study

In agreement with the center for research on the Epidemiology of disaster,approximately72% of natural disasters reported in the South African regions were severe weather which is hydro-meteorological (e.g., floods, flash floods, storms, drought, and extreme weather) (Guha *et al*., 2016). South Africa is part of the most vulnerable regions of the world to hydro-meteorological hazards including flash floods, cyclones, droughts, and extreme temperatures. As a result of these, lives have been lost, many dwellers have been displaced from their homes and properties have been destroyed with the spread of diseases such as malaria, cholera, fever, and water- borne diseases. This study thus attempts to determine the most appropriate flood inundation model that could be applied in the management of flash flood risk and related hazards in the selected flash flood-prone areas.

There is limited literature on flash flood risk management in South Africa. Previous studies focused on general flood disaster management in South Africa (Zuma, *et al* 2012), the coordination of disaster response and relief efforts on flood disaster management (Pyle&Jacobs,2012), and the use of regional frequency flood analysis based on a single-site approach for flood management (Smithers *et al*., 2015).

The response of the Government to flashfloods have been reactive rather than proactive in implementing measures to reduce the hazards related to flash floods. Also, there is a gap in the literature in determining suitable Flood inundation models in tackling flashflood hazards.

This study, therefore, attempts to fill in the gap by determining a suitable flood inundation model to minimize the incidence of flood and the associated hazards. This will assist the policymakers and Government to take effective measures to address the recurrent flooding hazards and the

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Introduction: Flash flood

Of the numerous natural disasters such as earthquakes, droughts, wind, storms, epidemic floods are the most common natural hazards with the largest impacts on society (WMO, 2009). Although remarkably devastating, recent flood impact records show that the number of related fatalities is gradually decreasing (Camille, A. et al., 2013). This trend is attributed to many developments among others, such as better early warning systems. The contrast to the decrease in fatalities is that damages to land and property show an increase probably due to insufficient prevention, economic growth, and a lack of flood sensitive land use planning. The latter case is mainly due to the old traditional fragmented approach to flood planning and management practices (Camille, A. et al., 2013)..

Flash floods have various impacts as illustrated herein:

i. Hydrological impacts – these result in drinking water quality problems, borehole contamination, and disruption of water supply systems;

ii. Social impacts – these result in drowning and displacement of people, destruction of living spaces, damages to transportation and communication infrastructure;

iii. Agricultural impacts – these result in crop and livestock losses and a consequent food security problem; and

iv. Health impacts – these result in epidemics such as malaria, dysentery, and cholera outbreaks.

The causes of a flash flood can be one or a combination of the following factors: be caused by intense rainfall, particularly when it takes place in a saturated area where rain has previously fallen or if the ground is frozen.

In these conditions, the additional rain runs off over the surface and accumulates in streams and rivers at an accelerated pace. Heavy rains, most frequently connected with convection clouds, cover small regions and are short-lived (from a few minutes to a few hours), but very intense such as 100 mm (or 100 Litres per square meter) in an hour or more. Violent rainfall causing flash floods can be accompanied by strong winds and heavy hail formation. They can also appear locally in a large area covered by rainfall. Flash floods are among the world's most destructive natural hazards. Flash floods account for more than 5000deaths annually on a global basis, with a mortality rate (defined as the number of deaths/number of persons affected) more than 4 times greater than other types of flooding (Jonkman, 2005). In the United States, 80% of all flood-related deaths are attributed to flashfloods (NWS, 2014). Also, flashfloods account for 50% of the flood-related damages to Property, infrastructure, and industry according to U.S. statistics (NWS, 2014).

## 2.2 Occurrence of floods

The occurrence of flood disasters throughout the world is observed as one of the most frequent natural disasters. This is visible in developing countries that are experiencing rapid population growth. Muchtar and Bahar, 2010 affirmed that floods generally around the world are seen as the most extremely damaging of all hazards and these natural disasters have been predicted to be more critical in years to come. The prevalence of floods has a lot of influence on various aspects of human life as a result of their destructive effects which create substantial expenses on mitigation efforts. For instance, human activities such as unexpected rapid human settlement, uncontrolled construction of buildings, and major land-use changes have an impact on the spatial and temporal pattern of hazards. (Pradhan, 2010b). Flooding is expected to occur more frequently in the future as a result of climate change (Lenderik and VanMeijgaard, 2008; Min *et al.*, 2011; Rojas *et al.*, 2013; Bruwier *et a*l.,2015).

Flooding has various origins, which can be grouped according to the way they occur. For example, some of the causes of flooding may be meteorologically triggered by weather conditions that are associated with precipitation (Doswell, 2003). Floods also occur through excess precipitation and related runoff which flows to the drainage basin more than what the drainage system can accommodate. When the walls that are required to hold a large quantity of water fail as a result of precipitation in form of rainfall or acts of human beings (war or sabotage), flooding can occur. Flooding could also occur due to lack of maintenance and failure of structural materials that are used in constructing the walls of a dam (Pradhan, 2010b). Other causes of flooding could be as a result of inappropriate design or maintenance of stormwater systems or development which can reduce infiltration and also raise the level of runoff through hardening of surfaces in built-up areas. Precipitation generally is regarded as the cause of flooding which can trigger other causes, such as heavy rainfall which is regarded as one of the primary causes of inland flooding in a built-up environment (Pradhan, 2010b)

Sene (2008), revealed that in comparison with other natural disasters all around the world, floods account for approximately 20-40% of the occurrences which have been reported. Flooding is naturally faster than normal in quantity because of a load of an amplified quantity of water upstream, which will lead to an increase in the pressure gradient that drives the flow.

In most cases, the damage potential is enlarged by debris that the water carries (e.g. trees, vehicles, boulders, buildings, etc.) (Doswell, 2003).Floodwaters contain silt and possibly toxic chemicals. This reveals that floods usually affect drinking water supplies, which results in short-term shortages of portable water, with the additional long-term cost in restoring the drinking water to residents of an area that is flooded. The mud and debris left after the flood has stopped can be costly to clean up and they also represent health hazards particularly once there are decomposing bodies of drowned wild animals and domestic animals in the debris. In some situations, floods can move wild animals of all kinds from their normal habitats which can cause a great hazard to human life (Doswell, 2003). According to the centre for research on the Epidemiology of disasters (CRED) in its recently released 2018 natural disaster report, flood affected more people in 2018 than any other disaster type (UN, 2019).

## 2.3 Types of floods

### 2.3.1 Urban floods

Floods in urban areas are regarded as growing issues of concern for both developed and developing countries. Urban floods cause damages to buildings, household assets, and losses of income in industries and trade, loss of employment to daily earners or temporary workers, and disruption to transport. Damage from urban flood are on the increase causing great amount of destruction and inconveniences such paralyzing day to day activities. Floods in urban areas occur as a result of a combination of causes such as heavy rainfall, long period of rain and lack of proper drainage. The environment in urban areas is subject to similar natural forces as the natural environment and the existence of urban settlements aggravates the problem. According to Jha *et al*, (2012), the urban environment can be flooded by rivers, coastal floods, pluvial floods, and groundwater floods. Floods in urban areas are caused effects of inappropriate land use planning. Many urban areas are facing the challenges of increased urbanization with an expanding population and high demand for land.

Infrastructure and various types of buildings, they are not enforced as a result of economic or political factors, capacity, or resource limitations. This results in obstruction in the natural flow path of water, which causes floods (Jha *et al*., 2012:57).

### 2.3.2 River or fluvial floods

This kind of flood occurs when the surface runoff exceeds the capacity of natural or artificial channels to accommodate the flow. The excess water overflows the banks of the watercourse and spills out into adjacent, low-lying flood plain areas. Floods in riverine areas can be slow due to sustained rainfall or rapid snowmelt. River floods can be caused by heavy rains from monsoons, hurricanes, or tropical depressions (Jha *et al*., 2012:58).

The brutality of a river flood is determined by the amount of precipitation in an area ,how long it takes for the precipitation to accumulate, previous saturation of local soils, and the terrain of the river system (Maddox,2014: para: 4 line1).

### 2.3.3 Pluvial or overland floods

Pluvial floods also referred to as overland floods are triggered by rainfall or snowmelt that is not absorbed into the land and flows overland through urban areas before it reaches drainage system or watercourses. This type of flood often occurs in urban areas before it reaches the drainage systems or waterways. Pluvial or overland flooding occurs in urban areas as the lack of permeability of the land surface, which means that rainfall cannot infiltrate rapidly enough resulting in flooding. This kind of flood is caused by localized summer storms or weather conditions that are related to unusually large low-pressure areas (Jha *et al*., 2012:60).
They canals occur repeatedly in some urban areas, mainly in tropical climates, draining away quickly but occurring more frequently during the rainy season (Jha *et al*.,2012:60).

### 2.3.4 Coastal floods

Flooding in coastal areas arises from invasion by the ocean or seawater. They are different from cyclic high tides in that they occur from an unexpected relative increase in sea level caused by storms or a tsunami caused by seismic activities. Concerning storms or hurricanes, a combination of strong winds that causes the surface water to pile up and the suction effect of low pressure inside the storm creates a dome of water. When this approaches a coastal area, the dome may be forced towards the land: the increasing seafloor level found in inshore waters the body water level to rise, creating a wave that inundates the coastal zones. In storms or hurricanes, the storm surges usually cause the sea level to rise for a relatively short period of four to eight hours, but in some areas, it might take much longer to recede to pre-storm levels. Floods in coastal areas caused by the tsunami are less frequent than storm surges but they can cause huge losses in low-lying coastal areas (Jha *et al*., 2012:60).

### 2.3.5 Groundwater floods

In groundwater floods, the level of water under the ground rises during the winter or rainy season and fall during the summer or dry season. Flooding as a result of groundwater occurs when the water table of the underlying aquifer in a particular zone rises until it reaches the surface level. Groundwater flooding also occurs after long periods of continuous high rainfall. Rising water levels may cause flooding in a normally dry land as well as reactivate flows in bourns, which are streams that flow for a part of the year. This can be a problem, especially during the rainy season when the non-perennial joins the perennial watercourses. This can result in an overwhelming quantity of water within an urban area. Furthermore, groundwater flooding can also occur in low-lying areas underlain by permeable rocks; where such an area has been developed and the effect of groundwater can be costly. According to Sandink, (2013), groundwater water flooding could occur through wastewater connection when water table elevation is higher than basement floor elevation, such as hydraulic gradient from the ground water zone into the basement. Leaking waste water infrastructure can also cause a pathway for groundwater to enter the house through drains and toilets if an effective backup valve is not present (Allouche & Freure, 2002: Sercu et al., 2011). Even though groundwater generally responds slowly compared to rivers, groundwater flooding might take weeks or months to dissipate. Groundwater is more difficult to avert than surface flooding, even though in some areas water pumps can be installed to lower the water table.

Most of the time it is difficult to differentiate between groundwater and surface water, increased filtration and rise in the water table may result in more water flowing into rivers which in turn are likely to overtop their banks (Jha *et al.*, 2012:61).

Flood waters contain silt and possibly toxic chemicals. This reveals that floods usually affect drinking water supplies, which results in short-term shortages of portable water, with the additional long-term cost in restoring the drinking water to residents of an area that is flooded. The mud and debris left after the flood has stopped can be costly to clean up and they also represent health hazards particularly once there are decomposing bodies of drowned wild animals and domestic animals in the debris. In some situations, floods can move wild animals of all kinds from their normal habitats which can cause a great hazard to human life (Doswell, 2003).

### 2.3.6 Flash floods

Flash floods which also means storm-driven floods can be defined from different areas, namely: as a hydro-meteorological phenomenon, natural agents, or geomorphic agents. From the hydro-meteorological view, flash floods are regarded as an event that involves too much water in a little space of time (Grundfest &Ripps, 2000). The world meteorological organization-defined flash floods as the rapid onset floods of short duration with a relatively high peak discharge. The American meteorological society also defined flash floods as floods that rise and fall quite rapidly with little or no warning usually as a result of intense rainfall over a relatively small area (WMO, 2007). Flash floods which are also referred to as rapid- onset floods are floods with a short duration that have a high peak discharge of water in a particular area. Flashfloods arise within 6hoursofheavyrainfall, which is up to 100mm fall, swift snowmelt or after an unexpected glacier lake upsurge or embankment failure or a swift disintegration of ice block which is as a result of an unexpected rise in temperature (WMO, 2012).

During occurrences of flash floods, there is usually an unexpected rise in water levels in streams and rivers which brings along with it a large amount of debris, boulders, uprooted trees, eradication of infrastructures and buildings along its path (Douvinet *et al*., 2013).

Bom, (2013), indicated that flashfloods occur due to short, intense burst of rainfall, often from thunderstorms. The word “flash flood” specifies an unexpected, quick hydrological response of a generally small catchment in which the level of water can rise to the maximum within minutes or hours after the commencement of rain. Flash floods are extremely confined in space: they are constrained to basins of a few kilometers or less. Flash floods are also constrained in time, in which the response times do not exceed a few hours or less. Hence, the time left for warning of flashfloods is very short (Georgakakos, 1987, 2006; Carpenter *et al.*, 1997, Collier, 2007).

Creutin *et al*, (2013) stated that flash floods cause widespread disruptions to various levels of livelihood, work, society, and spatial environments which makes flash floods natural hazards worldwide. Flash floods which are caused by life-threatening precipitation occurrences are anticipated to be more recurrent and more forceful in the future due to both climate change and land-use changes (Bronstert *et al.*, 2002; Modrick and Georgakkos, 2015).

Norbiato *et al.*, (2008) and Czigany *et al.* (2010) affirmed that soil moisture conditions before any major rainfall, are the main hydro-meteorological controls that induce flash floods. With the understanding of topography, soils, and the influence of human beings on the catchment (for instance steep slopes, drainage density, impermeable surfaces, saturated soils, and land use) the likelihood of the occurrence or non-occurrence of a flood can be established with some degree of accuracy.

Anthropogenic impacts are significant because some basins respond swiftly to intense rainfall at the commencement of disturbances in the natural drainage (stream channelization, deforestation, housing development, fire, etc.) (Norbiato *et al*., 2008). The lowest intensity and duration of a rainfall occurrence that can cause a flash flood is largely dependent on the hydrological conditions related to that particular event of a flash flood. The conditions such as topography and soil permeability play a significant role in influencing the extent of flash flooding (Doswell, 1997). The impact of flash floods is felt more in urban areas due to high population density, impervious surfaces, and increased flood wave velocity as a result of channelization of stream flow (Looper and Vieux, 2008).An increase in urbanization and aging or insufficient drainage aggravates the problem. Most of the available drainage networks are designed to manage a specific amount of rainfall and the amount of rainfall used in designing drainage networks does not take into consideration the future growth of the city, climate change, or flash flooding (Henonin *et a*l., 2011).

Flash floods are mostly categorized by their magnitude (total amount and intensity of inducing rainfall), and the return interval of total runoff.

Flash floods as a geomorphological phenomenon, are described as short duration occurrences that occur as a result of an unexpected rise in discharge of a river or stream which could have notable effects through erosion and sedimentation (Reid, 2004). Flash floods are most of the time linked with other natural hazards. Damage as a result of flash floods generates debris flows i.e. hyper-concentrated flows in which the proportion of a load of sediments exceeds that of water discharge (Iverson, 1997).It has been discovered from the world meteorological organization country-level survey in 2008 that out of 139 countries 105 has indicated that flash floods were among the top two most important hazards around the world and it requires special attention (WMO, 2008).

In line with the center of research on Epidemiology, it has been reported that about 72% of natural disasters in South African regions are as a result of harsh weather conditions which are hydro-meteorological (e.g., floods, flash floods, storms, drought, and extreme weather) (Guha *et al*.,2016).

Since December 2010, it has been reported that the region of South Africa has been experiencing rainfall which has been above average and this has caused flood havoc on a level that has never been experienced. As a result of this occurrence, 200,000 people have been reported to have been affected by floods, and an estimate of 40 people have died (DREF operation, 2011). These storms and flash floods caused significant damage to some residential areas including townships, and some suburbs were declared as areas prone to flood disasters. Recently in 2016, the province of Gauteng experienced another occurrence of flooding attributed to heavy rainfall which caused some rivers to burst their banks and affected major infrastructure like bridge (Aurelie, 2016)

***2.3.6.1 Characteristics of flash floods***

Flash floods have the following characteristics:

i. They occur suddenly with little lead time warning;

ii. They are fast-moving and violent, resulting in a high threat to life and severe damage to property and infrastructure;

iii. They are small in scale about areas of impact; and

iv. They are frequently associated with other events such as riverine floods and large streams and mudslides; they are rare (Gruntfest andHandmer,2001

**Table 2.1:** The summary of the major causes of flash flooding

| Type | Typical causes | Description |
|---|---|---|
| River flooding | Heavy rainfall/ or rapid snowmelt | High levels and flows in rivers ,streams ,and creeks due to intense rainfall from localized events, such as thunderstorms, as part of more widespread rainfall, possibly aggravated by block ages from debris |
| Ice Jams | High river flows leading to ice break up, probably linked with increased air temperature | Out of bank flows due to the build-up of water when floating, the ice gets trapped by bridges, channel constructions, and other features and sudden release of water when ice jams break up |
| Debris flows | Heavy rainfall/or rapid snowmelt | Fast-moving mud streams, rocks, and other debris generated by heavy rainfalls, probably aggravated by damage to vegetation caused by wildfires |
| Urban flooding | Heavy rainfalls and or/rapid snowmelt | Surface or pluvial flooding which occurs when the drainage network cannot remove water quickly, probably aggravated by a series of factors such as river flooding |
| Dam break | High flows, structural failure and /or landslides or debris flows into a reservoir | Over topping or failure of dam walls leading to fast- moving deep flows further downstream. Emergency flow releases or flows from self-priming siphons also present a risk at some reservoirs |
| Outburst floods | Same as dam break | Flash floods due to failure or overtopping of naturally occurring barriers to flow, with the same effect as dam break: for example, Glacial lake outburst floods |
| Levee breaches | High river levels and/or structural failures | Overtopping of failure of leveed due to high river levels and/ or structural issues leading to rapid inundation of previously protected areas |

## 2.4 Flood prone areas

The sections along a river that are prone to flooding can be divided into different groups namely the floodplain, floodway, and flood line. The floodway can be characterized by high velocities, deep water levels, and the presence of debris with possible erosion. No development should take place in the floodway, only critical infrastructure should be allowed within a floodway (ISDR2004; Wright, 2008).

A flood plain represents all areas around the river channel (FEMA, 2008; Wright, 2008).In flood plains, there exists no definable boundary because there is no limit to the magnitude of a flood. Therefore, the probability of inundation decreases as the elevation of a point on the floodplain increases (Alexander, 2000). A flood line is only a line that defines an area in which no development should take place as it is an indication of the water level of a flood with specified annual exceedance probability (Alexander, 2000). In analyzing floods regarding the probability of occurrence, the impact of floods, and management thereof, it is important that the three components defining the flood-prone areas are understood, identified, delineated, and managed properly.

## 2.5 Primary and secondary impacts of floods

Pelling *et al.*, (2004) affirmed that approximately196million people in more than 96 countries are exposed to disastrous flooding annually. Floods have a negative influence on communities and their surrounding environment and can be severe and disruptive to daily activities.

The following negative effects can arise due to flooding (Ec 2009b; Halloway and Roomaney 2000; Klijn 2009; Schulze 2003):

i. Health problems (increase in the spread of diseases, e.g., diarrhea or leptospirosis);

ii. injuries and death;

iii. Damages and loss of settlements;

iv. Damages and loss to infrastructures such as roads, bridges, and telephone lines;

v. Financial services cost for insurance and reinsurance;

vi. Disruption of water supply; and

vii. Damage to agricultural land and crops

An increase in the occurrence and severity of floods can be attributed to the contribution of climate change and the attitude of humans living in flood-prone areas (Halloway and Roomaney 2008; Klijn 2009; Wisner *et al.* 2004). Despite all the negative effects that occur due to flooding, communities still relocate back to flood-prone areas as rivers are vital to their livelihood. Studies indicate that people mainly relocate to flood-prone areas (Shulze, 2003; Wisner *et al.* 2004; Wright 2008) to:

i. Utilize the rich soil for agricultural purposes;

ii. Use the river for transportation;

iii. Safely access water for household purposes; and

iv. Use the flat plains to establish a settlement.

## 2.6 Causes of flooding

Floods can occur due to meteorological, partly meteorological, or other causes. Meteorological causes include snowmelt, rain, and ice melt. Coastal storm surges and estuarine interactions between stream flow and tidal conditions entail the partly meteorological causes (Alexander 2000; Ec 2009b; Smithson, Addison, and Atkinson 2002). The remaining causes of flooding can be attributed to other natural hazards (e.g., earthquakes, landslides) or by failing levees or collapse of dams (EC 2009b; Wisner *et al*., 2004).

### 2.6.1 Climatic factors

Several urban flood risk research works have different findings with regards to factors responsible for flood risk, although disaster problems may sit at the boundary of the natural and social environment. The risk associated with flooding has been conceptualized as a function of the changing climate, the socio-cultural environment, and sometimes a combination of both climate and the built environment. Some environmental researchers argue that global warming (greenhouse effect) and climate change are directly or indirectly increasing the amount of rain and ice melting and thereby increasing the magnitude of runoff and subsequent flooding. According to Karley (2009), the common causes of flooding in Ghana are intense rainfall leading to run-off, dam burst, and tidal waves and as a result of cyclone Eline in 2000 over Mozambique, South Africa, Malawi, Botswana, and Namibia (Vaz,2000). Criss (2009), affirmed that the increasing frequency of flood events could not be unrelated to climate change. However, the correlation between the climatic factors and flood hazard and its risk could not be accounted for as the only factor responsible for flood risk; therefore, more factors are needed to give adequate insight and understanding to the process.

### 2.6.2 Socio-Cultural factors

Another school of thought opines that cultural activities have significantly affected the working of the natural physical environment and as a consequence, the environment is only responding to these actions. Of all the land-use changes affecting the hydrology of an area, urbanization is by far the most forceful which brings about changes in peak flow characteristics, changes in the total run-off, changes in quality of water, and changes in hydrological amenities (Leopold, 1968).

The increasing human population in the urban areas and the encroachment and modification of floodplains of river systems are contributing factors to the increasing damages and risk causes of floods (Samarasinghe *et al.*, 2010). The volume of runoff is governed primarily by infiltration characteristics and is related to land, slope, soil type, and vegetation. It is thus directly related to the percentage of areas covered by roofs, streets, and other impervious surfaces at the time of hydrograph rising during storms (Leopold, 1968). The increase in impervious surfaces has consequences such as the effect of increasing flood peaks during storm periods and decreasing low flows between storms (Leopold, 1968). For example, removal of vegetative land cover by replacing it with concrete surfaces in urban areas increases impermeable surfaces, thereby causing an increase in overland flow and reduces infiltration, bypassing the natural storage and reduction of the subsurface flow leading to quick runoff and flooding. Therefore, urbanization increases the volume and rate of surface runoff through alteration of the natural drainage system and modification of runoff to streams. The result is a greater volume of runoff, discharging in a shorter period, and potentially leading to a dramatic increase in flood peaks (Smith, 2013). For instance, empirical studies show that climate change has not been a consequential factor in the observed increasing flood damages in Africa according to a study by Baldassare *et al*., (2010) on flood fatalities in Africa. The notable contributors include but are not limited to poor planning of the physical environment, poor management of wastes, and inadequate drains for the built-up areas. Hooijer, *et al*., (2004) examined that the impact of 30 years of urbanization on two sub-catchments of the Thames, showed a clear increase in flood frequency with urbanization, followed by a reduction in storage.

Daniel (2012) also claimed that the general view of heavy rainfall had been the major cause of urban flood has been disproved, but lack of urban infrastructures plays a major role in a flood disaster in Gombe metropolis, Nigeria. This perspective theorized based on empirical studies that the increasing flood risk is not only caused by climate change but the increasing build-up environment which affects how the environment works as the main cause of flooding. Subsequent progress in flood studies combined the two factors for flood incidence around the globe as illustrated in the following section.

### 2.6.3 Combined impact of Climatic and Socio-Cultural factors

Pielke (2000) argued that there is a weak relationship between the hydrological factors and the damaging floods because the damaging floods occur from a combined effect of physical and societal processes with floods that result from a combination of meteorological and hydrological extremes (WMO, 2009). The flood risk is increasing not only because of climate change but also due to the continued encroachment of people and properties in areas at risk of flooding resulting in increased potential damage (Hooijer *et al*., 2004). Criss (2015) concluded that flood levels rise as a result of climatic change and in-channel structures. In line with the above standpoints, risks related to flash floods can be perceived as a function of exposure, vulnerability, and hazard (Wisner *et al*., 2004).

The climatic change could be seen as the exposure to hazard, and the socio-cultural context could be regarded as the exposure to hazards and the vulnerability of people in hazard-prone areas. Flood risk hazard can be characterized by climatic change leading to probability and intensity of high river flows which causes inundation in an area. Exposure and vulnerability refer to the question of whether or not people or valuables in the range of floodwaters and the population and assets are in the hazardous zone. Therefore, risk linked with flooding can be understood as encompassing a combination of vulnerability, exposure, and hazard. If any of these three elements increase or decrease then the risk increases or decreases accordingly. As such, understanding flood risk could be an effective measure for risk reduction (Wisner *et al.*, 2004).

## 2.7 Assessment of risks associated with flashfloods

The antecedent soil moisture conditions before any major rainfalls are the major hydro-meteorological controls that induce flash floods. It, therefore follows that risks associated with flash floods would be influenced by the soil moisture conditions as well. All factors are held constant; soil moisture conditions are influenced in a great part by the inherent soil properties.

In assessing risks associated with flash floods, there are three soil properties to be considered:

i. Soil moisture with regards to the degree of saturation;
ii. Soil permeability, including the alteration of the soil surface, for example, compactions, paving, and fire; and
iii. Soil profile.

The most important factor to be considered for rapid runoff and flash flooding is soil moisture, principally in humid areas with deep soils. If the soil is saturated it will not allow additional rainfall to infiltrate and most of the rainfall will become runoff irrespective of the environmental conditions. The infiltration rate of rainfall can be affected by soil permeability. The general indicator of soil permeability is soil texture. Soil texture is the characteristics of the soil which is used to describe the relative proportion of various grain sizes of mineral particles in the soil. Other soil properties that determine the rate of soil permeability are crust formation, soil compaction, soil contraction, soil hydraulic conductivity, and root distribution (https://ww.meted.ucar.edu).

In agreement with the approach of Drau- Fersina (1999), assessing the risks associated with flash floods can be achieved through the following procedure:

i. Characterization of the area concerned;
ii. Analysis of the hazard;
iii. Assignment of probability to each scenario;
iv. Assessment of the hazard; and
v. Vulnerability analysis.

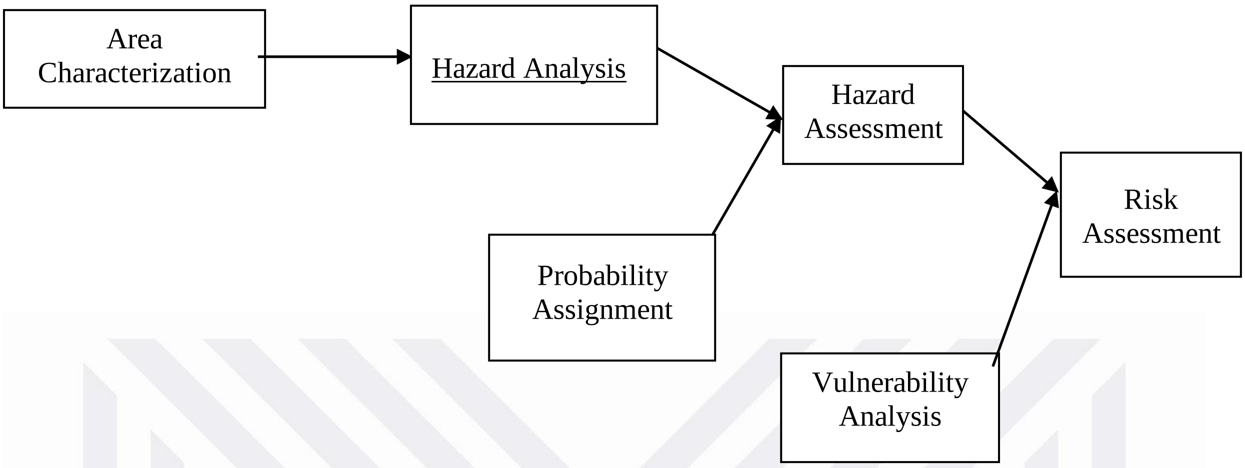


**Figure 2.1: Flowchart for assessing risks associated with flash floods (Drau-Fersina 199)**

**2.7.1 Characterization of the area affected by the impact of flash floods**

Characterization of the area concerned in assessing flash flood risks can be grouped into two categories: characterization based on the information to be collected and characterization based on the tools to be used.

***2.7.1.1 Characterization based on the information to be collected***

The kind of information to collect to characterize an area prone to flashfloods has to fall under two main tasks: provision of scientific data for hazard and vulnerability; and risk analysis. The second task, risk analysis will also assist decision-makers during the planning for mitigation measures. Other information that must be included in characterizing an area prone to flash floods are:

i. Geography i.e. the length of the river section, community/provinces involved, peculiarities of the area involved;

ii. Geology and geomorphology e.g. form of lithology (chalk, limestone, sandstone, clay, etc.), stratigraphy within the study area, tectonic history (whether it is a heavily folded or faulted area or not), nature of river (bed width, inclination, bed load regime) with its processes;

iii. Hydrologyandhydraulicse.g.airtemperature,watertemperature,annualprecipitation, months of maximal and minimal precipitation, channel discharge, water level (mean annual and peak) bank full discharge value, channel roughness, channel geometry, retention behaviour;

iv. Vegetation e.g. classification of vegetation (closed canopy, open canopy, scrublands, dwarf scrublands, herbaceous vegetation, non-vascular vegetation, sparse vegetation).

v. Land use e.g. Land use types (agricultural land, forest and other wooded lands, built-up and related land, wet open land, dry open land without or with insignificant cover); and

vi. Historical analysis of local flood events e.g. analysis of the occurrence of the historical floods (Scientific journals, national and local databanks, newspapers, interviews from victims damaged environment), analysis of the evidence of paleo floods (the study of post floods geomorphology, size of allochthonous material, such as boulders, pebbles, soil, etc.) (Drau- Fersina1999),

***2.7.1.2 Characterization based on the tools for collection of information for risks associated with flash floods***

Three tools that are important in characterizing an area subjected to flash floods are:

i. Database storage for general information;

ii. A Geographical information system (GIS) for graphical representation of maps and spatial analysis; and

iii. A set of computer programs for data processing (e.g. hydrological and hydraulic models).

### 2.7.2 Analysis of hazard

The method for hazard analysis includes the choice of the level of detail for the analysis (scale of map and hazard intensity scale), the definition of hazard scenarios, and the construction of a basic hazard map.

#### *2.7.2.1 Choice of the scale of map and hazard intensity scale*

The scale of the map which is to be used for hazard analysis and a scale for hazard intensity must be defined before starting data collection. The two scales are connected and the choice is usually made between the following alternatives:

i. Medium, level of detail (map scale ranges from 1: 10,000 to 1: 100,000, while the hazard intensity scale is subdivided into 3 degrees); and

ii. High level of detail (the map scale is in the range of 1:1,000 to 1: 10,000, while the hazard intensity scale is subdivided into at least 4degrees).

Table 2.2 represents an example of a hazard intensity scale modified by Kienholz, 1996 as a function of danger to the population. It considers three levels of intensity (low, medium, and high).

**Table 2.2: Hazard intensity scale for characterizing flash flood**

| **Hazard intensity** | **Danger to population** | |
|---|---|---|
| | **Indoors** | **Outdoor** |
| High | Yes | Yes |
| Medium | No | Yes |
| Low | No | No |

### 2.7.3 Assignment of probability to each scenario

A scale of probability level of hazard scenario can be defined and assigned based on the hydraulic and hydrology information, flooding frequency and water level of a certain time occurrence.

For example Table 2.3 reports the probability level scale produced by analyzing the flood of Drau-River to four levels of probability which were defined as low, medium, high and very high hazard scenario (Drau-Fersina, 1999).

**Table 2.3: Probability level scale for a hazard scenario**

| **Probability level** | **Return period T(Years)** | **Frequency (w)** |
|---|---|---|
| Very high | T<10 | w > t/10 |
| High | 10≤ T≤ 30 | t/10≥w≥ t/30 |
| Medium | 30≤ T≤ 100 | t/30≥w≥t/100 |
| Low | T≥ 100 | W< t/100 |

**Source: Drau-Fersina, 1999**

### 2.7.4 Assessment of hazard

Flash floods arise as a result of thunderstorms and heavy rainfalls. Flash floods can occur in small catchment areas and the steepness of the slope is a major factor in the destruction that comes with it (Khan et al., 2005). Risk assessment is a vital component of risk management processes and various methods have been recognized in assessing risks related to flash flood hazards. In agreement with Colombo et al. (Colombo *et al*., 2002), Goulby and Samuals flood risk assessment has four crucial elements which include characterizing the area, assessing hazards, assessing vulnerability, and assessing risk. In consonance with ICIMOD (International Center for Integrated Mountain Development, 2019,), flash flood hazard assessment has two important parts such as allocating the intensity of flash floods and the probability level of a hazard scenario. For example in identifying the occurrence of flash floods, assessing the risk, and executing real forecasting with suitable lead time is essential. Flashfloods are also regarded as short-fuse occurrences. Studies based on hydrology focus on the investigation and the analysis of watershed factors that alters flash flooding such as geometric properties of the river basin and the water channel flow.

Method centered on GIS (Geographic Information System) and remote sensing provide a very decent presentation by linking, controlling, and investigating the information for assessing the possibility for flash flood risk occurrences quickly and more skilfully (Kumar *et al*., 2000).

During flash flood hazard assessment, estimating different factors of the river basin is very crucial such as stream order, basin area, drainage density, stream frequency, and basin relief.

ISDR (International Strategy for Disasters Reduction) (2003), pinpoints the requirement of community-centered flood hazard maps such as inundation areas, depth of information, evacuation centers and routes, critical facilities, communication channels, emergency kits, and other numerous items for evacuation in hazard maps.

### 2.7.5 Vulnerability assessment

Literature suggests that people living in flood-prone areas are flash floods (Fothergill, 2004). The expression vulnerability has been used in the field of risk reduction, hazard and disaster management, and also in areas of global environmental changes such as climate change (Juergen, 2001). Vulnerability refers to the degree of hazard to a specific population or the capacity of a system, which suffer or respond destructively during the occurrence of any hazardous event (Proag, 2014). The concept of vulnerability assessment comprises different degrees of risk such as physical, social, and economic facets. Physical vulnerability is associated with buildings, livelihood linked to infrastructure, agriculture, road, communication systems, and other operations of the society. Social vulnerability is associated with women, children, physically handicapped persons, poor people, and refugees. Economic vulnerability assessment is associated with risk hazards and their effect on economic resources and practices. It is also connected to direct and indirect damages such as damages to livelihood, Infrastructure, and damages to crops. The occurrence and the degree of floods or flash floods have increased over the last decades with large amounts of deaths and damage of property than any other natural disasters. Flash floods convey different types of vulnerabilities in the society which can be perceived as economic, social, structural, agricultural, and psychological. Vulnerability is based on several constituents such as the internal side and the external side of vulnerability (Proag, 2014).

The internal side of vulnerability refers to the surviving ability of the people or systems, while the external side of vulnerability focuses on the external impact such as exposure of people to flash floods. The physical vulnerability can be appreciated by revealing elements at risk in a populated zone during the process of surface runoff or peak discharge of water, such as flow depths, build-up heights, flow velocities, and pressures that can damage unprotected elements (Fothergill, 2004).In flash flood linked vulnerability assessment, financial capital is a significant factor for the vulnerability of households.

### 2.8 Integrated approach to flood risk management

An integrated flood risk management approach consists of a combination of flood risk management measures that are taken as a whole can successfully reduce urban flood risk. Policymakers need to develop an integrated strategic approach to reduce flood risk which fits their specific conditions or needs. Flood management measures are usually portrayed as either structural or non-structural. Structural measures aim to reduce the risk of flooding by controlling the flow of water both outside and within the urban settlements.

They are complementary to non-structural measures that aim to protect from flooding through proper planning and management of urban development. A thoroughly integrated strategy must be connected with the existing urban planning, management policy, and practices (EU, 2017).

Structural and non-structural measures are complementary and the most effective strategies will combine both measures. It is also vital to realize the level and characteristics of existing risks and probable future changes risk which will be needed to attain the balance between long- and short-term investments in flood risk management. However, as both urbanization and climate change accelerates, there may well be the need to move away from over-relying on rigid-engineered defenses to more adjustable non-structural measures (EU, 2017).

### 2.8.1 Structural measures

Structural measures involve structural mitigations which are physical changes or acts of protection from hazards or disasters. Structural measures span from rigid-engineered structures such as flood defenses and drainage channels to more natural and sustainable complementary measures such as wetlands and natural buffers. Structural measures can be very effective when properly used as confirmed in the Thames barrier or the Dutch sea defenses (EU, 2017).

Structural measures include:

i. Conveyance;
ii. Flood storage;
iii. Drainage storage;
iv. Infiltration and permeability of urban area;
v. Groundwater management;
vi. Wetlands and environmental buffers;
vii. Building design resilience and resistance;
viii. Flood defenses; and
ix. Barrier and embankment systems for Estuary and Coastal flood protection.

Structural measures for example flood defenses and conveyances systems form a long-term solution to flooding risks by enabling flood plains to be habitable and also by protecting existing settlements.

#### *2.8.1.1 Flood defenses*

The purpose of flood defenses is to reduce the risk of flooding on people and the natural environment. Flood defenses are erected to protect and to reduce flood occurrence at a specific magnitude which is expressed as the risk in one year. For instance, flood defenses in urban areas can be constructed to offer protection against flood occurrences which can occur once in one hundred years. Flood defenses should be considered as a strategic approach in integrated flood risk management which is capable of managing the risk of flooding (EU, 2017).

#### *2.8.1.2 Demountable and temporary flood defenses*

Demountable and temporary measures are required within an urban environment, where space is restricted and access to river spaces, roads, infrastructures, and buildings are critical. The advantage of demountable and temporal measures is that they can be mounted just before or during a flood, but under normal circumstances, space and access remain unaffected (APFM, 2007) Structures that are regarded as demountable flood defenses have permanent and temporary elements. They usually have permanent foundations, with guides or sockets to erect barriers whenever there is a risk of flooding. The barriers are then removed when there is no risk of flooding (APFM, 2007). A temporary flood defense system is a system that can be erected during a flood incidence and then completely removed when the defense is no longer needed (APFM, 2007). The most common form of temporary flood defense measures are sandbags, they take time to fill and lay and they are also difficult to handle. Sandbags even when properly positioned, water still seeps into them making them less effective than temporary flood protection products such as free-standing barriers designed specifically for the purpose (APFM, 2007).

#### *2.8.1.3 Conveyance System*

With regards to flood risk management, the purpose of the conveyance system is to provide a route to divert impending floodwater away from the area of risk .Conventionally, this has been seen as a way to eliminate the problem of flooding from an urban environment. Those kinds of systems frequently form broader water management (EU, 2017:203). Structural measures can exceed in height by occurrences outside their design capacity. Numerous structural measures move the risk of flooding by reducing flood risk in one location just to increase the risk in another location. Changing the direction of the flow of water often has environmental impacts. In certain situations, structural measures can also be costly requiring a lot of investment and can also encourage complacency by their presence and they can result in increased impacts if they fail. From these considerations and the reality that there will always be a residual flood risk, this highlights the need to include non-structural measures into any strategy. When applying structural strategy, there is always a role for non-structural measures to build the capacity to cope with flooding in their environment (EU, 2017).

### 2.8.2 Non-Structural measures

Non-structural measures (NSMs) are set of mitigation/adaptation which does not make use of traditional structural measures. They are designed to protect people from flooding and to minimize the impact of flooding on people and assets exposed to risks in the absence of hard-engineering structural measures. They are not as costly as structural measures, but they depend on the understanding of flood hazards and proper flood forecasting systems such as a warning before an emergency evacuation plan. Non-structural measures have a role to manage risk by building the capacity of people to cope with the flood in their environments.

The early warning system, which is an example of non-structural measures, can be understood as the first step in protecting people in the absence of costly structural measures. Non-structural solutions have proven to be the most effective method of minimizing the impact of flooding in certain situations (EU, 2017).

Non-Structural measures include:

i. Flood awareness campaigns;
ii. Health planning and awareness campaigns;
iii. Land use planning and flood zoning;
iv. Flood insurance, risk financing, compensation, and tax relief;
v. Solid and liquid waste management;
vi. Emergency planning, rescue, damage avoidance actions, and temporary shelter;
vii. Business and government continuity planning (BGCP);
viii. Early warning system;
ix. Evacuation planning; and
x. Flood recovery and reconstruction (EU, 2017)

***2.8.2.1 Flood awareness campaigns***

In non-structural flood risk management, a flood awareness campaign is very vital. Methods to reduce the impact of flooding rests upon stakeholders becoming aware of the risk of flooding. Ignorance of awareness of flood risk will make people occupy flood plains which could lead to neglect of proper building designs. During flooding events, a lack of awareness of risk can lead to failure to adhere to warnings to evacuate, which will eventually endanger lives. Flood awareness campaigns are generally high in areas where the impact of flooding is high and minimal in areas with low impact of flooding. Increased awareness of flooding will lead to mitigation activities and preparedness which will ultimately minimize the impact of flood occurrences. The purpose of flood awareness campaign is to prompt debates on issues that are appropriate to the communities which are at risk. In flood risk solutions, raising awareness is one of the broader strategies. This should be followed by information and steps which will mitigate the risk of flooding. This is seen in a Vietnamese scheme, which was aimed at an interest group (builders, teachers, and School children): this method proved to be successful in inspiring homeowners to invest in flood-and typhoon resistant buildings (United Nations, 2007).

The major limitation of several non-structural measures encountered is the need to engage the involvement and agreement of stakeholders and their institutions. This consists of maintaining resources, awareness, and preparedness throughout the years without flood occurrence and also knowing that flood disasters tend to reduce with time (United Nations, 2007)

#### *2.8.2.2* **I*nter-relationship between land use planning and flood risk Management***

Land use planning also referred to as physical planning, is the detailed planning of how buildings and land are used. The purpose of land use planning is to provide a policy and regulatory mechanism that aids different and conflicting objectives to be integrated and addressed in a development framework. This process and outputs are referred to as integrated land use planning. Integrating flood risk management objectives into land-use planning is a crucial component of modern-day flood risk management.

Objectives of land use planning are to:

i. Identify appropriate areas, locations for specific land uses;

ii. Determine what risks are associated with specific land uses in specific locations;

iii. Determine and identify sensitive environmental features; and

iv. Determine the minimum requirements for particular land-use types.

Urban land-use plans should be integrated within a flood management plan which can include river management basin plans, coastal management plans, and surface water management plans. Those plans are the responsibilities of various government departments and the urban use plans will be informed by the flood risk management team. Land-use plans will also include flood risk combined with other priorities, land availability, and environmental hazards while broader plans will need to balance the requirement for urban growth with the desire to minimize flood risk (EU, 2017).

### 2.8.3 Classification of non-structural measures

Non-structural measures can be grouped under four major classifications:

i. Emergency planning and management including evacuation. For example, as used in local flood warning systems in the Philippines and the Lai Nullah Basin in Pakistan.

ii. Increased preparedness through awareness campaigns as used in Mozambique and Afghanistan. Preparedness comprises of flood risk reducing urban management procedures such as ensuring that drains are kept clean through better waste management.

iii. Controlling flood through land-use planning as seen in Germany Flood Act and planning regulations in England and Wales. Land use planning contributes both to the mitigation of and adaptation of urban floods

iv. Speeding up recovery and using recovery to increase resilience by improving building design and construction. Suitable financing of risk such as flood insurance where it is accessible or using donor or government sources to enable quick recovery (EU, 2017).

## 2.9 Parsimonious Model

Parsimonious models can be defined as simple models that have great explanatory and predictive power. This model interprets data with a minimum number of parameters or predictive variables. Parsimonious models are derived from Occam's razor or law of briefness (sometimes called lex parsimonae in the Latin). The law says one should not use more "things" than necessary; in the case (Stephen, 2015).

## 2.10 *Pearson Correlation*

Correlation between sets of data is a measure of how well they are related. The most common measure of correlation in statistics is the Pearson Correlation. Pearson Correlation, (the full name is the **Pearson Product Moment Correlation (PPMC))** shows the linear relationship between two sets of data. Two letters are used to represent the Pearson correlation:

Greek letter rho (ρ) for a population and the letter "r" for a sample. The strength of the correlation in the Pearson Correlation analysis is determined by the absolute value of the *Correlation Coefficient* (https://www.statology.org). The larger the number, the stronger the relationship.

### 2.10.1 *Pearson Correlation Coefficient*

Several types of correlation coefficients are in place. However, Pearson's correlation (also referred to as Pearson's *R*) is a **correlation coefficient** commonly used in linear regression (https://www.statology.org). There are many methods of obtaining the value of Pearson's R. The methods return a value between -1 and 1, where:

i. 1 indicates a strong positive relationship;

ii. -1 indicates a strong negative relationship; and

iii. A result of zero indicates no relationship at all

Figure 2.2 presents a graphical demonstration of the stated relationships

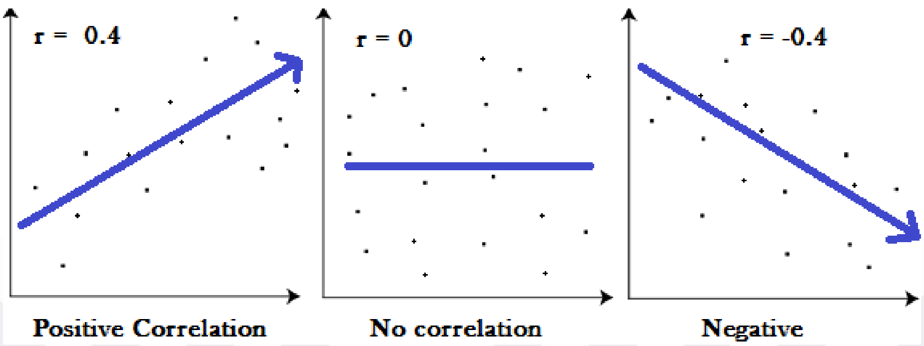


***Figure 2.2: Graphs demonstrating a correlation of -1, 0 and +1***

The interpretation of Figure 2.2 is as follows:

i. A correlation coefficient of 1 means that for every positive increase in one variable, there is a positive increase in a fixed proportion in the other. For example, the amount in a savings account goes up in (almost) perfect correlation with the amount deposited.

ii. A correlation coefficient of -1 means that for every positive increase in one variable, thereisanegativedecreaseofafixedproportionintheother.Forexample,the amount of ink in a printer cartridge decreases in (almost) perfect correlation with the number of printouts.

iii. Zero means that for every increase, there isn't a positive or negative increase. The two just aren't related.

As stated previously, the absolute value of the correlation coefficient gives us relationship strength. The larger the number, the stronger the relationship. A table of crude estimates for interpreting the strengths of Pearson's Correlations is as presented in Table 2.4.

## *2.11 Correlation Matrix*

A correlation matrix (also known as an asymmetric matrix) is a comparative tabular presentation of correlation coefficients between sets of random variables (Xij).

In this case, each random variable (Xi) in the resultant table is correlated with each of the other variables (Xj) in the same table. The tabular presentation allows for a quick analysis of the pairs with the highest correlation. Table presents an example of a coefficient matrix presented in a tabular format.

**Table 2.4: A correlation matrix showing correlation coefficients for combinations of n variables Var 1: Var n.**

| **Variable** | *Var 1* | *Var 2* | *Var 3* | *Var 4* | *Var 5* |
|---|---|---|---|---|---|
| *Var 1* | 1 | 0.53 | 0.73 | 0.87 | 0.43 |
| *Var 2* | 0.53 | 1 | 0.44 | 0.96 | 0.71 |
| *Var 3* | 0.73 | 0.44 | 1 | 0.41 | 0.72 |
| *Var 4* | 0.87 | 0.96 | 0.41 | 1 | 0.56 |
| *Var 5* | 0.43 | 0.71 | 0.72 | 0.56 | 1 |

### *2.11.1 Identity Matrix*

An identity matrix is a matrix in which all of the values along the diagonal are 1 and all of the other values are zero (0) (Table 2.5)

**Table 2.5: An identity matrix for combinations of n variables Var 1: Var n.**

| **Variable** | *Var 1* | *Var 2* | *Var 3* | *Var 4* | *Var 5* |
|---|---|---|---|---|---|
| *Var 1* | 1 | 0 | 0 | 0 | 0 |
| *Var 2* | 0 | 1 | 0 | 0 | 0 |
| *Var 3* | 0 | 0 | 1 | 0 | 0 |
| *Var 4* | 0 | 0 | 0 | 1 | 0 |
| *Var 5* | 0 | 0 | 0 | 0 | 1 |

In Table 2.5, if the numbers in the matrix represent correlation coefficients, it would mean that each variable is uncorrelated (perfectly orthogonal) to every other variable. This condition would imply that a data reduction technique like Principle Component Analysis (PCA) or Factor Analysis (FA) would not be able to “compress” the data significantly. Thus, the reason we conduct Bartlett’s Test of Sphericity is to make sure that the correlation matrix of the variables in our dataset diverges significantly from the identity matrix so that we know a data reduction technique is suitable to use.

If the p-value from Bartlett's Test of Sphericity is lower than our chosen significance level (common choices are 0.10, 0.05, and 0.01), then our dataset is suitable for a data reduction technique.

**Table 2.6: Crude estimates for interpreting Pearson's Correlations (Adapted from https://www.statology.org).**

| R-value | Strength of Correlation |
|---|---|
| +.70 or higher | Very strong positive relationship |
| +.40 to +.69 | Strong positive relationship |
| +.30 to +.39 | Moderate positive relationship |
| +.20 to +.29 | weak positive relationship |
| +.01 to +.19 | No or negligible relationship |
| 0 | No relationship [zero correlation] |
| -.01 to -.19 | No or negligible relationship |
| -.20 to -.29 | weak negative relationship |
| -.30 to -.39 | Moderate negative relationship |
| -.40 to -.69 | Strong negative relationship |
| -.70 or higher | Very strong negative relationship |

### *2.12 Sphericity*

Sphericity can be compared to homogeneity/uniformity of variances in a between-subjects Analysis of Variance (ANOVA). As indicated in the *Laerd Statistics (*statistics.laerd.com*)*, Sphericity is the condition where the variances of the differences between all combinations of related groups (levels) are equal. In certain instances, tests can violate the Sphericity assumption which could lead to an increase in the Type I error rate if necessary, corrections are not instituted to produce a more valid critical *F*-value to reduce the increase in Type I error rate. The violation of sphericity can seriously affect the validity of results particularly for the repeated measures ANOVA.

Such a violation causes the test to have an increase in the Type I error rate. Violation of sphericity is deemed present when the variances of the *differences* between all combinations of related groups are not equal. However, if sphericity violation has been determined in the analysis of the statistics of a particular test, correction tools such as the *Huynh-Feldt correction, Greenhouse-Geisser correction,* and the *lower- bound estimate* can be applied. The correction tools rely on estimating sphericity. In applying these tools, the corrections are developed to produce a more valid critical *F*-value that minimizes the increase in Type I error rate. This is accomplished by approximating the degree to which sphericity has been violated and applying a correction factor to the degrees of freedom of the *F*-distribution (statistics.laerd.com).

### *2.12.1 Mauchly's Test for Sphericity*

This is a widely used formal means of testing for sphericity. The method has been widely criticized for often inadequately detecting deviations from sphericity in small samples and over-detecting them in large samples (statistics.laerd.com). Mauchly's Test of Sphericity tests the null hypothesis that the variances of the differences between all combinations of related groups or levels are equal. This implies that, if the test is determined as statistically significant ($p<0.05$), sphericity has been violated. The null hypothesis is then rejected and we can accept the alternative hypothesis that the variances of the differences are not equal. If the sphericity assumption is not violated, the *F*-statistic that is determined is considered valid and can be used to define the statistical significance of the data. Otherwise, the *F*-statistic is positively biased making it void and increasing the risk of a Type I error. To remedy this, an adjustment to the degrees of freedom is done through Greenhouse-Geisser and the Huynd-Feldt procedures (statistics.laerd.com).

### 2.12.2 Bartlett's test for Sphericity

Stephanie (2016) indicate that Bartlett's test compares the determined Pearson correlation matrix to the identity matrix. The Bartlett's test probes if there is a redundancy between variables that can be plotted with a few numbers of factors (Stephanie, 2016). Bartlett's test for sphericity is frequently implemented before a data reduction technique such as principal component analysis or factor analysis is applied to validate the need to use a data reduction technique to compress the data in a meaningful way (Zach, 2019).

## *2.13 Kaiser-Meyer-Olkin (KMO) Test for Sampling Adequacy*

The Kaiser-Meyer-Olkin (KMO) Test appraises the level of suitability of a given set of data for Factor Analysis. The test assesses sampling appropriateness for each variable in the model and the complete model. The KMO statistic/number is an estimate of the fraction of variance amongst variables that might be common variance. The lower the fraction, the more suitable the set of data is to Factor Analysis. The KMO statistic is a value between 0 and 1. A *rule of thumb* for interpreting the statistic (www.statology.org):

i. KMO values between 0.8 and 1 designate the sampling is adequate.
ii. KMO figures less than 0.5 indicate the sampling is inadequate and that corrective measures should be taken.
iii. KMO values near zero imply that there are large partial correlations compared to the sum of correlations i.e. there are prevalent correlations which are a big problem for factor analysis.

Kaiser's interpretation of the statistics is as follows (www.statology.org):

i. 0.00– 0.49unacceptable.
ii. 0.50 – 0.59miserable.
iii. 0.60 – 0.69mediocre.

iv. 0.70 – 0.79 middling.

v. 0.80 – 0.89meritorious.

vi. 0.90 – 1.00marvellous.

The formula for the KMO test is

$$KMO_j = \frac{\sum i \neq jr^2 ij}{\sum i \neq jr^2 + \sum i \neq j^u} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.1)}$$

where:

R = [$r_{ij}$] is the correlation matrix; and

U = [$u_{ij}$] is the partial covariance matrix.

R = [rij] is the correlation matrix; and

U = [uij] is the partial covariance matrix.

## CHAPTER THREE

## 3.0 RESEARCH METHODOLOGY

### 3.1 Introduction

In this section, the research methodology is presented, which includes the description of the study area, the study population, the sampling procedure, and information gathering from the respondents. The methods adopted for the data analysis were also presented where various statistical tools were utilized for specific purposes. Importantly all the methodological issues presented in this section revolved around capturing the research objectives.

### 3.2 Brief description of the study area.

The study targets the township of Alexandra in Johannesburg which has been identified from literature as a flood-prone area (Aurelie, 2016). Figures 3.1and 3.2 present information on the study area. The township of Alexandra is the economic center of not only South Africa but also the whole of Africa. The province is presently experiencing rapid development with more vacant land areas being occupied mostly by informal settlers. Gauteng is located at an elevation of 1500m on South Africa’s interior plateau and because of this, the province receives most of its rainfall during the summer months. Heavy rainfall occurrences that cover most of the province can last several days at a time, sometimes resulting in widespread flooding. The province of Gauteng can also have very intense rainfall occurrences which have the potential to cause flash flooding (Omere, 2011).

The Township of Alexandra is located near the upper-class suburb of Sandton. The population of Alexandra Township is estimated to be about 179,629 informal dwellers according to the 2011 census, in which African blacks make up 99% of the settlers. Alexandra is situated on the banks of the Jukskei River. The Jukskei River is one of the ten river catchments in Johannesburg Metropolitan (Coordinating Committee for Community Open Space, 1986) and forms part of the catchments of Limpopo Rihe Dehe ver which flows into the Indian Ocean.

The river catchment is 800km² (Campbell, 1996) and its source is situated upstream of Bruma Lake at the foot of the Witwatersrand area. Jukskei River is a shallow river that is not deep enough for transportation. The Jukskei River flows through the Northern parts of the city of Johannesburg. Jukskei River was reported to have collapsed because of heavy rainfall (Aurelie, 2016). The river is heavily polluted by urban runoff due to lack of maintenance of flood channel infrastructure and illegal dumping of rubbles. These have allowed the flow of raw waste into the river daily. The banks are prone to bursting especially in summer when rainfalls are the heaviest during the year. This is disastrous for poor residents who build their shacks along the riverbanks to have access to water for washing and cooking.


***Figure 3.1: The Landscape of Alexandra Township area Source: (Murray, 2009:176)***

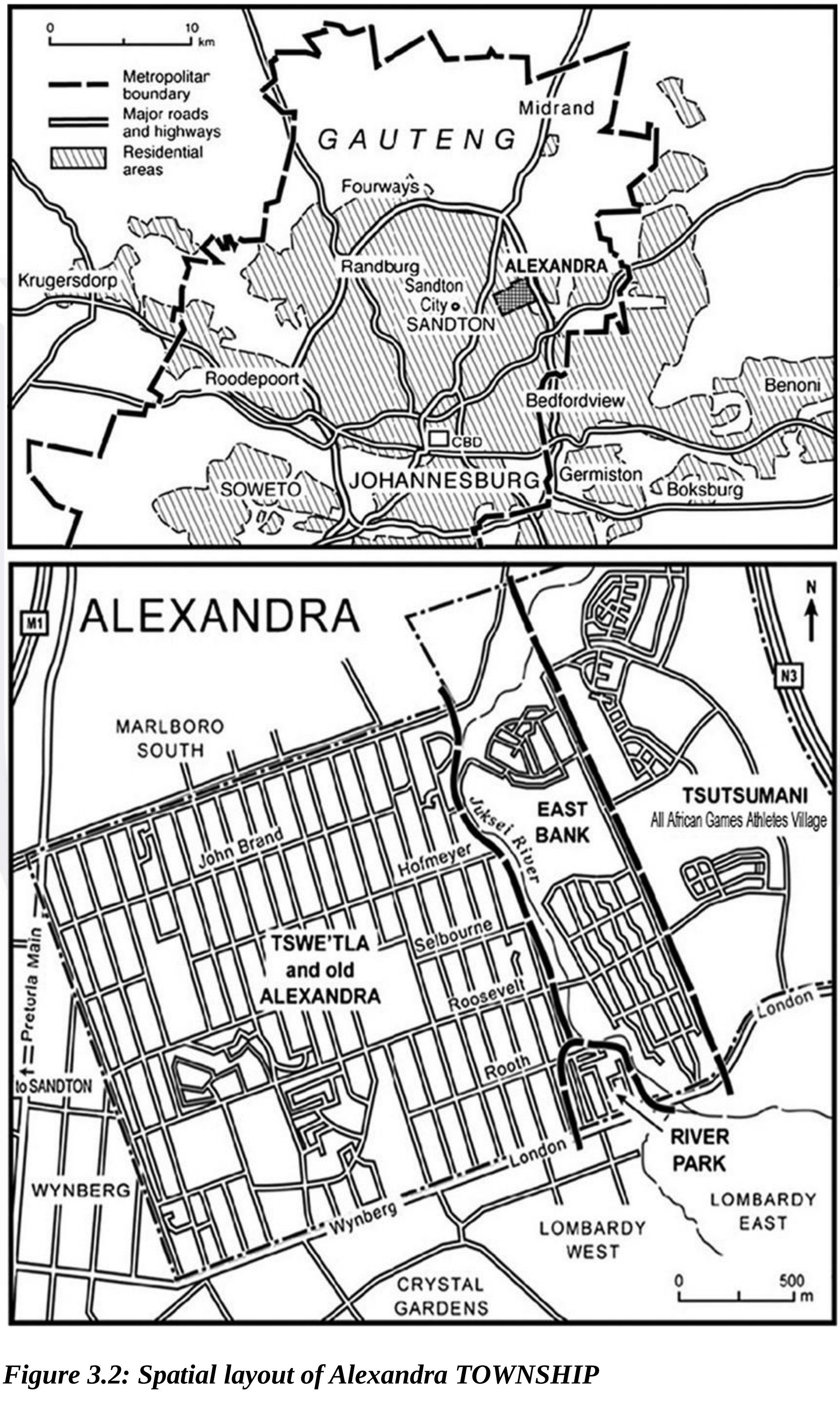


***Figure 3.2: Spatial layout of Alexandra TOWNSHIP***

It could be seen in figure 3.3, that a higher concentration of shanties are built close to the course of the Jukskei River which implies the following:

i. That the construction of structures increases the possibilities of flash floods due to the increased coefficient of runoff. This has the potential of shortening the time-to-peak from the onset of a rainfall event, consequently leading to vulnerability to flash floods (hence the classification of the area as a flash flood-prone area);

ii. Also that with the expected expansion of the occupation of the no-go-zones of the flood plain, the area could be expected to remain in the category of flash flood-prone areas for a very long time thus calling for this expected anomaly to be factored in in the integrated development plan of the City of Johannesburg and Ekurhuleni as well as the neighbouring Tshwane Metro;

iii. The observed lack of solid waste management, as well as water and wastewater systems, expose the stormwater and by extension the Jukskei River to the pollution which renders the river water expensive to treat for domestic purposes;

iv. The pollution of the surface water and stormwater that drains into the river also disturbs the river ecosystem (flora &fauna);

v. Most of the informal settlements are in contravention of the flood plain and riparian river land utilization regulation. The implication of this is that effecting such regulations become counterproductive and further contravenes the implementation of the Environmental Management Act; and

vi. The downstream side of the river shows the extent to which the informal settlements encroach into the cemetery area. This could be catastrophic in the long run with regards to the intrusion of polluted groundwater into the mainstream during flash floods and base flow river regimes

***Figure 3.3: Setswetla informal settlement in Alexandra along the banks of the Jukskei River (Ntwaagae Seleka)***


***Figure3.4: Floods in Gauteng Province 08th February 2020. Photo Gauteng Province community safety.***

### 3.3 Population of Alexandra Township

The population of Alexandra Township is estimated to be about 179,629 informal dwellers according to the 2011 census, in which African blacks make up 99% of the settlers. The population is majorly comprised of indigent dwellers, most of whom depend on the government social grants for their daily amenities. The structures that they can afford are thus either self-built shanties or the RDP houses provided for by the government. This goes by implication that the infrastructure for water, wastewater, and solid waste management is either lacking or inadequate to maintain a sustainable and conducive living environment in the township. The result is mostly a case of neglect especially in the solid waste management of the existing environment. Improper management of solid waste, as stated in the previous sections is a key contributor to the flash flood events and pollution of stormwater during rainfall events.

### 3.4 Impact of flash flood in Alexandra Township

According to the Oxford advanced learners dictionary, the impact is the powerful effect that something has on people and the environment. The impact can also be defined as the action of one object coming forcibly into contact with another .Impacts of flash flood shave a devastating effect on the economy, people, and the environment. In the recent flash flood event that occurred on the 8$^{th}$ of February 2020, flash floods swept through homes and forcing residents to evacuate. Johannesburg Emergency Management Services reported that they were monitoring the rising water levels along the Jukskei River near Setswetla informal settlement in Alexandra. Also, the flash floods damaged a building of Johannesburg Helen Joseph Hospital (Flood list News, 2020).

It was also reported that flash flood events in 2016, indicated that at least 376 shacks and 889 people were affected and displaced due to the flash floods in Alexandra Township Report of

City of Johannesburg. (COJ: Public Safety Committee Disaster Management on flash flood in Setswetla, 2016) Those who were displaced by the flash flood in the Township of Alexandra were housed in temporary shelters or camps in different areas of the Township.

Report of the City of Johannesburg. (COJ: Public Safety Committee Disaster Management on flash flood in Setswetla, 2016).

### 3.5 Collection of rainfall and flash flood data

Secondary data was collected such as the rainfall data (1989-2010) which was obtained from the South Africa Weather Services in Pretoria (Appendix I). An interview was also conducted with two senior officials in the Disaster Management Services in Sandton who were in charge of handling flash floods in the municipality of Alexandra. Information on the cause, the management, and the extent/impact of the flash flood was obtained.

i. Three visits were made to Emergency Management Services in Sandton for information gathering and inspection visits were also made to Alexandra Township damage to infrastructure and also to Jukskei River where rubbles were dumped in to the river which eventually polluted the river.

ii. During the visit to Alexandra Township, the community leaders attended to us (The Disaster Manager and myself) and showed us the situation in the Township, especially how certain individuals in the Township were allowing people to dumb rubbles into the Juskei River and as a result polluting the River.

iii. A report of the City of Johannesburg (COJ): Public Safety Disaster Management on the Flash Flood Incident that occurred at Setswetla Informed statement Region A, ward109 and105onthe9th ofNovember 2016, was collected from the Emergency Manager at Sandton Fire Station (Appendix IIa and IIb).

A feedback report on the Jukskei River flooding by the City of Johannesburg Health department was obtained from the Emergency Manager at the Sandton Fire Station

(Appendix III).

## 3.6 Determination of flash flood risk factors

The study aims to determine the most appropriate flood inundation model that could be applied in managing risks associated with flash floods and their related hazard in the selected flood- prone area in Alexandra Township.

The factors and forces namely- poor drainage network, inadequate solid waste disposal, and human settlements causing flash floods in the area of study were investigated, the flood channels were assessed, and proper education about litter disposal which can cause blockage of the drainage system and sewerage system was conducted.

## 3.7 Assessment of flood risks and data analysis.

The aim of assessing flood risks was to determine the risk associated with flash floods in the selected area of study (Alexandra Township).

## 3.8 Methods of data collection

This study employed the use of (a) In-depth interview with the Disaster Manager and another independent officer at the Disaster Management Service. Interviews with pre-determined interview questions were used as the main tools of data collection on flash flood risk and assessment on the extent of the flash flood in the study area. The in-depth interview consisted of fifteen (15) itemized questions and answers which were recorded, transcribed, and summarized.

### *3.8.1 Survey (Questionnaire)*

Questionnaires were administered to the officials of Emergency Management Services who are involved in handling hazards and risks related to flash floods in the location of the study (Setswetla) and also the community leaders of Setswetla who could give the required information regarding the hazards they faced relating to flash floods in the Setswetla.

The questionnaire (Appendix IV) was formulated using a four (4)-point Likert scale (the scale ranged from 1= Strongly Disagree; 2 = Disagree; 3 = Agree; 4 = Strongly Agree). A Likert scale was used to evaluate the respondent's opinion with regards to a specific statement. The questionnaire has two sections which were designated as sections A and B.

**Section A**: focused on the risk factors which could be the cause of flash floods in the selected area of study (Setswetla Township).

**Section B**: focused on the mitigation which could be used to reduce flash flood in the selected area of study.

### 3.8.2 Data analysis

The primary data obtained from this study was a combination of probable risk factors in the assessment of the extent of flash flood hazards and factors to be considered for mitigation. With such a combination, there is a need for an assessment of probable existence and the form of correlation between sets of the various factors. A parsimonious model that adequately represents the relationship between the sets of factors was developed to validate the relationship. A factor analysis approach is suitable for meeting such objectives. In this study, the factor analysis was conducted using the SPSS version 20.0 software. Also, Pearson correlation, correlation matrix, identity matrix, sphericity test, Bartlett's test of sphericity, Kaiser-Meyer-Olkin test for sampling adequacy were utilized to highlight the relationship between the set factors.

#### *3.8.2.1 Factor analysis*

Factor Analysis, a multivariate statistical technique is commonly conducted for the following purposes (Business Analytics, 2012):

i. Data/variable reduction, from large to small;

ii. Establish and delineate underlying dimensions and relations between measured variables and constructs; and

iii. Provide construct validity evidence.

Factor Analysis can either be Exploratory (EFA) or Confirmatory (CFA). For this study, the EFAstudywasimpliedgiventhatthestudywasconductedwithnoprioriconceivedtheories and or expectations. The uses of factor Analysis include:

i. Interdependency and pattern delineation (e.g. correlation analysis);

ii. Data reduction;

iii. Structure identification;

iv. Classification of the form and type of data set relation;

v. Scaling; and

vi. Hypothesis testing.

Some of the key components in Factor Analysis that were useful in the data analysis in this study are discussed briefly in the section 3.8.2.1. From the responses obtained, there were six (6) probable Risk Factors in the assessment of the extent of flash flood hazards and sixteen (16) factors to be considered for mitigation. An analysis of all these factors to determine a parsimonious model would require a very complex computational and correlation analyses process. As a typical solution in such instances, a Factor Analysis was considered for data reduction.

A total of 34 sets of primary data was collected through structured questions interviews and field survey questionnaires. Of the 34 sets, four (4) were targeted structured questions interviews of the management staff of the Department of Disaster Management Services of Setswetla and a set of thirty (30) was from a field survey of individuals constituted from the Emergency Services officials and the Community leaders of Setswetla. The interview conducted with the management staff was from two selected managers in the designated department of Disaster Management Services of Alexandra Township. The interviews were designed with two objectives:(i) to determine possible risk factors and assessment of the extent of flash flood hazards in Alexandra Township, and (ii) to determine the level of participation and execution of the mandate of the Department of Disaster Management Services in Alexandra Township. The first objective had a set of fifteen (15) questions and the second objective had a set of fifteen (15) themes. The field survey framework was structured in line with the set-out objectives of the study. The primary data obtained from this study was loaded to the SPSS software version 20.0 for the analysis.

SPSS version 20.0 was used to obtain a correlation matrix of the risk factors. This gave us an idea of how linearly dependent the risk factors are on each other. Statistical Package for Social Science (SPSS) was also used to statistically test for the significance of these correlation coefficients in the KMO and Bartlett test of Sphericity. R programming language was used to obtain the principal components of the risk factors. This gave a data reduction of about 50%. R programming was also used to obtain the coefficients (weights) of the principal components (PCs).

### 3.8.3 Hazard or risk maps for Alexandra

The risk maps were drawn from the Geographical Information System (GIS) based on extensive surveys of vulnerability combined with topographic maps. From previous studies, these features enabled the identification of weak points contributing to flash flooding in the floodplain as not only failure of dykes but also seepage through the dykes and penetration of floodwater through the drainage, the sewerage system, or the watercourses inside Alexandra Township (Kowalczak, 1999 and Eric, 2002).

### 3.9 Assessment of flood risks

The aim of assessing flood risks in this study was to determine the risk associated with flash floods in the selected area of study (Alexandra) using an ordinal scale (low, moderate, high)and also to determine the critical points in the basin surfaces by the geometrical characteristics of the contributing surfaces. The extent of risk in an area is determined by a combination of the hazard of the contributing surfaces and the vulnerability of the territory beneath the critical point.

### 3.10 Determination of appropriate measures to mitigate flashfloods

In determining appropriate measures to mitigate flash floods in the selected area of study, both structural and non-structural measures could be employed because both measures will complement each other when considering the evaluation of flood management. Structural measures can directly reduce the hazards and risks which are related to flash floods to a level, but they are not always efficient and cost-effective. In certain cases, structural measures can enhance flash flood problems increasing the hazard in the other (e.g. downstream) location. In this stud, both structural and non-structural measures were employed.

A) Structural measures that were considered in the area of study are:

i. Regulating rivers and streams: The purpose of regulating rivers and streams is to control the water regime by limiting the slope of rivers and stream beds, thereby reinforcing the banks to reduce erosion. The basic forms are barriers made of wood, stone, or gabions, wooden or stone thresholds, various types of anti-debris dams, as well as dykes, and embankments to protect buildings. Many engineering projects are presently made with natural materials, to minimize impacts on the environment and the landscape. In urban areas, well-organized drainage systems, made up of channels, culverts, sewers, etc., are meant to prevent floods by conveying stormwater away (WMO, 2008b);

ii. Shaping retention: shaping retention aims to reduce immediate flooding. In practice, many hydro technological operations are used to increase the catchment area's retention. The various sorts of small reservoirs that collect water permanently or temporary retention reservoirs, dry reservoirs, and polders. It is also possible to add small dykes and dams raised from local materials and such structural measures as building culverts under roads; and

iii. River conservation: For a river valley to be prepared to redirect flood water, a river corridor must be shaped in a precise manner to maintain a river corridor that is mainly concerned with the river bed to control its depth and slope, and care for the capacity of the valley (cutting down trees). These will treat the water environment as a whole (including not just the layout of the land, but also its flora and fauna); they protect these elements and make use of those which aid activities to limit various damages caused by floods.

B) Non-structural measures offer a wide range of possibilities such as land use planning to construction and structure management codes, soil management and acquisition policies, insurance, perception and awareness, public information actions, emergency systems, and post-catastrophe recovery, which contribute towards the mitigation of flood-related problems. The advantage of non-structural measures is that they are sustainable and also less expensive. On the other hand, they can only be efficient with the participation of a responsive population and an organized institutional network.

### 3.11 Risk Analysis

Statistical Package for Social Science (SPSS) version 21.0 was used for the analysis. Descriptive statistics such as frequency, percentage, and inferential statistics such as Factor analysis, Principal Component Analysis (PCA), were used to determine the most significant risk factors of flash floods. R-programming was used to provide comprehensive information on the individual principal components, PC1 to PC6 (Terrain, Soil texture, Human settlement, solid waste disposal, Drainage and Rainfall) (Objective 1 &2). Multiple linear regression was used to develop a model that will best manage the flash flood risk (Terrain, Soil texture, Human settlement, Solid waste disposal, Drainage and Rainfall) (Objective 3) and the related hazard in Alexandra Township.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

### 4.1 Introduction

This chapter presents the results of the data collected on flash flood risk factors and the extent of flash flood hazard in Alexandra Township. It also presents the level of participation and execution of the mandate of the Department of the Disaster Management Services in Alexandra Township. The appropriate, effective, and efficient measures to mitigate flash flood hazards to the life and property of the people in the affected area (Alexandra) were also determined. An applicable flash flood inundation model was also developed which can be used to manage flash floods and related hazards in the selected area.

As earlier discussed in the methodology a total of 34 sets of primary data was collected through structured questions, interviews and field survey questionnaires. Of the 34 sets, four (4) were targeted structured questions interviews of the management staff of the Department of Disaster Management Services of Setswetla and a set of thirty (30) was from a field survey of individuals constituted from the Emergency Services officials and the Community leaders of Alexandra. The interview conducted with the management staff was from two selected managers in the designated department of Disaster Management Services of Alexandra Township. The interviews were designed with two objectives: (i) to determine possible risk factors and assessment of the extent of flash flood hazards in Alexandra Township, and (ii) to determine the level of participation and execution of the mandate of the Department of Disaster Management Services in Alexandra Township. The first objective had a set of fifteen (15) questions and the second objective had a set of fifteen (15) themes. The field survey framework was structured in line with the set-out objectives of the study. The primary data obtained from this study was loaded to the SPSS software version 20.0 for the analysis.

From the responses obtained, there were six (6) probable Risk Factors in the assessment of the extent of flash flood hazards and sixteen (16) factors to be considered for mitigation. An analysis of all these factors to determine a parsimonious model would require a very complex computational and correlation analyses process. As a typical solution in such instances, a Factor Analysis (FA) was considered for data reduction.

## 4.2 Mean monthly rainfall information for Johannesburg (1989 –2010)

Figure4.1presents the data as Histogram of the Mean Monthly daily rainfall (mm) for the station (0426990) Johannesburg INTWO from 1989-2010. The data shows that although the rainfall was heavy (125,67mm) in December, the heaviest rainfall (142, 67) was in January. The least rainfall (1.57mm) was in July. Heaviest rainfall in Johannesburg was between December and February.

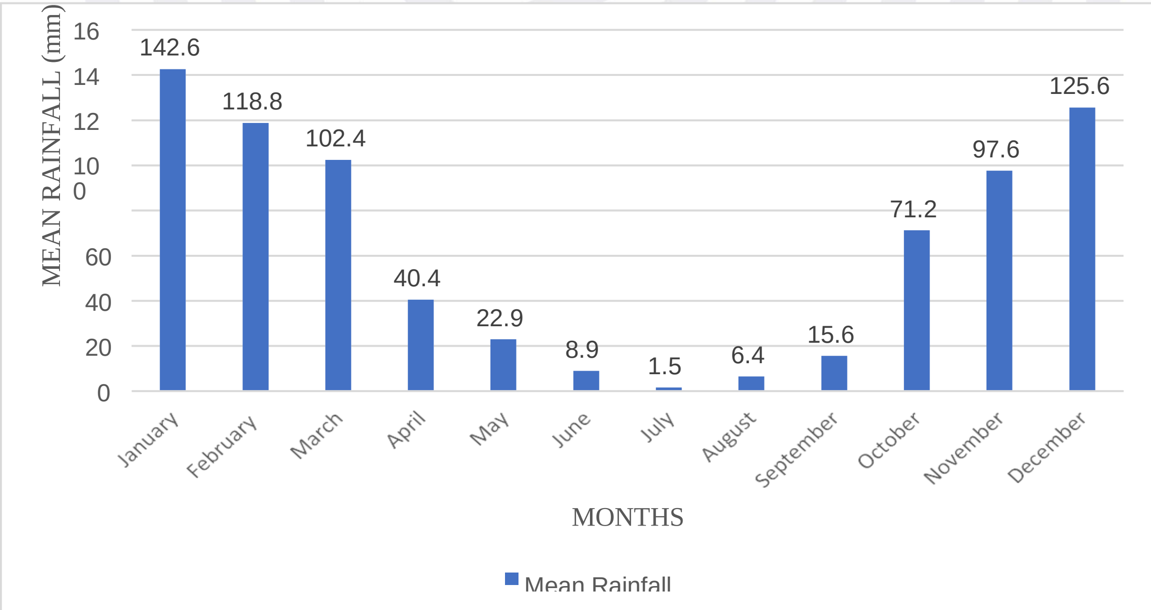


***Figure 4.1: Histogram of the Mean Monthly daily rainfall (mm) for the station (0426 990) Johannesburg INTWO from 1989- 2010.***

## 4.3 Outcomes of the Interviews and Survey

As part of the primary data acquisition, interviews based on predetermined questions were conducted in the study area. The interviews were used to determine possible risk factors and assessment of the extent of Flash Flood Hazards in the selected area of study (Objective 1).

### 4.3.1: In-Depth-Interview with Disaster Managers at the Disaster Management Services on risks of flash flood and flash flood hazards.

**Objective 1: To determine possible risk factors and assessment of the extent of flash flood hazards in Alexandra Township**

As part of primary data acquisition, interviews based on predetermined questions were conducted in the study area. The interviews were used to determine possible risk factors and assessment of the extent of Flash Flood Hazards in the selected area of study (Objective 1). A set of 15 questions was developed to address this theme. Two (2) managers in the Disaster Management Services department were identified for this study. The following are the responses from the interviews of the team at the Disaster Management Services in Alexandra Township.

**a. Involvement of the Department of Disaster Management Services in managing flash floods structure?**

The Managers of the Disaster Management Services reported that there portfolio for flash flood risk reduction within the Disaster Management Services, include the following:

i. Those residents are regularly educated about flash floods in Alexandra through organized Indabas and the involvement of the community leaders

ii. The education is for people not to build on low lane areas and not to build theirs hacks along the Jukskei River.

iii. The disaster management services have a cordial working relationship with the South African Weather Services which send early warning messages about an imminent flood.

iv. The portfolio for Risk Reduction has also trained community volunteers about flash flood risks and disaster management.

v. The community leaders call the Emergency Management Centre for personnel to be dispatched. The emergency personnel assesses the situation at the site.

vi. The disaster managers assess the extent of damage, analyze the needs, and then request additional resources for the affected people.

vii. The disaster managers also request for the assistance of NGOs such as the Gift of the Givers for alternative accommodation, water, temporary electricity in need for the affected people.

viii. After the assessment has been done the city of Johannesburg stakeholders will be debriefed.

**b. The methods of managing flash floods in Alexandra**

The main method of managing flash floods in Alexandra is the maintenance of storm water channels, education of the community not to dump waste into the drainage system.

**c. The causes of flooding in Alexandra**

The causes of flooding in Alexandra were building of shacks without abiding by the rules and regulations prevents the flow of stormwater thus causing flash floods.

**d. Inavailability of effective drainage systems in Alexandra**

The drainage system in Alexandra was usually blocked because of the illegal dumping of solid waste.

**e. Preparation of people of Alexandra for the risk associated with flash floods**

The people were made to be aware of the risks. Also, the Disaster Management Services trained volunteer’s on what to do. However, nobody is prepared to move to safer grounds as they call their current location “home” and would not wish to be relocated.

**f. Location in Alexandra which was usually affected by flash floods**

The Township of Setswetla was reported to be usually affected by Flash floods.

**g. Limitation to flash floods risk management in Alexandra**

It was reported that the limitation to flash flood management was financially related. The City of Johannesburg Engineering services department has recommended structural measures for construction of gabions to combat recurrent flash floods in Alexandra. However, due to budget constraints, the gabions could not be built along the Jukskei River to accommodate the rise in water level to prevent flash floods in the township. Added to this, the problem of river riparian land invasion compounds the burden of the Municipality to contain the risks of flash floods in Alexandra Township.

**h. The stormwater volumes management system in Alexandra**

The population growth has adversely affected the storm drainage system which used to be in perfect condition hence the need to overhaul the drainage system.

**i. The approximate number of people affected by flash flood in Alexandra**

It was reported that according to 2016 flood data, the number was ± 800 people.

**j. Information on land usage in Alexandra**

Alexandra was reported to be a residential, business, and industrial area.

**k. Insurance cover for the property in Alexandra**

Report indicated that the majority of people in Alexandra did not have insurance cover because most people do not pay tax which made it difficult for the municipality to provide such services.

**l. The impact of flash floods in the community**

The impact included the loss of life, destruction of shacks, and the spread of diseases such as dysentery.

**M. The level and form of perception of/ by the community on the need to protect themselves against flooding**

The people did not show interest or even took part in the awareness campaign on flash floods. They did not take flash flooding seriously.

**N. Categorization of flash floods in Alexandra**

The Disaster Managers categorized Flash flood in Alexandra is categorized as high risk.

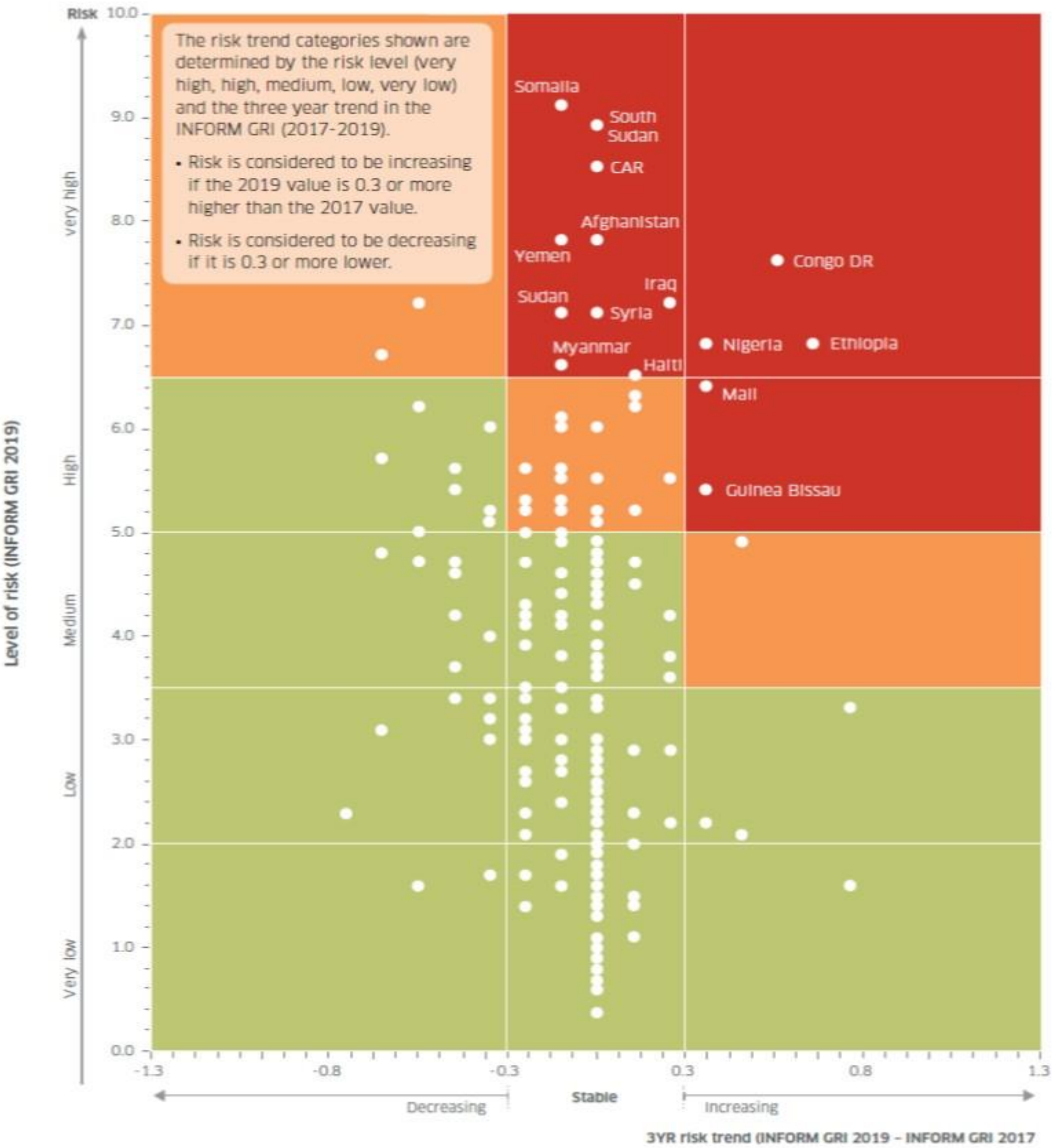


*Figure 4.2: Prioritizing risk levels and trends categories in the INFORM CRI (2017-2019)*

**O. The most appropriate method in managing flash flood risk in Alexandra**

The Disaster Managers were of the opinion that the most appropriate method in managing flash flood risks in Alexandra was for the Weather Rainfall station to sending Early Warning messages to the community on the occurrence of flash floods.

**In addition to above:**

i. The city of Alexandra, unlike Johannesburg, did not have efficient Disaster Management Plans. Agency (J.R.A) center carries out regular maintenance of the drainages, roads, and stormwater channels.

ii. The capacity of the flash floods risk management in Alexandra does not meet with population growth.

iii. The city of Alexandra depends on the Johannesburg Road Agency (JRA) to clean up the drainages during the winter before the rainy season which is in summer.

iv. Alexandra should have their own Independent Alexandra Road Agency (ARA) and not depend on JRA for regular maintenance of the drainage systems.

### 4.3.2 Interview with Disaster Managers at the Disaster Management Services

**Objective: To determine the level of participation and execution of the mandate of the Department of Disaster Management Services in Alexandra Township**

Given the specificity of the study, a set of thematic interview questions were designed to obtain primary information from the personnel at the management level on the level of participation and execution of the mandate concerning the management of flash floods as a disaster cluster. The following section presents the themes and the respective responses obtained from the management team. In this study, two (2) managers in the Department of Disaster Management Services were selected as the respondents.

**Theme 1: The involvement of Disaster Management Department Services on flash flood Management**

Information obtained from the in-depth interview on how the flash flood was being managed by the Disaster Management Services indicated that:

i. The portfolio for risk reduction within the disaster management ensured that people were educated about the flash flood in Alexandra for them not to build on low lane areas and also not to build their shacks along the Jukskei River;

ii. The disaster management services have a relationship with the South African Weather Services which send early warning messages about imminent flood;

iii. The disaster management services had also trained community volunteers on flash floods risks and disaster management;

iv. The community leaders usually call the Emergency Management Centre for personnel to be dispatched to assess the situation at the site;

v. The Disaster Managers assess the extent of damage, analyze the needs and request for resources for the affected peoples; and

vi. After assessment had been done the city of Johannesburg stakeholders would be debriefed.

**Theme 2: Methods of Managing flash flood in Alexandra**

Responses from the interview concerning Theme 2, the main methods of managing flash flood in Alexandria were:

i) Maintenance of stormwater channels; and

ii) Education of the community not to dump waste into the drainage system.

**Theme 3: The main causes of flooding in Alexandra**

The main response from the interviewed managers indicated that the main identified cause of flooding in Alexandra is the building of shacks without abiding by the rules and regulations of the by-laws of the local government that regulates the erection of dwellings within its precincts. The reason provided behind this response was that the shanties are closely located and built of material that reduces infiltration. As a result, the shanties not only reduced the peak time of runoff (causing a sharp peak of runoff within a very short time) but also increased the volume of runoff collected within a given duration of a rainfall event. The result of this thus causing flash floods.

**Theme 4: Availability of effective drainage system in Alexandra**

The response from both respondents indicated that the drainage system in Alexandria was usually blocked because of illegal dumping of waste.

**Theme 5: Preparedness of people for risk of flash floods**

The respondents indicated that the people were educated on the risk of flash floods. There was also an indication from the respondents that the department of Disaster Management Services also trained volunteers on what to do to prepare for flashfloods.

**Theme 6: Location which is usually affected in Alexandra by flash floods**

The respondents indicated that the Setswetla region of the study area was frequently reported to be affected by flash floods.

**Theme 7: Limitation to flash flood risk management in Alexandra**

Inadequate finances were reported as the main limitation in the implementation of strategies to combat frequent flash floods in the study area. The Engineering Services department of the City of Johannesburg has strongly recommended the construction of gabions as the current best structural mitigation measure to curb frequent flash floods in the study area. However, due to the limited funds allocated to the Disaster Management Services department, the gabions could not be built along the Jukskei River to accommodate the rise in water level to prevent flash floods in the township. A further problem that was cited was that of a land invasion. This is considered a problem that cannot be dealt with by the Township management alone but requires a multidisciplinary approach. However, in the current scenario, it remains a critical and delicate limitation to efforts to manage flash floods in Alexandra.

**Theme 8: Stormwater management system in Alexandra**

The respondents indicated that population growth adversely affected the stormwater drainage system which used to be in perfect condition. The unplanned informal settlements along with the riparian river land and within the hazard flood zone region have led to unmanageable operation and maintenance protocols in Alexandra. The need to overhaul the drainage system and develop a more robust and resilient system to accommodate the current scenario was also suggested.

**Theme 9: The intensity of fatalities to people affected in Alexandra**

According to the 2016 flash floods report, a ratio of one fatality per 800 people affected by the flash flood was recorded

**Theme 10: Land usage in Alexandra**

Alexandria was reported to be a residential, business, and industrial area.

**Theme 11: Insurance cover for property in Alexandra**

The respondents indicated that the majority of people in Alexandria did not have insurance cover because most people did not pay tax and this made it difficult for the municipality to provide such services

**Theme 12: Impact of flash floods in the community**

Loss of life, destruction of shacks (by extension homelessness), and spread of diseases such as dysentery were reported.

**Theme 13: Perception of the community on the need to protect themselves against flash flooding**

The report indicated that the people did not show interest and did not take part in the awareness campaign on flash floods because they did not take flash floods seriously. The indication was that flash flooding is not a daily occurrence in their lives and thus wasn't a priority as compared to the need for daily livelihood and the comfort of a place to call "home".

**Theme 14: Categorization of flash flood risk in Alexandra**

Given the likelihood of occurrence is very likely (1 in 5 years) that the consequences in terms of flood depth (1.0 – 2.0 m) being severe, the flood risk in Alexandra is categorized as a high risk.

**Theme 15: The suggested most appropriate method of managing flash flood risk in Alexandra**

The indication was that the Weather Rainfall Station should ensure Early Warning System for the Community on Imminent occurrence of flash flood

## 4.4 Field survey

This survey was conducted among the officials of Emergency Services and the Community Leaders of Alexandra. Alexandra being the area identified as the one most prone to flash flooding in the study area. A total of thirty (30) individuals were surveyed. The field survey frame work was structured in line with the set-out objectives of the study. In reporting the outcomes of the field survey, the structure herein follows the responses per objective as set out in the survey framework.

**4.4.1 Objective One:** To determine the possible forces /flash flood risk factors and assessment on the extent of flash flood hazards in the selected area of study.

The opinion of the stake holders on the risk of flash floods is presented inTables4.1a and 4.1b. Observations from Tables 4.1a and 4.1b show that 26.7% and 6.7% of the respondents strongly disagreed and disagreed respectively, while 23.3% and 43.3% of the respondents strongly agreed and agreed respectively that the terrain of Setswetla was vulnerable to the flash flood. Similarly, 20.0% and 13.3% of the respondents strongly disagree and disagree while 23.3% and 43.3% strongly agree and agree respectively that the soil type of Setswetla made the area vulnerable to flash flooding. Also, 16.7% and 3.3% strongly disagree and disagree while 50.0% and 30.0% strongly agreed and agreed that human settlement and dwelling structures erected as a result was a factor leading vulnerability of the study area to flash flooding. A low proportion; 0.0% and 20.0% respectively, strongly disagreed and disagreed while 46.7% and 33.3% strongly agreed and agreed that solid waste disposal was also a critical factor that renders the study area vulnerable to flash flooding. Further, the results show that a low proportion (3.3%and3.3%) and disagreed while 56.7% and 36.7% strongly agreed and agreed that poor drainage network contributed respectively to the vulnerability of the study area to flash flooding. Finally, another low proportion of the respondents; 0.0% and 6.7%, respectively, strongly disagreed and disagreed while 70.0% and 23.3% strongly agreed and agreed that the annual rainfall intensity of the study area contributed to the vulnerability of Alexandra to flash flood.

**Table 4.1a: Response of the respondents on flash flood risk factors**

| | RISK FACTORS | SD n (%) | D n (%) | A n (%) | SA n (%) |
|---|---|---|---|---|---|
| **1** | The terrain of Setswetla is vulnerable to flash floods | 8 (26.7) | 2 (6.7) | 13 (43.3) | 7 (23.3) |
| **2** | The soil type of Setswetla is vulnerable to flash flood | 6 (20.0) | 4 (13.3) | 13 (43.3) | 7 (23.3) |
| **3** | Human settlement in Setswetla makes it vulnerable to flash floods | 5 (16.7) | 1 (3.3) | 15 (50.0) | 9 (30.0) |
| **4** | Solid waste disposal in Setswetla makes it vulnerable to flash floods | 0 (0.0) | 6 (20.0) | 14 (46.7) | 10 (33.3) |
| **5** | Poor drainage network contributes to flash floods in Setswetla | 1 (3.3) | 1 (3.3) | 17 (56.7) | 11 (36.7) |
| **6** | Annual rainfall intensity contributes to flash floods in Setswetla | 0 (0.0) | 2 (6.7) | 21 (70.0) | 7 (23.3) |

**SD = Strongly Disagree, D = Disagree, A = Agree, SA = Strongly Agree; n = Frequency**

As presented in Table 4.1 and 4.1b, the main risk factors identified (agreed or strongly agreed) were, poor drainage in Setswetla (93.3%); annual rainfall intensity (93.3%); solid waste disposal (80.0%); human settlement (80.0%); the terrain (66.7%) and soil type (66.7%).

**Table 4.1b: Summary of the response of the respondents on flash flood risk factors**

| | RISK FACTORS | SD□D n (%) | A□SA n (%) |
|---|---|---|---|
| **1** | Poor drainage network contributes to flash floods in Setswetla | 2 (6.7) | 28 (93.3) |
| **2** | Annual rainfall intensity contributes to flash floods in Setswetla | 2 (6.7) | 28 (93.3) |
| **3** | Human settlement in Setswetla makes it vulnerable to flash floods | 6 (20.0) | 24 (80.0) |
| **4** | Solid waste disposal in Setswetla makes it vulnerable to flash floods | 6 (20.0) | 24 (80.0) |
| **5** | The terrain of Setswetla is vulnerable to flash floods | 10 (33.3) | 20 (66.7) |
| **6** | The soil type of Setswetla is vulnerable to flash flood | 10 (33.3) | 20 (66.7) |

**SD→D = Strongly Disagree + Disagree A→SA = Agree→Strongly Agree; n= Frequency**

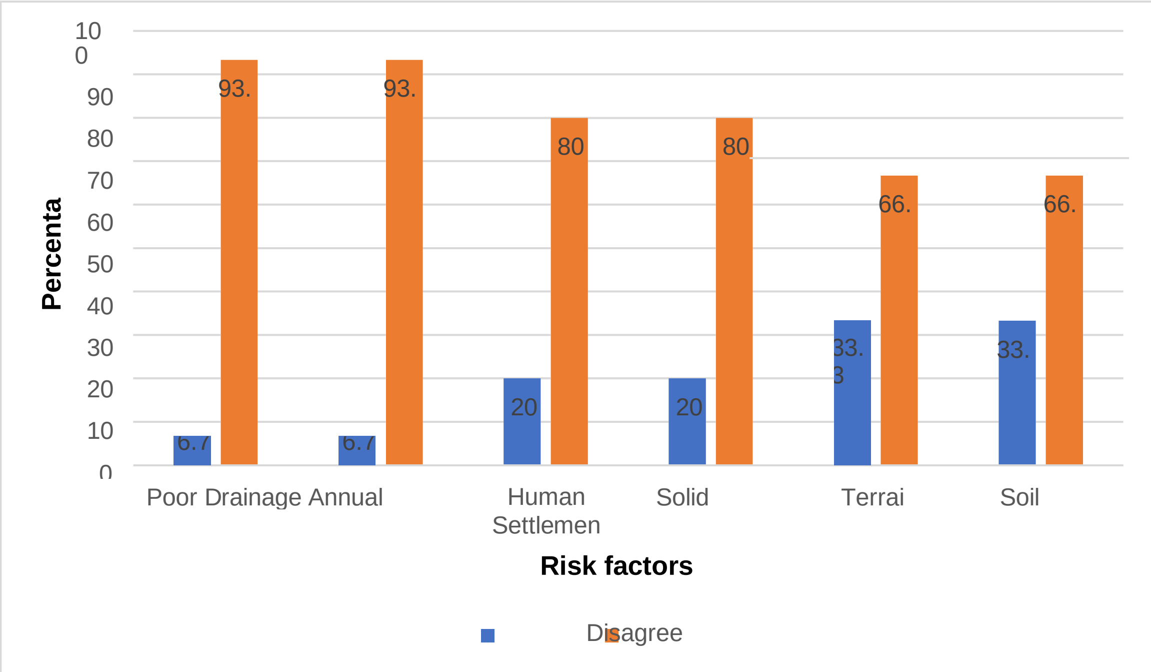


***Figure 4.3: Risk factors identified by respondents in order of importance based on their response***

The correlation matrix showing the risk factors of the flash flood in the Setswetla is given in Table 4.2. It shows a significant relationship between terrain and soil type ($r= 0.946^{**}$, $p < 0.05$); terrain and drainage($r=0.395^{*}$, $p<0.05$) and there is also a relationship between Human settlement and solid waste disposal ($r = 0.385^{*}$, $p <0.05$). However, there is no significant relationship between terrain and Human settlement ($r=0.038$, $p>0.05$); terrain and solid waste disposal ($r = 0.270$, $p > 0.05$); terrain and rainfall ($r = 0.048$, $p >0.05$). There is no significant relationship between soil type and Human settlement ($r = 0.142$, $p> 0.05$), soil type and solid waste disposal ($r = 0.322$, $p > 0.05$); soil type and drainage ($r = 0.350$, $p > 0.05$); and soil type and rainfall($r=0.215$,$p>0.05$).There is no significant relationship between Human settlement and drainage ($r = 0.026$, $p >0.05$); Human settlement and rainfall ($r = 0.031$, $p > 0.05$). There is no significant relationship between solid waste disposal and drainage ($r = 0.132$, $p > 0.05$); solid waste disposal and rainfall ($r = 0.208$, $p >0.05$). There is no significant relationship between drainage and rainfall ($r = 0.345$, $p >0.05$). If there is significant correlation coefficient between two variables, it means there is no significant evidence to conclude that there is a significant linear relationship between the two variable which means the two variables may have no relationship e.g. Terrain and Human settlement; or drainage and rainfall.

**Table 4.2: Correlation Matrix between the risk factors**

| Correlations | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| Terrain (1) | Pearson Correlation | 1 | .946** | 0.038 | 0.270 | .395* | 0.048 |
| | Sig. (2-tailed) | | 0.000 | 0.841 | 0.148 | 0.031 | 0.801 |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| Soil type (2) | Pearson Correlation | .946** | 1 | 0.142 | 0.322 | 0.350 | 0.215 |
| | Sig. (2-tailed) | 0.000 | | 0.455 | 0.083 | 0.058 | 0.253 |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| Human Settlement (3) | Pearson Correlation | 0.038 | 0.142 | 1 | .385* | 0.026 | 0.341 |
| | Sig. (2-tailed) | 0.841 | 0.455 | | 0.036 | 0.891 | 0.065 |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| Solid waste disposal (4) | Pearson Correlation | 0.270 | 0.322 | .385* | 1 | 0.132 | 0.208 |
| | Sig. (2-tailed) | 0.148 | 0.083 | 0.036 | | 0.487 | 0.271 |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| Drainage (5) | Pearson Correlation | .395* | 0.350 | 0.026 | 0.132 | 1 | 0.345 |
| | Sig. (2-tailed) | 0.031 | 0.058 | 0.891 | 0.487 | | 0.062 |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| Rainfall (6) | Pearson Correlation | 0.048 | 0.215 | 0.341 | 0.208 | 0.345 | 1 |
| | Sig. (2-tailed) | 0.801 | 0.253 | 0.065 | 0.271 | 0.062 | |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | | | | |
| *. Correlation is significant at the 0.05 level (2-tailed). | | | | | | | |

Where: X1 = Terrain, X2 = Soil type, X3 = Human settlement, X4 = Solid waste disposal, X5 = Poor drainage, X6 = Annual rainfall

**KMO-Bartlett's Test of Sphericity**

Bartlett's Test of Sphericity is normally conducted to make sure that the correlation matrix of the variables in our dataset diverges significantly from the identity matrix so that we know a data reduction technique such as Factor Analysis (FA) and Principal Component Analysis (PCA)is suitable to use. In cases of orthogonal variables in a dataset, data reduction techniques like FA or PCA would experience difficulties in condensing these variables into linear combinations that can capture significant variance present in the data.

The p-value from Bartlett's Test of Sphericity measured against the chosen significance level of the statistical analysis is used as an indicator of the suitability of the dataset for a data reduction technique application. The common choices of the significance levels are 0.01, 0.05, and 0.1. If the p- value from Bartlett's Test of Sphericity is lower than the chosen significance level, then the given dataset is suitable for a data reduction technique. Unsuitable otherwise. Table 4.3 presents the Test of Sphericity.

**Table 4.3: Test of Sphericity**

**KMO and Bartlett's Test**

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | .459 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 89.628 |
| | Df | 15 |
| | Sig. | .000 |

For this study, the chosen significance level is 0.05. It is observed that the KMO statistic is 0.459; $x^2$ = 89.628; the degrees of freedom (Df) = 15, and the sigma (p)-value = 0.00. Given that the p-value is less than the significance level (0.00 < 0.01). Bartlett's test of sphericity shows the relationship between the risk factors was significant. Since the test of sphericity is significant, we shall use the Principal Components Analysis (PCA) to identify the principal components contributing to the Flash flood in Setswetla to transform the correlated variables to uncorrelated quantities called principal components (PCs) such that the PCs are the linear combinations of the variables. $X_1$, $X_2$ …, $X_n$ and the coefficients ax*i*s.

$$PC_i = a_1X_1 + a_2X_2 + a_3X_3 + \cdots + a_nX_n; \quad i=1, 2, 3, \ldots\ldots, n \qquad (4.1)$$

Where $X_1$ = Terrain $X_2$ = Soil type
$X_3$ = Human settlement $X_4$ = Solid waste disposal $X_5$ = Poor drainage
$X_6$ = Annual rainfall.

Table 4.4, provides information according to the importance of the principal components (based on the % of the variance of the PCs scores) contributing to the flash flood. For this study, a proportion of variance explained greater than or equal to 10% was considered significant. The first four PCs namely-PC1=Terrain (42.0%),

PC2= Soil Texture (23.0%) andPC3= Human settlement (17.0%) and PC4= Solid waste disposal (10%) were observed to contribute about 92% of the total variance to the flash flood. The first four Principal components (PC1), (PC2), and (PC3) and PC4 contributed about 42%, 23%, and 17%, and 10% of the total variance respectively. The three principal components contributing to flash floods in Setswetla were terrain, soil texture, Human settlement, and solid waste disposal. These factors contributed to 92% of the flash flood risk factors.

The importance of the Principal Components is summarized in the table below:

**Table 4.4: Summary of the Principal Components according to their level of importance.**

| | PC 1 (Terrain) | PC 2 (Soil Texture) | PC 3 (Human Settlement) | PC 4 (Solid waste disposal) | PC 5 Drainage | PC 6 (Rainfall) |
|---|---|---|---|---|---|---|
| Std. Dev. | 1.5794 | 1.1747 | 0.9988 | 0.7792 | 0.69933 | 0.17866 |
| % of Variance | 0.4157 | 0.2300 | 0.1663 | 0.1012 | 0.08151 | 0.00532 |
| Cumulative % | 0.4157 | 0.6457 | 0.8120 | 0.9132 | 0.99468 | 1.00000 |

**Scree plot**

In multivariate statistics, a scree plot is described as a line plot of the eigenvalues of factors in an analysis (George *et al*., 2010).The scree plot is employed to determine the number of factors to be kept in exploratory factor analysis (FA) or principal components to be kept in a principal component analysis (PCA). The method of obtaining statistically significant factors or components using a scree plot is also known as the scree test. The Scree plot was introduced by Catell in 1966(Catell, 1966). A scree plot always shows the eigenvalues in a downward curve, ordering the eigenvalues from the largest to the smallest. In line with the scree test, "the elbow of the graph where the eigenvalues seem to level off is established and factors or components to the left of this point should be maintained as significant (Alex *et al*., 2007).

Figure4.4 shows the scree plot which is an exploratory technique to check or verify the number of principal components to choose. The four major PCs were selected based on their percentage contribution to flash floods. These three represents 50% reduction of the six identified risk factors. The four Pcs contribute about 92% of the total risk factors contributing to flash floods in Alexandra.

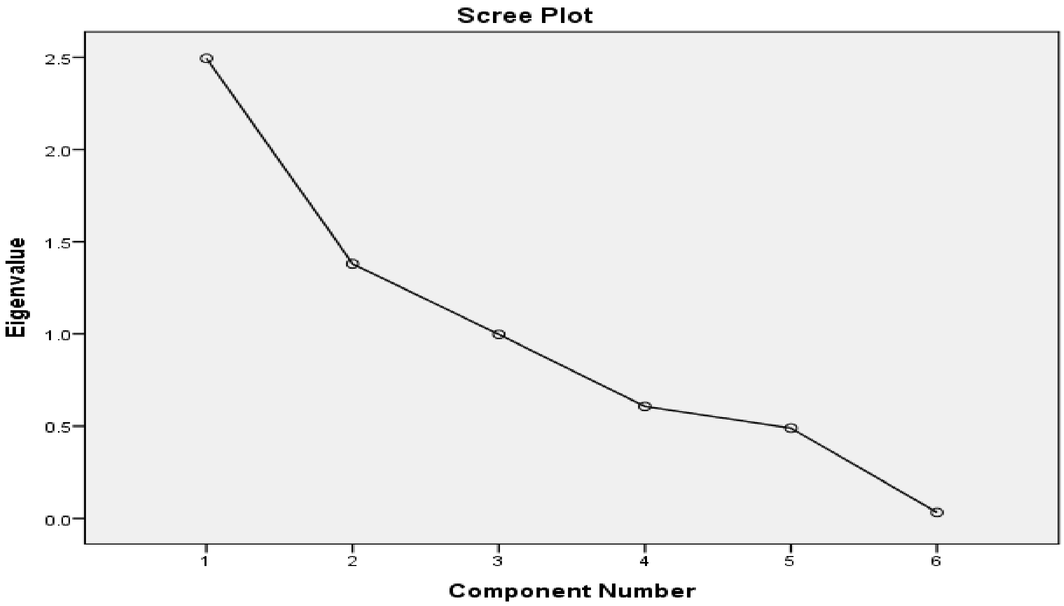


***Figure 4.4: Scree plot showing the contribution of the principal components on flash floods.***

**Application of principal component Analysis**

Principal Component Analysis is a well-established technique for dimensionality reduction and multivariate analysis. Examples of its many applications include data compression, image processing, visualization exploratory data analysis, pattern recognition, and time-series application (Hotelling, 1933).

The equation for obtaining the principal components of this study are presented as follows:

$PC1 = 0.53429X1 - 0.56415X2 - 0.22901X3 - 0.34995X4 - 0.37386X5 - 0.285656$

$PC2 = -0.40539X1 - 0.2792X2 + 0.63302 X3 + 0.34922 X4 - 0.07928 X5 + 0.4782 X6$

$PC3 = 0.16738 X1 + 0.1551 X2 + 0.25538 X3 - 0.44121X4 - 0.63550 X5 -0.53307X6$

$PC4 = 0.16833 X1 + 0.28699X2 + 0.36659 X3 - 0.69943 X4 - 0.44380 X5 +0.26219X6$

$PC5= -0.02227 X1 + 0.13723 X2 - 0.58879 X3 + 0.2677 X4 - 0.49535 X5 + 0.56299X6$

$PC6 = 0.70239 X1 - 0.69172 X2 + 0.02378 X3 + 0.0063 X4 - 0.08805 X5 + 0.14078X6$

To identify the four most significant risk factors, we investigate the coefficients of the PC1, PC2, and PC3, and PC4 which contributed about 42%, 23%, and 17%, and 10% respectively. The most influential coefficients were 0.5342920, 0.5641463 and 0.3738571, and 0.34995 which corresponded to Terrain, soil type, and solid waste disposal respectively. The response of the respondents on the four principal components are represented in Figure 4.5. The figure shows the classification of the assessment of the respondents regarding the contribution of the four major principal components. A higher proportion of the respondents either agree or strongly agreed that terrain, soil texture, and poor drainage, and solid waste disposal were the major risk factors in Alexandra Township. However, according to the respondents, poor drainage was considered to be the major principal component.

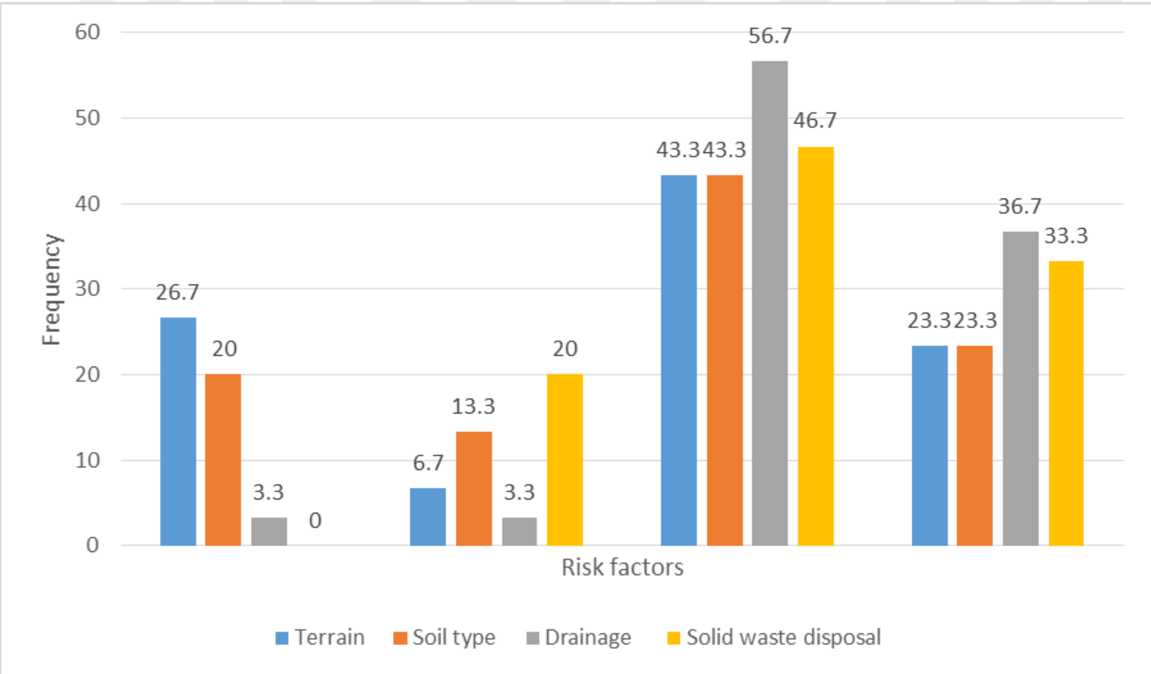


***Figure 4.5: The response of the respondents on the four most significant risk factors on flash floods in Setswetla.***

### 4.4.2 Respondents report on mitigation factors on flash flood in Setswetla

**Objective Two:** To determine appropriate, effective, and efficient measures to mitigate flash flood hazards to life and property.

#### 4.4.2.1 Respondents report on Mitigation factors on flash flood in Setswetla

Table 4.5a and 4.5b indicate that majority (66.7%) of the respondents strongly disagreed that wooden barriers were constructed to prevent flash floods in Setswetla. One-third (33.3%) of the respondents agreed while 63.3% disagreed that stones (Gabions) barriers were constructed to prevent flash floods in Setswetla. Many (66.7%) of the respondents strongly disagreed that anti-debris dams were constructed to prevent flash floods. Similarly, less than half (43.3%) of the respondents strongly disagreed while 76.7% disagreed that dykes were constructed to avert flash floods in Setswetla.

Likewise, a majority (70.3%) of the respondents disagreed that culverts were constructed to control flash floods in Setswetla. Similarly, many (70.0%) of the respondents disagreed that adequate drainage channels were constructed to control flash floods. almost all the respondents (90.0%) disagreed that sewers were constructed to control flash floods and small reservoirs were constructed to control flash floods in Setswetla. Many (80.0%) of the respondents also disagreed that the Jukskei river around Setswetla was regularly drained. Likewise, many (73.3%) of the respondents cared for by cutting of trees. Similarly, (70.0%) of the respondents disagreed that there was proper land use planning in Setswetla. More than half (53.3%) of the respondents strongly agreed that there was an adequate public awareness campaign against flash floods in Setswetla. About a half (56.7%) of the respondents disagreed that there was an early warning system in Setswetla. Likewise, many (83.3%; 68.7% and 93.3%) of the respondents strongly disagreed that there is effective maintenance of flash flood infrastructures, effective metrological measures to mitigate flash floods, and adequate hydrological measures to control flash floods in Setswetla respectively.

In summary, the majority of the stakeholders agreed that most of the appropriate mitigating factors to prevent flash floods in Setswetla were not available. However, more than half of the respondents (53.3%) agreed that public awareness was adequate.

Thus, there is a need to apply adequate and appropriate mitigation factors to prevent flash floods in Setswetla.

**Table 4.5a: Flash flood risk Management factors in Alexandra Township: Mitigation factors reported by the respondents**

| | MITIGATION FACTORS | SD n (%) | D n (%) | A n (%) | SA n (%) |
|---|---|---|---|---|---|
| **1** | Wooden barriers are constructed to prevent flash floods in Setswetla | 20 (66.7) | 6 (20.0) | 3 (10.0) | 1 (3.3) |
| **2** | Stones (Gabions) barriers are constructed to prevent flash floods in Setswetla | 9 (30.0) | 10 (33.3) | 10 (33.3) | 1 (3.3) |
| **s3** | Anti-debris dams are constructed to prevent flash floods in Setswetla | 20 (66.7) | 7 (23.3) | 1 (3.3) | 2 (6.7) |
| **4** | Dykes are constructed to avert flash floods in Setswetla | 13 (43.3) | 10 (33.3) | 4 (13.3) | 3 (10.0) |
| **5** | Culverts are constructed to control flash floods in Setswetla | 18 (60.0) | 4 (13.3) | 7 (23.3) | 1 (3.3) |
| **6** | Adequate drainage channels are constructed to control flash floods in Setswetla | 13 (43.3) | 8 (26.7) | 4 (13.3) | 5 (16.7) |
| **7** | Sewers are constructed to control flash floods in Setswetla | 18 (60.0) | 9 (30.0) | 2 (6.7) | 1 (3.3) |
| **8** | Small reservoirs are constructed to retain flash floods in Setswetla | 18 (60.0) | 8 (26.7) | 2 (6.7) | 2 (6.7) |
| **9** | Juskei river around Setswetla is regularly drained | 15 (50.0) | 9 (30.0) | 5 (16.7) | 1 (3.3) |
| **10** | The valley of the river is regularly cared for by cutting trees | 16 (53.3) | 6 (20.0) | 5 (16.7) | 3 (10.0) |
| **11** | There is proper land use planning in Setswetla | 15 (50.0) | 6 (20.0) | 6 (20.0) | 3 (10.0) |
| **12** | There is adequate public awareness campaign against flash floods in Setswetla | 9 (30.0) | 5 (16.7) | 6 (20.0) | 10 (33.3) |
| **13** | There is early warning system in Setswetla | 4 (13.3) | 13 (43.3) | 6 (20.0) | 7 (23.3) |
| **14** | There is effective maintenance of flash flood infrastructures in Setswetla | 16 (53.3) | 9 (30.0) | 2 (6.7) | 3 (10.0) |
| **15** | There are effective metrological measures to mitigate flash floods in Setswetla | 16 (53.3) | 10 (33.3) | 1 (3.3) | 3 (10.0) |
| **16** | There are adequate hydrological measures to control flash floods in Setswetla | 16 (53.3) | 12 (40.0) | 1 (3.3) | 1 (3.3) |

**SD = Strongly Disagree, D = Disagree, A = Agree, SA = Strongly Agree; n= Percentage Frequency**

As summarised in Table 4.5b, the majority (86.7%) of the respondents disagreed that wooden barriers were constructed to prevent flash floods in Setswetla but only a few (13.3%) agreed. Likewise, many (63.3%) of respondents disagreed that stones (Gabions) barriers were constructed to prevent flash floods in Setswetla while 36.7% disagreed. Most (90.0%) of respondents disagreed that anti-debris dams were constructed to prevent flash floods in Setswetlabutone-tenth(10.0%)agreed.Similarly,many(76.7%)ofrespondentsdisagreedthat dykes were constructed to avert flash floods in Setswetla while 23.3% agreed. A greater proportion (73.3%) of the respondents disagreed that culverts were constructed to control flash floods in Setswetla while a few (26.7%) agreed.

**Table4.5b: Summary of the Stakeholders Responses on the Mitigation Factors being used in Alexandra Township**

| | MITIGATION FACTORS SD□ | D n (%) | SA□ A n (%) |
|---|---|---|---|
| 1 | Wooden barriers are constructed to prevent flash floods in Setswetla | 26 (86.7) | 4 (13.3) |
| 2 | Stones (Gabions) barriers are constructed to prevent flash floods in Setswetla | 19 (63.3) | 11 (36.7) |
| 3 | Anti-debris dams are constructed to prevent flash floods in Setswetla | 27 (90.0) | 3 (10.0) |
| 4 | Dykes are constructed to avert flash floods in Setswetla | 23 (76.7) | 7 (23.3) |
| 5 | Culverts are constructed to control flash floods in Setswetla | 22 (73.3) | 8 (26.7) |
| 6 | Adequate drainage channels are constructed to control flash floods in Setswetla | 21 (70.0) | 9 (30.0) |
| 7 | Sewers are constructed to control flash floods in Setswetla | 27 (90.0) | 3 (10.0) |
| 8 | Small reservoirs are constructed to retain flash floods in Setswetla | 26 (86.7) | 4 (13.3) |
| 9 | Jukskei river around Setswetla is regularly dredged | 24 (80.0) | 6 (20.0) |
| 10 | The valley of the river is regularly cared for by cutting trees | 22 (73.3) | 8 (26.7) |
| 11 | There is proper land use planning in Setswetla | 21 (70.0) | 9 (30.0) |
| 12 | There is an adequate public awareness campaign against flash floods in Setswetla | 14 (46.7) | 16 (53.3) |
| 13 | There is an early warning system in Setswetla | 17 (56.7) | 13 (43.3) |
| 14 | There is effective maintenance of flash flood infrastructures in Setswetla | 25 (83.3) | 5 (16.7) |
| 15 | There are effective metrological measures to mitigate flash floods in Setswetla | 26 (86.7) | 4 (13.3) |
| 16 | There are adequate hydrological measures to control flash floods in Setswetla | 28 (93.3) | 2 (6.7) |

SD→**D =** Disagree**; SA**→**A =** Agree n = Percentage Frequency

Likewise, a majority (70.0%) of the respondents disagreed that adequate drainage channels were constructed to control flash floods in Setswetla while 30.0% agreed. Most (90.0%) disagreed that sewers were constructed to control flash floods in Setswetla while 10.0% agreed. The majority (86.7%) of the respondents disagreed that small reservoirs were constructed to retain flash floods in Setswetla while 13.3% agreed. Similarly, a majority (80.0%) of the respondents disagreed that the Jukskei River around Setswetla was regularly drained while 20.0% agreed. Likewise, many (73.3%) of the respondents disagreed that the valley of the river was regularly cared for by cutting trees while about a quarter (26.7%)

agreed. The majority (70.0%) of the respondents disagreed that there was proper land use planning in Setswetla while 30.0% agreed. Less than half (46.7%) of the respondents disagreed that there was adequate public awareness campaign against flash floods in Setswetla while more than half (53.3%) agreed. Likewise, many (56.7%) of the respondents disagreed that there was an early warning systeminSetswetlawhile43.3% agreed. Most (83.3%) of the respondents disagreed that there was effective maintenance of flash flood infrastructures in Setswetla while 16.7% agreed. Likewise, many (86.7%) of respondents disagreed that there were effective metrological measures to mitigate flash floods in Setswetla while only a few (13.3%) agreed. Similarly, most (93.3%) of the respondents disagreed that there were adequate hydrological measures to control flash floods in Setswetla while only a few (6.7%) agreed.  This indicates that infrastructural facilities to mitigate the impacts of flashflood were either inadequate or not available.

Table 4.5c presents the responses of the stakeholders according to their level of agreement on the mitigating factors being used against flash floods in Setswetla. More than half (53.3%) of the stakeholders agreed that an adequate public awareness campaign was being used. However, most of the stakeholders 93.3% disagreed that infrastructural facilities to mitigate the impact of flashflood were not available

**Table 4.5c: Summary of the responses on the Mitigation factors being used in Setswetla**

| **MITIGATION FACTORS** | **SD→D n (%)** | **SA→A n (%)** |
|---|---|---|
| There is an adequate public awareness campaign against flash floods in Setswetla | 14 (46.7) | 16 (53.3) |
| There is an early warning system in Setswetla | 17 (56.7) | 13 (43.3) |
| Stones (Gabions) barriers are constructed to prevent flash floods in Setswetla | 19 (63.3) | 11 (36.7) |
| Adequate drainage channels are constructed to control flash floods in Setswetla | 21 (70.0) | 9 (30.0) |
| There is proper land use planning in Setswetla | 21 (70.0) | 9 (30.0) |
| Culverts are constructed to control flash floods in Setswetla | 22 (73.3) | 8 (26.7) |
| The valley of the river is regularly cared for by cutting trees | 22 (73.3) | 8 (26.7) |
| Dykes are constructed to avert flash floods in Setswetla | 23 (76.7) | 7 (23.3) |
| Jukskei river around Setswetla is regularly dredged | 24 (80.0) | 6 (20.0) |
| There is effective maintenance of flash flood infrastructures in Setswetla | 25 (83.3) | 5 (16.7) |
| Wooden barriers are constructed to prevent flash floods in Setswetla | 26 (86.7) | 4 (13.3) |
| Small reservoirs are constructed to retain flash floods in Setswetla | 26 (86.7) | 4 (13.3) |
| There are effective metrological measures to mitigate flash floods in Setswetla | 26 (86.7) | 4 (13.3) |
| Anti-debris dams are constructed to prevent flash floods in Setswetla | 27 (90.0) | 3 (10.0) |
| Sewers are constructed to control flash floods in Setswetla | 27 (90.0) | 3 (10.0) |
| There are adequate hydrological measures to control flash floods in Setswetla | 28 (93.3) | 2 (6.7) |

**SD→D =** Disagree, **SA→ A =** Agree; n= Percentage Frequency

4.4.3 **Objective Three:** To develop an applicable flood inundation model that will manage flash flood risk and related hazards in the selected area.

Sixteen (16) mitigation factors were investigated. Each mitigation factor was regressed on the risk factors namely Terrain, Soil Texture, Human settlement, Solid waste disposal, drainage, and Rainfall. From the statistical analysis, only construction of Sewers and dredging Jukskei Rivers yielded the best fit with both having coefficient of determination *($R^2$)* of about 50%. The coefficient of determination is the amount of variation in the response variables (Construction of Sewers and dredging of Rivers) that contributed to the risk factors. The remaining 50% of the variation is due to other risk factors. The applicable flash flood inundation model that will manage Flash Flood and related hazards in the selected area of Alexandra Township was developed from the response of stakeholders to the questionnaires.

As indicated in Table 4.6a, the relationship between the mitigation factor, the rivers, and the risk factor is captured in the model below:

**Table 4.6a: The relationship between mitigation factor (Jukskei River) and the risk factors**

| Model | Unstandardized Coefficients | | Standardized Coefficients | T | Sig. |
|---|---|---|---|---|---|
| | B | Std. Error | Beta | | |
| (Constant) | 2.110 | .973 | | 2.168 | .041 |
| Terrain | -.507 | .450 | -.660 | -1.127 | .271 |
| Soil type | .089 | .476 | .108 | .187 | .853 |
| Human settlement | .436 | .145 | .509 | 3.002 | .006 |
| Solid waste disposal | -.090 | .199 | -.076 | -.455 | .653 |
| Drainage | .622 | .229 | .495 | 2.711 | .012 |
| Rainfall | -.728 | .329 | -.445 | -2.211 | .037 |

Model:

=2.110−0.507X1+0.089X2+0.434X3−0.090X4+0.622X5−0.728X6+ei……….(4.2i)

Where X1 = Terrain X2 = Soil type

X3 = Human settlement X4 = Solid waste disposal X5 = Poor drainage

X6 = Annual rainfall.

Alternatively,

Yi = 2.110 − 0.507(Terrain) + 0.089(Soil Texture) + 0.434(Human Settlement)

− 0.090(Solid waste disposal) + 0.622(Drainage) − 0.728(Rainfall)+ei…….. (4.2ii)

The model can be interpreted that: as for any unit increase in terrain, the volume of the river would decrease by (-0.507), for any unit increase of the type of the soil, the volume of the river would increase 0.089 and so on till rainfall. The coefficient of determination of the model is about 50%. This implies that the amount of variation in the mitigation factor (River) that is traced to the risk factor is 50%.

Similarly, the relationship between sewers and the risk factors is captured in the model as shown in table 4.6b:

**Table 4.6b: The relationship between the mitigation factor (Sewer) and the risk factor**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 1.466 | .866 | | 1.693 | .104 |
| | Terrain | .881 | .401 | 1.282 | 2.199 | .038 |
| | Soil type | -.530 | .423 | -.721 | -1.252 | .223 |
| | Human settlement | .421 | .129 | .550 | 3.256 | .003 |
| | Solid waste disposal | -.388 | .177 | -.365 | -2.193 | .039 |
| | Drainage | -.269 | .204 | -.240 | -1.320 | .200 |
| | Rainfall | .013 | .293 | .009 | .043 | .966 |

Model:

$$Yi = 1.466 + 0.881(\text{Terrain}) - 0.530(\text{Soil Texture}) - 0.421(\text{Human Settlement}) - 0.388(\text{Solid waste disposal}) - 0.269(\text{Drainage}) + 0.013(\text{Rainfall}) + ei \ldots\ldots\ldots (4.3)$$

The model can be interpreted that: as for any unit increase in terrain, the volume of the sewers would increase by (0.881), for any unit increase of the type of the soil, the volume of the sewers would decrease (-0.530), and so on till rainfall. The coefficient of determination of the model is about 50%. This implies that the amount of variation in the mitigation factor (Sewers) that is traced to the risk factor is 50%. The most appropriate model that will manage flash flood risk and related hazards in the selected area are rivers and sewers.

The factors that were responsible for flash flood risk management were identified and arranged in order of importance by the bar chart as shown in Figure 4.6. The risk factors could be eliminated through a solution to the identified listed problems: Sewers and solid waste disposal, Jukskei River dredging, construction of Gabions, Anti-debris dams, the valley of Jukskei River, Wooden barriers, Culverts, Drainage channels, Reservoirs to retain flash flood, adequate Dykes, Adequate Hydrological measures, early warning systems, effective maintenance, adequate public awareness, and land use planning. However, Sewers and solid waste as well as the Jukskei River around Setswetla provided the highest risk factors. Solid waste disposal in Setswetla should be taken seriously by providing dumping sites, incinerators and defaulters should be sanctioned. The sewer systems should be maintained, a facility for treatment for raw sewers should be installed and raw sewer must not flow into Jukskei River to produce flash floods and pollution. The shallow Jukskei River should be dredged, widened and steel- reinforced embankment to accommodate a larger volume of water and prevent the collapse of the riverbank.

The most appropriate model that will manage flash flood risk and related hazards in the selected area are rivers and sewers.

1. **Barrier:**

$$Yi = 1.28 + 0.202\,(\text{Terrain}) + 0.023\,(\text{Soil texture})$$
$$+\ 0.456\,(\text{Human Settlement})\ 0.003\,(\text{Rainfall}) + \epsilon_i \ldots (4.4)$$

2. **Gabions:**

$$Yi = 0.338 + 0.177\,(\text{Terrain}) + 0.350\,(\text{Soil texture}) + 0.210\,(\text{settlement})$$
$$-\ 0.355\,(\text{Waste}) - 0.137\,(\text{Drainage}) + 0.409\,(\text{Rainfall}) + \epsilon_i \ldots (4.5)$$

**3.** **Dam:**

Yi = 2.886 + 0.237 (Terrain) + 0.177 (Soil texture) + 0.377 (Human settlement) − 0.486 (Waste) − 0.230 (Drainage) − 0.410 (Rainfall) + Ɵ … (4.6)

4. **Dykes**:

Yi = −0.236+ 0.890 (Terrain) − 0.485 (Soil texture) + 0.222 (Human settlement) − 0.083 (Solid waste) − 0.133 (Drainage) +0.362 (Rainfall)+ Ɵi … (4.7)

5. **Culverts**:

Yi = −0.688 + 0.944 (Terrain) − 0.581 (Soil texture) + 0.269 (Human settlement) + 0.116 (Solid waste disposal) − 0.047 (Drainage) + 0.148 (Rainfall)+Ɵi (4.8)

**6.** **Channels:**

Yi = 0.08 + 0.302 (Terrain) + 0.035 (Soil texture) + 0.147 (Human settlement) + 0.246 (Solid waste) + 0.534 (Drainage) − 0.594 (Rainfall)+Ɵi (4.9)

**7.** **Sewers:**

Yi = 1.466 + 0.881 (Terrain) − 0.530 (Soil texture) + 0.421 (Human settlement) – 0.388 (Solid waste) − 0.269 (Drainage) + 0.013(Rainfall)+Ɵi (4.10)

**8.** **Reservoirs:**

Yi = 0.440 + 0.703 (Terrain) − 0.344 (Soil texture) + 0.328 (Human settlement) – 0.067 (Solid waste disposal) − 0.494 (Drainage) + 0.348(Rainfall) +Ɵi (4.11)

**9.** **Rivers:**

Yi = 2.110 – 0.50 (Terrain) + 0.089 (Soil texture) − 0.434 (Human settlement) + 0.090 (Solid waste disposal) + 0.622 (Drainage) − 0.728 (Rainfall)+Ɵi (4.12)

10. **Valleys**:

Yi = 1.877 – 1.575 (Terrain) + 1.612 (Soil type) + 0.442 (Human settlement) – 0.013 (Solid waste disposal) + 0.199 (Drainage) − 0.680(Rainfall)+Ɵi (4.13)

11. **Planning**:

Yi = 2.028 – 0.645 (Terrain) + 0.879 (Soil type) + 0.108 (Human settlement)+ 0.018 (Solid waste disposal) + 0.132 (Drainage) − 0.507 (Rainfall) +Ɵi (4.14)

12. **Awareness**:

Yi = 0.660 – 0.769 (Terrain) + 1.001 (Soil type) − 0.271 (Human settlement) + 0.109 (Solid waste disposal) + 0.388 (Drainage) + 0.132 (Rainfall)+Ɵi (4.15)

13. **Warning**:

Yi = −0.700 – 0.142 (Terrain) + 0.188 (Soil type) + 0.214 (Human settlement) + 0.307 (Solid waste disposal) + 0.412 (Drainage) + 0.052 (Rainfall)+Ɵi (4.16)

**14.** **Maintenance:**

Yi = 0.119 + 0.372 (Terrain) + 0.611 (Soil type) + 0.358 (Human settlement) + 0.108(Solid waste disposal) + 0.486 (Drainage) − 0.218(Rainfall)+Ɵi (4.17)

**15.** **Metrological:**

Yi = 0.134 + 0.624 (Terrain) − 0.789 (Soil type) + 0.429 (Human settlement) – 0.162 (Solid waste disposal) + 0.321 (Drainage) + 0.080 (Rainfall)+Ɵi (4.18)

The best fit for mitigating flashflood in Alexandra Township is construction of sewer/appropriate solid waste disposal and dredging of Juskei River.

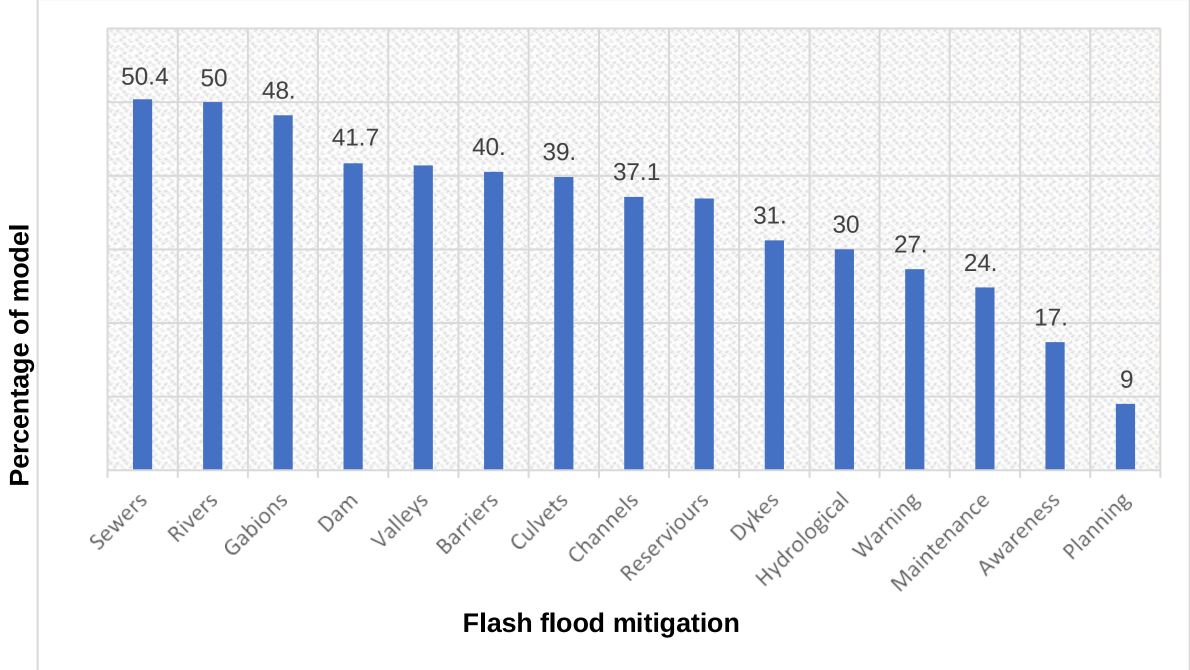


***Figure 4.6: Arrangement of the model that will best manage flash flood in order of importance***

### 4.5 Discussion

#### 4.5.1 Response from the City of Johannesburg (COJ: Public Safety Committee on flash flood in Setswetla)

A sustainable flash flood risk management requires a flood risk assessment to identify factors causing flash flood risk in Alexandra Township which is a flood-prone area since it is situated on the bank of Jukskei River which was reported to have collapsed because of heavy rainfall (Aurelie, 2016). Jukskei River is a shallow river that was reported to have collapsed because of heavy rainfall (Aurelie, 2016). Report from this study revealed that k River is heavily polluted by urban runoff and lack of maintenance of flood channel infrastructure as well as illegal dumping of rubbles. This indicates the need to dredge the river, channelization, and reinforced the concrete embankment of the river. This will help to increase the capacity of the river and prevent collapsing. There is a flow of raw waste into the river daily. The banks are prone to bursting especially in summer when rainfalls are the heaviest during the year.

The river becomes disastrous for poor residents who build their shacks along the river banks to have access to water for washing and cooking. This indicates that the poor residents should build their shacks at a regulated distance from the bank and drainages should be improved to control the direction of runoff water

From the feedback report on Jukskei River flooding, (COJ: Public Safety Committee Disaster Management Report, 2016), the recent severe rain in the province and subsequent flash flood, Jukskei River had to burst its bank and several citizens in the township were displaced and had to be housed in temporary shelters. Over 376 shacks and 889 persons were affected by their displacements and there was an outbreak of a communicable disease such as typhoid and cholera as a result of the flood. This information highlights the impact of the flash flood on the resident and the need to provide a permanent solution rather than the current ad-hoc actions to this disaster; Alexandra Township was also reported as a densely populated township with absolute grinding poverty within the community with several residents living in very dirty and unhygienic circumstances that may expose them any time to all common communicable diseases such as typhoid, cholera, and tuberculosis. This report indicates the need for proper town planning and enforcement of sanitation by Public Health Officials.

Information obtained from the In-depth Interview with the Disaster Manager and other Senior Officers at the Disaster Management Services indicated that the Disaster Management Department Services in flash flood management ensured that people were educated about flash floods in Alexandra for them not to build on low lane areas and also not to build their shacks along the Jukskei River. Also, early warning messages about imminent floods were provided for the people. Community Volunteers were also trained on flash flood risks and disaster management.

All these indicate that the Disaster Management Services has an existing management structure for flash floods. However, the main method of managing flash floods is mainly the maintenance of stormwater channels and the education of the community not to dump solid waste into the drainage system. This information highlights the need for solid waste dumping site incinerators and wastes to wealth-waste recycling. There is also a need for strong rule enforcement and sanction for defaulting in waste dumping regulations. One of the main causes of flash floods that were reported in Alexandra Township was the unregulated building of shacks without abiding by the rules and regulations which prevented the flow of stormwater causing flash floods. Also, the drainage system in Alexandra was usually blocked because of the illegal dumping of solid waste. This indicates that the building of shacks should be according to the laid out plan and the drainage system should be maintained regularly and if possible, should be expanded to accommodate the volume of stormwater as a civil engineering solution. According to Berz *et al.,* (2001), one of the corner stones of flood risk management is the preparedness of people at risk. There port also indicates that for the preparedness of people for the risk of flash floods, people were educated on the risk of flash floods, and volunteers were trained on what to do to prepare for flashfloods.

According to Guha *et al.,* (2016) and in agreement with the center for research on the Epidemiology of disaster, approximately 72% of natural disasters reported in South African regions were severe weather which is hydro-metrological such as flash flood storms. The report indicated that Setswetla was usually affected by flash floods due to devastating extreme weather conditions. Most of the community was left homeless. However, it was discovered that most of those affected resided along Jukskei River Bank in Alexandra, and approximately a hundred shacks were washed away by the flood (COJ: Public Safety Committee Disaster Management Report, 2016). Although the weather cannot be controlled, the disaster can be improved by ensuring that shacks are not built close to the Jukskei River and the riverbank should be structurally reinforced.

One of the main limitations to flash floods risk management in Alexandra was reported to be inadequate finance to build gabions along the Jukskei River to accommodate the rise in water level to prevent flash floods in the township. There was also the limitation of land invasion; the government would need to consider the building of gabions along the Jukskei River as a solution and as a priority to mitigate the impact of flash floods on life and property in Alexandra. It was also reported that population growth adversely affected the stormwater drainage system which used to be in perfect condition. The need to overhaul and regular maintenance of the drainage system was suggested to provide for the increase in population growth.

According to the Report of the Public Safety Committee Disaster Management (2016), approximately three hundred and seventy-six (376) households and approximately eight hundred and eighty-nine (889) people were affected and the displaced were temporarily accommodated at the pre-school. Males were housed in tents while women and children were housed in one of the pre-schools within the area. With regards to insurance cover for life and property in Alexandra, it was reported that the majority of people in Alexandra Township were not having insurance cover because most people were not paying tax which made it difficult for the municipality to provide such services. This indicates that the people in Alexandra would need to be educated on the necessity for tax payment to provide insurance cover.

The impact of flash floods is a disaster with a serious effect on people. The impact of flash floods in the Alexandra community included loss of life, destruction of shacks, and the spread of disease. All these indicate the necessity for more effective intervention against another occurrence of flash floods.

With regards to the perception of the community on the need to protect themselves against flash floods, the report indicated that the people did not show interest and did not take part in the awareness campaign organized on flash floods because they did not take flash floods seriously. The sustained campaign on the adverse effects of flash floods and the necessity to show interest in its mitigation should be emphasized.

According to Guha *et al.*, (2016), South Africa is part of the most vulnerable region of the world to hydro-metrological hazards including flash floods, cyclones, droughts, and extreme weather. As a result of these, lives had been lost, many dwellers had been displaced from their homes; the property had been destroyed along with the spread of communicable diseases such as cholera and other water-borne diseases. Flash flood in Alexandra was categorized as a high risk. The most appropriate method suggested for managing flash floods in Alexandra was that the weather rainfall stations should ensure the Early Warning System on the imminent occurrence of flash floods for the community.

### 4.5.2 The Survey

Flash flood has been recognized as one of the major natural hazards in South Africa due to the country's semi-arid or arid climate. Flash floods were among the top two most important hazards around the world and it requires specific attention (WMO, 2008). To determine the most appropriate flood inundation model that could be applied in the management of flash floods and related hazards in Alexandra Township which is a flash flood-prone area in South Africa, a survey was conducted as the second phase of this study with three objectives.

From the outcome of the survey, the possible flash flood risk factors in descending order are: Poor drainage network, annual rainfall intensity, human settlement, solid waste disposal, the terrain of Setswetla, and soil texture were observed to be the risk factors of flash floods. The poor drainage network is a civil engineering problem as well as poor human settlement, planning, and sanitation. These problems can be solved by expanding the drainage network to accommodate a larger volume of stormwater and also through regular maintenance and avoidance of solid waste dumping. Good human settlement planning and sanitation are also essential in solving these problems. Solid waste disposal can be undertaken by providing solid waste dumping sites, incinerators, and waste to wealth by recycling and biogas. Good sanitation needs to be enforced by Public Health Officials. Annual rainfall is a natural phenomenon contributing to flash floods in Setswetla, however, the problem it creates can be restricted by public awareness through Early Warning and Public awareness in form of education and pro- active action to mitigate the effect of intensive rainfall.

The terrain of Setswetla can be improved by civil engineering works-grading and filling, by earthworks, and providing a free flow of water. Soil texture can be improved by proper landscaping of the Township and planting of trees around the Jukskei River to prevent the soil from the impact of rain.Plantingoftreeswillhelptobindandholdsoilinplacewiththeroots thus preventing soil erosion and the silting of the River which reduces the flow capacity and further reduces the problem of flooding (https://www.nwtree.com/blog/can- trees-flooding/).

Major civil engineering work like dredging, reinforced concrete embankment should be undertaken on the shallow river to accommodate the volume of water from flash floods and to allow free flow of flash flood water. Dumping of solid waste and industrial waste should be penalized. Also, the sewer system should be maintained by providing a modern facility for the treatment of raw sewer which must not be allowed to flow into the river, which will cause flash floods and pollution hazards to human health.

The correlation matrix between the risk factors indicated that out of the six identified flash flood risk factors four factors- terrain, soil texture, human settlement, and solid waste disposal significantly correlated with flash flood risk in Setswetla. Several studies have been carried out on the improvement of flash flood hazards in South Africa (Balica *et al*., 2013; Musyoski *et al*., 2016). These studies dealt with the effect of flash floods on communities. to highlight the long-term proactive measures in dealing with flash floods in Alexandra Township principal components were selected based on their contribution. The principal components contributing to the flash flood in Setswetla were analyzed to be the terrain, soil texture, and human settlement, and inappropriate solid waste disposal. The government and civil society should take effective action to stem the effects of these principal components (i.e. main risk factors) contributing to flash floods in Setswetla.

The second objective of the second phase of this study was to determine appropriate, effective, and efficient measures to mitigate flash flood hazards to life and property. Based on the stakeholder's responses, appropriate measures to prevent flash floods in Setswetla were not being taken. The main mitigating factor identified to be operating as a public awareness campaign against flash floods in Setswetla. However, other mitigation factors which were not effectively used are: early warning system, construction of stone gabions barriers, adequate drainage channels, land use planning, and adequate culverts were not constructed, the valley of the river was not regularly cared for, no construction of enough dykes and so on. The government needs to take cognizance of these factors to mitigate flashfloods.

The third objective was to determine an applicable flash flood inundation model that will best mitigate flash flood risks and related hazards in Alexandra Township. Out of the sixteen mitigating factors identified in this study, the maintenance of drainage network, embankment, dredging, and reinforced concrete of Jukskei Riverbank to accommodate flash flood, produced the best model applicable in the study area. Thus, the best fit for mitigating flash flood risks in Alexandra Township  are construction of sewers for proper drainage, provision of dumping site for disposal of solid waste such as incinerator and dredging of shallow areas of Juskei river and as well as  use of steel embankments to prevent the collapse of Juskei river bank.

## CHAPTER FIVE

## 5.0 CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

Flash Floods in South Africa has been identified as one of the major natural hazards because of the Country's semi-arid to arid climate. It has been discovered from the World Meteorological Organization Country-level Survey in 2008 that out of 139 Countries, 105 has indicated that Flash Floods were among the top two most devastating hazards around the world (WMO, 2008).

Flash Floods in Setswetla Township in Alexandra is very devastating and destructive to both lives and properties in the community. It was discovered from this study's findings that people living in the community do not abide by the rules and regulations when building their shacks. The residents build their shacks very close to the banks of the Jukskei River which makes it very easy for the shacks to be swept away when there is arise in the water level of the Jukskei River during heavy rainfall.

The living condition of the community is very unhygienic and dirty due to lack of proper drainage systems and dumping sites. This makes the people in the community open to all kinds of diseases such as dysentery, cholera, and Tuberculosis. The Disaster Management in Sandton engages in awareness campaigns to educate the community on the risks and hazards associated with Flash Floods. Volunteers in the Township of Setswetla were trained on methods of handling the risks and the hazards associated with Flash Floods whenever the devastating event occurs. The Disaster Management in Sandton has a good relationship with the South African Weather Services which sends early warning messages about the imminent Flash floods to the Disaster Managers in Sandton. The Disaster Managers also warn the community leaders on the Flash flood events so that the community will be fully prepared in handling the risks and hazards related to Flash flood. The Disaster Management also request for the assistance of NGOs (Non-Governmental Organizations) and Gifts of the Givers to provide temporal accommodation, water, food, and blankets for the people affected by the devastating and destructive effect of Flash Floods. One of the limitations to flash floods in the Township of Alexandra was financially related. This made it difficult for gabions to be built along the Jukskei River to reduce the rise in the water level of the Jukskei River during heavy intense rainfall in the Township.

The main risk factors contributing to flash floods in Setswetla Township were discovered to be annual rainfall intensity, poor drainage system, and population growth of the people in the Township. The capacity of flash flood risk management in Alexandra does not meet up with the population growth of the city.

The study revealed that the residents in the Township of Alexandra were not paying tax and they did not have insurance cover for the municipality to provide the necessary services and amenities that will mitigate the risks associated with flash floods. Also, the residents did not take awareness campaigns on flash floods seriously. They were not participating in gatherings where awareness of the implications of flash floods was organized. The main flash flood risk factors observed obtained from the survey carried out in the Township of Alexandra were heavy annual rainfall intensity, poor drainage system, and human settlement. it was discovered that there was public awareness campaign and early warning system. However, the appropriate effective measure to mitigate flash floods include construction of sewer, appropriate waste disposal, dredging of Juskei Riverbank, construction of stone gabions barriers, construction of adequate drainage channels, good land use planning and building of dykes among others. The best fit for mitigating flash flood in Alexandra is construction of sewers, appropriate disposal of solid waste and dredging of Juskei River.

## 5.2 Recommendations

To manage the Flash Floods risks and hazards to lives and properties in Setswetla in Alexandra, the following recommendations should be adhered to

i. Human settlement in the Township of Alexandra should be properly planned with good sanitation enforced by public health officials

ii. Solid waste disposal in Setswetla can be undertaken by providing solid waste dumping sites, incinerators, and waste to wealth by recycling and biogas

iii. The terrain of Setswetla can be improved upon Civil Engineering works-grading and filling by earthworks and providing free flow of stormwater.

iv. A major Civil Engineering work should be undertaken on the shallow Jukskei River to reduceflashfloods.Thisincludeschannelizationoftheriverbydredging, embankment to keep flash floods back, and also widening of the river to accommodate the volume of water from flash floods as well as to allow the free flow of storm waters.

v. Dumping of refuse and garbage's and industrial waste into the river should be penalized by the Government

vi. The sewer system should be maintained by providing a facility for the treatment of raw sewer to flow into the river to reduce flash floods and pollution which is hazardous to good health.

vii. The government should consider building gabions along the Jukskei River to mitigate the impact of Flash Floods on the lives and property in Setswetla Township of Alexandra

viii. The Drainage system in the Township of Alexandra should be overhauled and regularly maintained to meet the increase in population growth

ix. The Township of Alexandra should be educated on the necessity for tax payment to provide insurance cover

x. Sustained campaign and necessity to show interest in reducing the impact of flash floods in Setswetla Township in Alexandra should be emphasized

xi. It will be valuable to keep records by the Municipality on flash flood and their impact to have the frequency and magnitude of flash flood events as well as the level of damage caused by the recurring flash floods to justify Alexandra Township to be classified as prone to flash floods.

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# APPENDIX Ia

**Monthly Daily Rain (mm) Data for station [0476399 0] – Johannesburg INT WO measured at 08:00**

| Year | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1989 | | | | | | 53,1 | 0 | 1,2 | 0 | 63,6 | 175,8 | 57,4 |
| 1990 | 84,5 | 131,7 | 98,9 | 109,6 | 11,8 | 0,4 | 2,5 | 0,6 | 7,7 | 44,5 | 38,5 | 103,9 |
| 1991 | 138 | 92,5 | 126 | 2,5 | 5,1 | 6,1 | 0 | 2 | 13,7 | 66,9 | 54,4 | 88,3 |
| 1992 | 109,2 | 91,7 | 21,7 | 20 | 0 | 5,4 | 0 | 15,2 | 14,7 | 25,1 | 114,6 | 91,8 |
| 1993 | 145,7 | 64,8 | 137,9 | 31,6 | 0,8 | 0 | 0 | 0,4 | 29,8 | 148,7 | 111,3 | 97,5 |
| 1994 | 105,8 | 190,3 | 84,2 | 22,1 | 0 | 0 | 0 | 0 | 4 | 103,8 | 50,9 | 166,4 |
| 1995 | 86,9 | 70,6 | 138,7 | 74,7 | 4,2 | 0 | 0 | 7,9 | 2,6 | 114 | 148,2 | 220,4 |
| 1996 | 168,7 | 322,5 | 59 | 63,4 | 24 | 2,2 | 0 | 13,7 | 0,4 | 46,3 | 86,2 | 114 |
| 1997 | 172,5 | 35,4 | 333,9 | 30 | 99,2 | 7,6 | 7,3 | 3,3 | 28,4 | 34,7 | 146,2 | 105,4 |
| 1998 | 154,1 | 78,2 | 26,6 | 12,2 | 0 | 0 | 0 | 0 | 32,2 | 75,2 | 208,2 | 130,1 |
| 1999 | 125,3 | 25,3 | 55,4 | 41,6 | 56 | 5,3 | 0,8 | 3,4 | 8 | 15 | 0 | 170 |
| 2000 | 153,6 | 263 | 164,5 | 33,8 | 25,1 | 2 | 0 | 4,5 | 39,4 | 117 | 114,8 | 170,8 |
| 2001 | 66,4 | 102,9 | 49,4 | 32,2 | 67,6 | 5,6 | 1,6 | 10,2 | 99,4 | 177,3 | 110,4 | 76,6 |
| 2002 | 81,1 | 86,6 | 83,4 | 25,2 | 63,5 | 18,7 | 0 | 23,8 | 4,1 | 41,8 | 22,6 | 141 |
| 2003 | 129,3 | 105,6 | 91,1 | 3,3 | 0 | 20,2 | 4,8 | 8,8 | 9 | 84,4 | 43,1 | 45,5 |
| 2004 | 164,2 | 211 | 110,9 | 46,2 | 13 | 4,2 | 14,5 | 3,8 | 0,5 | 26,9 | 53,5 | 214,4 |
| 2005 | 157,6 | 75,2 | 106,7 | 100,3 | 1 | 0 | 0 | 0 | 1,6 | 47,7 | 132,8 | 67,8 |
| 2006 | 174,1 | 167,9 | 77,6 | 31,3 | 1,3 | 0 | 0 | 34,2 | 1 | 32,3 | 110,3 | 149,9 |
| 2007 | 70,6 | 23,6 | 38,3 | 50,4 | 0 | 32,4 | 0,8 | 0 | 29,2 | 108,5 | 60 | 74,4 |
| 2008 | 231,1 | 61,3 | 122,7 | 19,5 | 43,1 | 16,9 | 0 | 0 | 0 | 73 | 123,9 | 110,8 |
| 2009 | 208,4 | 164 | 124,2 | 0,5 | 31,4 | 16,2 | 2,2 | 8,6 | 18,2 | 91 | 132,6 | 159,7 |
| 2010 | 268,9 | 131,5 | 100 | 99,1 | 35,2 | 0 | 0 | 0 | 0 | 29,4 | 109,9 | 208,6 |

**APPENDIX Ib**

**Summarized Table of the Mean Monthly Daily Rainfall (mm)**

| Month | Mean Monthly daily Rainfall(mm) |
|---|---|
| JAN | 142,67 |
| FEB | 118,84 |
| MAR | 102,43 |
| APR | 40,45 |
| MAR | 22,97 |
| JUN | 8,92 |
| JUL | 1,57 |
| AUG | 6,44 |
| SEP | 15,63 |
| OCT | 71,23 |
| NOV | 97,65 |
| DEC | 125,67 |

## APPENDIX IIa

**Report of City of Johannesburg (COJ): Public Safety Disaster Management on flash flood in Setswetla**

**a) The extent of flash flood hazard in Alexandra**

Based on the report of City of Johannesburg (COJ): Public Safety Disaster Management on Flash flood incident that occurred at Setswetla informed statement, Region A, Ward 109 and 105 on 9th November 2016 (Appendix IIa and b).

i. The purse of the report was to inform the Disaster Management Directorate of the disaster, outline the response and relief measures taken.

ii. The Sandton Disaster Management Centre Joint Operation Centre (JOC) was activated and all City Stakeholders were notified to put measures in place with regards to their preparedness plans.

iii. Verification was conducted by the team, community leaders, and Housing Department The extent of flash flood hazard in Setswetla was indicated as shown below:

i. Alexandra is situated on the banks of the Jukskei River

ii. Juskei River is a shallow river that was reported to have collapsed because of heavy rainfall

iii. Jukskei River is heavily polluted by urban runoff and lack of maintenance of flood channel infrastructure and illegal dumping of rubbles

iv. There is a flow of raw waste into the river daily

v. The banks are prone to bursting especially in summer when rainfalls are the heaviest during the year

The river becomes disastrous for poor residents who build their shacks along the riverbanks to have access to water for washing and cooking.

**b) Impact ASSESSMENT Conducted**

i. The report indicated that the heavy rainfall left the community of Setswetla destitute.

ii. Most of the community were left homeless

iii. Disaster Management Team was dispatched to the area to conduct a damage assessment and needs analysis.

iv. It was discovered that most of those affected resided along the Jukskei river bank in Alexandra.

v. Approximately 200 shacks were washed away by the flood

vi. Approximately 376 households and eight hundred and eighty-nine people were affected.

vii. Thosethatweredisplacedweretemporarilyaccommodatedatschoolandtentsinto different gender groups (men/ women and children)

viii. A work about was conducted immediately after the floods by Public Safety Committee Disaster Management Team.

ix. One child was reported missing by his family.

x. The City of Johannesburg Emergency Management Services (Water Search and Rescue Unit together with SAPS Dog Unit searched the Jukskei River and two weeks after, the body of the missing child was recovered.

xi. DNA tests were conducted to establish the identity of the body of the child to confirm that the parents are the biological parents and a burial arrangement was made.

xii. Two cases of diarrhea were reported among children of the displaced citizens. The children were treated and discharged home.

xiii. The office of Human Settlement, also the city Executive Mayor, Gauteng Provincial Disaster Management Center, and the Honourable President of South Africa conducted a work about and addressed the affected community.

xiv. Various media were present to cover the story.

xv. A resolution was taken to declare the incidence of a Provincial Disaster as more than one municipal was affected.

**Stakeholders role and responsibilities**

i. A Venue Opening Centre (VOC) was established and the various City Stakeholders were represented.

Briefing sessions were held daily and task were assigned to stakeholders

**APPENDIX IIb**

**Report on the flash flood incident that occurred in Setswetla informal settlement, Region A, Ward109 and 105 on the 09thNovember2016.**

**COJ: Public Safety Committee**
**Disaster Management 09 November 2016**

## 1. Strategic thrust

Safer City Responsive City

## 2. Objective

The purpose of this report is to inform the Disaster Management Directorate about the flash flood incident that occurred on the 09$^{th}$ November 2016 at Setswetla Informal Settlement, Alexandra, Region E, in Wards 105 and 109. The report will further outline the response and relief measures undertaken by the CoJ Disaster Management Centre and other stakeholders.

## 3. Background

Flooding of several shacks were reported on the 09$^{th}$ November2016, at approximately17h00. Disaster Management Teams who were on standby were mobilized to respond to the incident. The Sandton Disaster Management Centre Joint Operation Centre (JOC) was activated and all the City Stakeholders were notified to put measures in place with regards to their preparedness plans. The community of Setswetla was left destitute due to the heavy rainfall that occurred.

### 3.1 Impact ASSESSMENT Conducted

Due to the devastating extreme weather conditions following the floods at Setswetla, most of thecommunitywerelefthomeless.TheDisasterManagementTeamwasdispatchedtothearea to conduct a damage assessment and needs analysis. It was discovered that most of those that were affected reside along the Jukskei river bank in Alexandra and approximately two hundred shacks were washed away by the floods.

A beneficiary list of all the affected community members was compiled and approximately three hundred and seventy-six (376) households and approximately eight hundred and eighty-nine (889) people were affected. A thorough verification was conducted by the team, community leaders, and the Housing Department and those that were displaced were temporarily accommodated at the pre-school and a tent. They were separated into the different gender groups whereby males were housed in the tent and women and children were housed in one of the pre-schools identified within the area. A walk about was also conducted immediately after the floods by the Public Safety MMC and his team. Information at our disposal stated that one child was reported missing by his family. The City of Johannesburg Emergency Management Services (Water Search & Rescue unit) together with the SAPS Dog Unit searched the Jukskei River from Centurion up to Alexandra. Two weeks later, the body of the missing child was recovered by construction workers at Burchleu. DNA tests were conducted to establish the identity of the body as the parents were not in the possession of their documents that confirms they are the biological parents. The tests confirmed that they are the parents and subsequently the burial arrangements were made. On 21st November 2016, there was a report on only two cases of diarrhea amongst the displaced citizens. These were children between one year and three years old, that were resident in the camp at Gift of the Givers Green Houses. Two both the children were duly referred to the Alexandra Clinic 1st Avenue by EMS Ambulance and they were treated and subsequently discharged to go home. On the 07th December 2016, the burial took place, and Gift of Givers together with other NGO's assisted with all the burial arrangements. The body was laid to rest at the Waterfall cemetery and continuous trauma counseling was rendered to the family. The affected families lost all their belongings due to the heavy rainfall experienced and it was also noted that about eighty percent of the affected are foreign nationals.

On the11th November2016, the Office of the MEC of Human Settlement, the City's Executive Mayor, Gauteng Provincial Disaster Management Centre, and the Honourable President of South Africa conducted a walkabout and addressed the affected community. Various media were also present to cover the story. A resolution was taken to declare the incidents as a Provincial Disaster as more than one Municipality was affected.

### 3.2. Stakeholders roles and responsibilities

On the 10thNovember2016, a Venue Operating Centre (VOC) was established and the various City's stakeholders were represented. Briefing sessions were held daily for further guidance and the following tasks were assigned to the stakeholders:

| Stakeholders | Responsibilities |
|---|---|
| COJ Disaster Management | Stakeholder coordination and facilitation |
| PDMC | To advise and support |
| City of Johannesburg Social Development<br>Gauteng Provincial Social Development<br>Community Leaders | Designed a form which will be used to capture all the info/ list for all those affected, verification processes |
| CoJ Department of Housing<br>CoGTA | A database of all affected was created including Migrants and children |
| City Community Development Workers<br>Social Development Volunteers | Assisted with the verification process Sanity Packs, Matrasses, and Blankets were provided, Psychological trauma counseling of the bereaved family. |
| SASSA | Provided 46 blankets to the affected families on the 09th/11/2016 |
| DSD coordinated Food Bank | Provided hot meal lunch and supper as from 21st until 25th November 2016. |
| Bramley SAPS | Continuous patrol in the area |
| Ward 109 Councillors:<br>PR Councillor Shadrack Mkhondo | Provide the team with an update as and when required. |
| CoJ Environmental Health<br>A sampling of the streams and rivers | Food inspection as and when required.<br>Taking samples in all the catchment areas for analysis:<br>• Bacteriology analysis<br>• Chemical analysis |
| Alexandra Home Affairs: Mr.Moodley<br>076 769 6129 | Identity documents application submission |

### 3.3. Contributions/ donations made by NGO'S

**The following contributions were made**

| NGO's | Items contributed |
|---|---|
| 1. Gift of Givers | Two meals were served daily |
| 2. Limbro Park Muslim community Contact person: Adamose<br>Contact #: 082 966 2201 | 5x boxes of sandwiches |
| 3. Bramley Community members Neslie Sue | 9x10kg Maize meal 6x boxes of clothes Tin fishes 4x 1litre full cream milk |
| 4. Alexandra community members 1-11th Avenue Contact person: Sara Mathe Contact #:084 248 5272<br>073 4155 026 | Clothing |

| | |
|---|---|
| 5. Joburg Market | Food Parcels Vegetables (Cabbages, potatoes, onions, butternut, and carrots) |
| 6. BUSAMED private medical services: Modderfontein<br>Contact person Moloko Malady<br>Contact #: 082 661 0039 | 400x8 litres bottled water Bags of clothes<br>Baked beans<br>Toiletries |
| 7. Lombardy community members Contact person: Freedom Mbuli 327 Denne Crescent Lombardy East<br>Contact Person 072 371 8882 | Clothing |
| 8. Itlhokomeleng Old Age 141-8th Avenue, Alexandra<br>Contact person: Vickerman Contact #: 072 371 8882 | 17 bags of clothing |
| 9. Paul Steyn<br>Contact #082 217 8143 | 1X Box of chicken Vienna's<br>Sweet corn Bread |
| 10. Community member<br>6-3rd Avenue, Alexandra<br>Contact person: Kgomotso Petersen Contact #: 076 2243240 | Clothing |
| 11. ZCC – Alexandra<br>Contact person: Marlarel Makgoba 322 Kyalami Glen<br>Contact #: 071 469 2399 | Clothing Vegetables |
| 12. Alex Listeners<br>Contact Person: Thoko Contact #: 082 8453 009 | Clothing<br>12x Toilet papers |
| 13. Phuthaditchaba<br>Contact Person: Mr. Linda Thwala Contact#: 082 442 2866 | 3x boxes of sausage rolls 10x 2litres soft drinks Security clothes<br>Rolls |
| 14. Nhlanhla foundation<br>Norkem Park - Kempton Park Contact person: Nhlanhla Dhladhla Contact #: 072 3355421 | Vegetables Tin fishes Baked beans<br>2x 2kg maize meal<br>4x 10kg of rice |
| 15. Community member<br>Contact person: DuduzileMazibuko<br>Contact #: 083 411 9696 | |
| 16. City Water Sanitation department<br>Contact person: Mmadira Ramasehla<br>Contact#: 078 928 8820 | Clothing for kids and females<br>Toys<br>Blankets |
| 17. Alex Black conscious / Methodist church<br>Contact person: Rebecca Tsholo Contact #: 071 273 5488/084 577 0388 | Blankets Clothing |

| | |
|---|---|
| 18. Athol Islamic community forum (AICF) in conjunction with Almazachir Institute almazaahir@gmail.com<br>Contact #: 065-667<br>NPO/PBO93329262<br>Contact person:<br>Mohamed Minty – 0787804786 Firoz Abram -082 4515786<br>4 Ayr road, Atholl,Sandton | 164 x Food hampers Blankets<br>Sanitary pads/hygiene packs Toilet papers |
| 19. Meals on Wheels 10th Ave Alexandra | Bread and soup Rice and mince |
| 20. UNISA Community Engagement outreach<br>Contact # 012 429 3524<br>072 6309069<br>mashatr@unisa.ac.za | Clothing |
| 21. The revelation Church of God Contact # 082 496 0409<br>Contact person: Prophet Dr. Samuel RadebeInfo@therevelationchurchofgod .co.za | 800x Food hampers<br>• Maize meal<br>• Fish oil<br>• Tin staff<br>• Salt<br>16x boxes of clothing |
| 22. Shoprite mobile soup kitchen | Soup and bread |
| 23. Rivers of living water Church | Food Hampers and Clothes & shoes |

### 3.4 Challenges

**i.** No protocol was observed due to regular journalist' svisits.

**ii.** Political interference disturbed the process.

**iii.** Communities rebuilding their shacks on the banks of the river.

**iv.** The issuing of warnings during the incident for illegal structures owned by the City's Housing Department made the community aggressive.

**v.** Learners were affected as their school books were destroyed.

**vi.** Trauma counseling was limited, not every affected family received the service.

**vii.** By-law enforcement, not the site to provide security and to stop re-erecting/rebuilding of shacks at the flood line.

**viii.** Deployment of Migrant officials, JMPD, and SAPS patrol vehicles was not taken into consideration.

**ix.** City Power's delegate was not on-site to attend queries logged.

**x.** An alternate site has not been identified for the displaced families.

**xi.** The displaced families cannot provide food for themselves, as most of them are unemployed.

**xii.** Home affairs transport arrangements to provide support to those who lost their identity documents were not well communicated.

**xiii.** The Mozambique Embassy's visit was not clear as no proper feedback was provided to the foreign nationals after the compilation of the list.

**4. Policy and implications**

By-Laws

**5. Financial implications**

Overtime

**6. Economic implications**

Some of the affected never reported for work and this has a negative impact on their livelihoods.

**7. Communication implications**

The report will be communicated to relevant stakeholders.

**8. Constitutional and Legal implications**

Disaster Management operates within the legislative parameters provided in the following Acts and policies:

i. Disaster Management Act 57 of2002
ii. National Disaster Management Framework(NDMF)
iii. Fire Brigade Services Act 99 of1987
iv. Municipal Systems Act (Act 32 of 2000)
v. National Building Regulation and Building Standards Act 103 of1977
vi. Occupational Health and Safety Act 85 of1993
vii. Safety at sports and recreation events Act, No2 of2010

**9. Other Departments / Bodies Consulted**

i. CoJ Social Development;
ii. CoJ Disaster Management team;
iii. Ward leaders;
iv. Disaster Management Volunteers;
v. PIKITUP;
vi. Regional Director E;
vii. Gauteng Provincial Social Development;
viii. CoJ Housing Department;

ix. Gif of Givers
x. SASSA;
xi. FOODBANK;
xii. CoJ EMS;
xiii. CoJ Social Development; and
xiv. Setswetla Ward Leaders

**10. It is recommended:**

i. That the contents of this report **BE** noted.

ii. Continuous training and awareness be conducted in the ward.

iii. That is the case of a major incident, all relevant standby personnel for the particular area should respond and assist with fieldwork and administration personnel to do the data capturing.

Compiled by:
Sepheu Nkoele/ Lucia Maloka
CoJ Disaster Management Officers 011 286 6002/9

**APPENDIX III**

**Feedback report on Jukskei River flooding: City of Joburg: Health Department**

**21/11/2016**

**1. Strategic thrust**

Well-governed and managed City Health and Community Development.

**2. Objective**

To give feedback to the Executive Director of Health effects and measures taken after the floods in Alexandra Township. And also, to report on a purported outbreak of a cute diarrheal disease amongst displaced citizens in the Alexandra Township, due to floods at Jukskei River.

**3 Summary**

**3.1. Background**

The Alexandra Township (Alex) is a heavily populated African township north of the City of Johannesburg. The population is estimated to be around 179 629 according to the 2011 census. African Blacks make up almost 99 % of the population. It is situated on the banks of the Jukskei River. This is a river that flows through the northern aspects of the city of Johannesburg.

As a result of the recent torrential rain in the province and the subsequent flash flooding, this river had to burst its banks around some parts of this township. Several citizens in the township had to be displaced and would have to be housed in temporary shelters or camps erected in different areas of the township. There were three of these shelter camps as at the time of this report. Two of these are located at an area called Green point within the Setswetla informal settlements and the third camp is located at Number 66,of 19th Avenue. In all over 376 shacks and 889 persons were affected by these displacements as a result of the floods

**3.2 Discussions**

On the evening of the 17th November 2016, the City Manager informed the Executive Director about an outbreak of 7 diarrheal cases in Alex CHC. There portals had it that "several people mainly from the displaced shelter camps had been seen and treated at the Alexandra Clinic". As an outbreak response measure, the City of Johannesburg together with Gauteng Outbreak Response Team counterpart (GPORT) carried out a fact-finding mission to the three displaced people shelter camps in the township. The Gauteng Provincial Health Outbreak Response Teams visited the Alexandra CHC which happens to be the busiest health facility in the area. It also acts as a referral facility to other smaller health facilities in the area. Allacute diarrhea cases are referred straight to this facility that is located along the London Road

**4.2 Findings from the visit by the outbreak response team**

Findings from the Community:

i. The Alexandra Township is densely populated;

ii. There are several (both documented and undocumented)informal settlements that make up this sprawling township;

iii. The Jukskei River bisects the township almost into two parts with thousands of people living along the river banks; and

iv. There is absolute population grinding poverty noted within the community with several residents living in very squalid and unhygienic circumstances that may predispose them at any time to all the common communicable disease conditions such as typhoid, shigellosis, cholera, E. Coli infections, Schistosomiases, Rotavirus, TB, etc.

Findings from the Displaced People Shelter Camps: from the Venue Operations Committee (VOC):

i. There are three camps in the Township that have been designated as temporary shelters for the displaced citizens;

ii. Though the general environmental conditions of these camps appear neat and hygienic from afar, ablution facilities are not up to acceptable standards;

iii. There are not enough toilet facilities for the number of people that have been housed in these temporary shelters. Their numbers fluctuate by the day since residents tend to leave the camps by the day;

iv. The Gift of the Givers Foundation is providing 3 meals a day to all displaced families;

v. 45 males staying at the tent, 47 mothers and children staying at the ECD and 150 staying at $19^{th}$ Avenue Church; and

vi. There was a report of only two cases of diarrhea amongst the displaced citizens. These were children between one year and three years old, that were resident in the camp located at $19^{th}$ avenue. Three of the children were duly referred to the Alexandra CHC where they were treated and subsequently discharged to go home.

**Findings from the Alexandra Clinic:**

i. The facility Managers here say though they do not keep records of all the diarrhea cases they see in the clinic; the number tends to fluctuate from day to day and from one week to the other. But just by estimating on the average, they see about three of four cases of acute diarrhea cases amongst adults per day and also around the same number amongst children every day. These cases are not residing in any of the shelters; and

ii. They do refer to these acute diarrhea cases with severe dehydration to the Eden vale Regional Hospital.

| FUNCTION | ACTIVITIES |
|---|---|
| Address the pollution of rivers and streams | EHP'S to investigate the sampling spots to determine the reasons for such high E coli on such a consistent basis. Apply the necessary corrective interventions e.g:<br>• Report sewerage spillages/blocked manholes<br>• Health education<br>• Put up signage<br>• Place Moore pads for cholera samples<br>• Highlight the hot spots areas<br>• Regular monitoring of these areas |
| A sampling of the streams and rivers | Taking samples in all the catchment areas for analysis:<br>• Bacteriological analysis<br>• Chemical analysis |
| Social mobilization in Informal settlement | • Door to door<br>• Health education talks<br>• Distribution of pamphlets/fliers<br>• Giving health education talks in all clinics to attendees<br>• Issuing of pamphlets and fliers to Patients/clients<br>• Distributing flyers and pamphlets to outlets |
| Health education at Taxi Rank (especially those that aregoing outside South Africa and Gauteng Province) Park station | • Health education talks to commuters in taxis<br>• Distribution of pamphlets on Cholera and other water-borne diseases |

Environmental Health and Health Promotion interventions:

i. Since the morning of Thursday, the 17 November till late Friday afternoon, they had attended to only 13 diarrhea cases. These cases had come from different areas in the community (not form the shelters) and they were not related to the flooding incident;

ii. On Thursday, the 17 November 2016, they attended to three adults with diarrhea as well as four children with diarrhea. None of the adult clients were referred. All four children were referred to Eden vale Regional Hospital where they were seen and discharged home. They were not admitted;

iii. O Friday, the 18 November 2016, three adults and three children with diarrhea were seen and attended to. All three adults were referred to the Eden vale Hospital. Two of these three adults have to be admitted. Three children with diarrhea were seen and referred to the Eden vale Hospital. All three children were admitted into the hospital; Because the health center does not normally ask for the home addresses of their clients, they would not be so certain these clients had come from the displaced people shelter camps; and

iv. In short, the facility managers have not noticed any unprecedented increase in diarrheal cases coming into that facility.

**4. Outbreak response measures**

As a result of this purported diarrheal disease outbreak, the Gauteng and the City of Johannesburg Outbreak Response Teams will remain activated and members to be on complete high alert. The City of Joburg Health Department has prepared an on-call list for both Environmental Health and Primary Health

The two teams will continue to be part of the Disaster Management team that meets regularly on these displaced people matters

Health promotions and social mobilization activities around diarrhea and other water-borne diseases such as Typhoid and Shigellosis will continue

Health Facilities in Alexandra and surrounding townships have also been asked to be on the high alert against increased cases of all types of diarrheal diseases.

They have also been asked to keep a line list (details) of all diarrheal disease cases

**4.1 For follow up and statistical purposes**

Stool microscopy, culture, and sensitivity had to be requested from all diarrheal patients for the next seven days: To determine any circulating culprit pathogens.

Environmental Health Practitioners (EHPs) in the City of Johannesburg areas will continue with their usual practice of taking water samples from the Jukskei River for bacteriological and chemical analysis to detect any potential communicable water-borne organisms.

**5. Policy implications**

All Outbreak response guidelines and SOP's have been followed during the investigations.

**6. Legal and Constitutional implications**

None

**7. Financial implications**

Payment for overtime where necessary.

Funds will be made available under Health education vote number **305925 228 2620** for the printing of educational material.

**8. Communication implication**

This information has been communicated to our communication officer and Gauteng Health Province.

**9. Other Bodies and Stakeholders consulted**

This report has been compiled in collaboration with Gauteng Health Province and CoJ Health Department.

**10. Recommendations It is recommended that:**

i. It is recommended that Executive Director Health take note of the contents of this submission.

______________________

**Futhi Maseko**
**Deputy Director: Environmental Health**

**Date:**

______________________

**Peter Manganye**
**Director: Environmental Health**

**Date:**

______________________

**Baski Desai**
**Director: Public Health**

**Date:**

______________________

**Dr. Mary Daka**
**Deputy Director: Public Health**

**Date:**

______________________

**Dr. Refik**
**Bismilla Executive Director: Health**

## APPENDIX IV

**Questionnaire on Flash Flood Risk Management in South Africa: A Case Study of Alexandra**

**SECTION A: RISK FACTORS** **SD D A SA**

1 The terrain of Setswetla is vulnerable to flashfloods
2 The soil type of Setswetla is vulnerable to flashflood
3 Human settlement in Setswetla makes it vulnerable to flashfloods
4 Solid waste disposal in Setswetla makes it vulnerable to flashfloods
5 Poor drainage network contributes to flash floods in Setswetla
6 Annual rainfall intensity contributes to flash floods in Setswetla

**SECTION B: MITIGATION FACTORS**

7 Wooden barriers are constructed to prevent flash floods in Setswetla
8 Stones (Gabions) barriers are constructed to prevent flash floods in Setswetla
9 Anti-debris dams are constructed to prevent flash floods in Setswetla
10 Dykes are constructed to avert flash floods in Setswetla
11 Culverts are constructed to control flash floods in Setswetla
12 Adequate drainage channels are constructed to control flash floods in Setswetla
13 Sewers are constructed to control flash floods in Setswetla
14 Small reservoirs are constructed to retain flash floods in Setswetla
15 Jukskei river around Setswetla is regularly dredged
16 The valley of the river is regularly cared for by cutting trees
17 There is proper land use planning in Setswetla
18 There is an adequate public awareness campaign against flash floods in Setswetla
19 There is an early warning system in Setswetla
20 There is effective maintenance of flash flood infrastructures in Setswetla
21 There are effective metrological measures to mitigate flash floods in Setswetla
22 There are adequate hydrological measures to control flash floods in Setswetla

**SD- Strongly Disagree, SA – Strongly Agree, A – Agree, D –Disagree**

# APPENDIX V

Department of Civil Engineering,

Vaal University of Technology
Andries Portgieter Boulevard
Vanderbijl Park
16 October 2018

The Head of Unit,
South African Weather Services,
Eco Glades Block 1B,
Cnr Oliveven houtbosh and Ribbon Grass Street,
Centurion
0157, Pretoria

Dear Sir/ Madam

**<u>LETTER OF PERMISSION TO COLLECT DATA: MR ADEKUNLE O FADUPIN (STUDENT NO: 216163994)</u>**

This letter serves to introduce Mr Adekunle O Fadupin to you, who is requesting for permission from your office. He is currently enrolled for a Masters degree qualification in Civil and Building Engineering at Vaal University of Technology, Vanderbijlpark, South Africa. His research interest is on Flash Flood Risk Management in South Africa, using Alexandra Township as his case study.

He intends to embark on data collection process which will involve some information from your office, such as the rain fall pattern for Alexandra Township, monthly rainfall data and data on flash flood records in Alexandra Township.

Mr Adekunle will therefore need an approval from your office. All data collected in this research will be for academic purposes only.

Yours truly,

____________________

Prof (G, M) Ochieng
Thesis Supervisor
VAAL UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF CIVIL AND BUILDING ENGINEERING

## APPENDIX VI

Department of Civil Engineering,

VAAL UNIVERSITY OF TECHNOLOGY
ANDRIES PORTGIETER BOULEVARD
VANDERBIJL PARK
16 OCTOBER 2018

THE HEAD OF UNIT,
SOUTH AFRICAN WEATHER SERVICES
ECO GLADES BLOCK 1B
CNR OLIVEVENHOUTBOSH AND RIBBON GRASS STREET,
CENTURION 0157
PRETORIA

Dear Sir/ Madam

LETTER OF PERMISSION TO COLLECT DATA: MR ADEKUNLE O FADUPIN (STUDENT NO: 216163994)

This letter serves to introduce Mr Adekunle O Fadupin to you, who is requesting for permission from your office. He is currently enrolled for a Masters degree qualification in Civil and Building Engineering at Vaal University of Technology, Vanderbijlpark, South Africa. His research interest is on flash flood risk management in South. Africa, using Alexandra Township as his case study.

He intends to embark on data collection process on data collection process which will involve some information from your office, such as the rain fall pattern for Alexandra Township, monthly rainfall data and data on flash flood records in Alexandra Township.  Mr Adekunle will therefore need an approval from your office. All data collected in this research will be for academic purposes only.

Yours truly,

____________________

Prof (G, M) Ochieng
Thesis Supervisor
VAAL UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF CIVIL AND BUILDING ENGINEERING

## APPENDIX VII

Department of Civil Engineering,

Andries Poergieter Boulevard,

Vanderbijlpark.

22 April
2018

The Head of Unit,

City of Johannesburg Municipality,

Johannesburg, Gauteng.

Dear Sir/Madam

**LETTER OF INTRODUCTION FOR PERMISSION TO COLLECT DATA: MR ADEKULE O FADUPIN (STUDENT NO: 216163994)**

This letter serves to introduce Mr Adekule O Fadupin to you, who is requesting for permission from your office. He is currently enrolled for a Master's degree qualification in Civil and Building Engineering at Vaal University of Technology, Vanderbijlpark, South Africa. His research interest is on flash flood risk management in South Africa, using Alexandra Township as the location of study.

He intends to embark on data collection process which will involve some information from your office, such as the land cover data, topography data and the historical data of flash flood in the township of Alexandra. Mr Adekunle will therefore need an approval from your office. All data collected in this research will be for academic purposes only.

Your assistance to him will be highly appreciated as it will be counted as one of the many ways to tackle flash flood risks and related hazards in South Africa.

Yours truly,

_____________________

Prof (G.M) Ochieng

Thesis Supervisor

VUT Faculty of Civil and Building Engineering