Assessing flood vulnerability in the Nelson Mandela Bay Metro

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DECLARATION:

In accordance with Rule G5.6.3, I hereby declare that the above-mentioned treatise/ dissertation/ thesis is my own work and that it has not previously been submitted for assessment to another University or for another qualification.

SIGNATURE:

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List of acronyms (in order of usage)
NMBM: Nelson Mandela Bay Metro
CRED: Centre of Research and Epidemiological Disasters
SAWS: South African Weather Service
GIS: Geographic Information Systems
DEM: Digital Elevation Model
WS: Watershed
FA: Flow Accumulation
ST: Standardizing of thematic layers
RK: Ranking of thematic layers

Chapter 1: Introduction

1.1 Introduction

Floods are the most frequent amongst all global natural disasters at present, causing problems such as bridge collapses, fatalities, building damages and traffic delays. Between 1995 and 2015, there were approximately 3062 global flood disasters which accounted for 56% of all declared natural disasters and these affected 2.3 billion people (almost a third of the world's population at the time) (EMDAT, 2015). The cost of damages for this period incurred for buildings and other infrastructure was at an all-time high of R23.69 (US$1.891) trillion. It is postulated through various studies that the number of urban flood events reported is increasing significantly in comparison to the previous decades (Armah et al., 2010; Lóczy, 2013; Leaning and Guha-Sapir, 2013; EMDAT, 2015; Tanoue et al., 2016; Rogger et al., 2017). Some research has also noted an increase in the number of floods per year, which has ascended to an average of 171 in this decade, from an annual average of 127 in the previous one (Dozier, 2013; Guha Sapir et al., 2016).

Sources such as the Centre of Research and Epidemiological Disasters (Guha Sapir et al., 2016) recorded that from 1995 to 2015, globally, millions of homes were vulnerable to weather-related disasters, along with 130,000 health and education facilities. During this period, urban floods accounted for 98% of houses damaged and 99.9% of education and health facilities demolished by a weather-related disaster (Davies, 2017). Flooding is particularly harmful in terms of fatalities in developing countries due to inadequate flood protection and mitigation measures (Di Baldassarre et al., 2010; Dozier, 2013). Some studies attribute the high fatalities in developing countries to the inadequate disaster management strategies implemented to counter the impacts of urban flooding (Egbinola et al., 2015; Pazzi et al., 2016; Mavhura et al., 2017). Other authors have attributed the high fatalities to the sheer number of people residing in areas prone to flooding, which has been the knock-on effect of rapidly expanding cities, overwhelmed government agencies, and a pre-existing political and social system that promotes marginalisation (Collins, 2008; Aboagye, 2012).

The occupation of flood-prone areas by settlements, which is a common feature in developing countries, is the major contributor to the fatalities as it involves a degree of risk. Risk is exposure to an undesired event, in this case flooding, and contributes directly to differing levels of vulnerability (Samuels, 2018). Communities have differing perceptions of flood vulnerability because of a combination of factors. These include the magnitude of the flood experienced, the number of people or the value of assets potentially affected by flooding due to location, and the lack of socioeconomic capacity to do anything to alter their vulnerability to a disaster (Hall et al., 2005; Adger, 2006; Birkmann et al., 2013; Rogger et al., 2017). Some communities acknowledge that there are people residing in flood prone areas and take measures to reduce or eliminate the risk through social, political and economic networks. In other cases, communities are able to identify their exposure to flooding but do not have the capacity to reduce the effects (Bouchard et al., 2007; Agbaoye, 2012; Musungu et al., 2012; Siyongwana, Heijne, and Tele et al., 20155).

The latter has become a common occurrence in most regions in the developing world, and in South Africa in particular, where flooding has devastated millions of people and continues to do so (Thomas et al., 2011; Kjeldsen et al., 2012; Dalu et al., 2017). Regardless of repeated flood occurrences in South Africa in the past, there are still many areas with inadequate flood mitigation measures in place. The most devastating floods recorded in this century in the region were a result of the 2010 - 2011 La Nina event (IFRC, 2013). The event caused abnormal summer rains that began in December 2010 and ended in late January 2011. As a result, flooding displaced thousands across eight provinces and killed at least 141 people (Jongman et al., 2012). Most of the fatalities that occurred were a result of people being trapped in floodwaters rather than structural collapse, although the total damages cost to infrastructure was estimated at R160 billion for that event (Smith, 2011).

A year later, a flood disaster occurred in the Nelson Mandela Bay Metro (NMBM) area and led to approximately R1 billion worth of damage (HeraldLive, 2017). Damages to houses and infrastructure accounted for 60% of the costs incurred by government agencies for the event and much of the damage that occurred was in informal settlements in flood-prone low-lying areas (Siyongwana et al et al., 2015). In most cases, such settlements have arisen because of high land prices and a pre-existing state of poverty, which has left certain communities with a lack of capital to purchase land or build a house (Dalu et al., 2017). In order to rectify this, the Nelson Mandela Bay Municipality (NMBM) has put measures in place to provide adequate shelter but the annual population increase has continued at a rate that is difficult to manage.

The current situation regarding service delivery has the NMBM delivering 7617 formal houses between 2012 and 2016 (NMBM, 2014a; 2014b). During that period, the population in the NMBM grew from approximately 1.176 million people to 1.258 million people. Most of the people who contributed to this increase are poor and cannot afford adequate housing. Therefore, they reside in poorly-sited areas due to the cheap cost of accommodation and sometimes the proximity to income-earning opportunities (Richards et al., 2007; Adegun, 2015; Siyongwana et al. et al., 2015; Sachikonye et al., 2016). Usually accommodation in such areas is available in the form of informal settlements and state-subsidised houses that are sited and erected without adhering to building standards. Such areas have been overlooked in terms of research as most post-Apartheid government policies have focused on improving rural communities rather than improving lives of the poor in urban centers (Agbaoye, 2012; Roberts, 2008; Siyogwana et al. et al., 2015).

Research on vulnerability and mitigation of urban flooding has spanned across the world with a majority of the case studies coming from Africa. South Africa has already identified that it will face more flooding occurrences because of climate change in the near future (Knox et al., 2012; Muller et al., 2014; Ziervogel et al., 2014; Turco et al., 2015). For this reason, there has been some research for areas such as the NMBM concerning risk and adaptation to flooding (Solomon and Viljoen, 2003; Mahlangu and Braune, 2010; NMBM, 2010; Siyongwana et al., 2015; NMBM, 2014a), but none has publicly focused on the use of adequate maps to assist with disaster management strategies. Against this backdrop, it is critically important that future of urban planning maps and manages the vulnerability that will result from flooding. Thus, this study aimed to assess flood vulnerability within the NMBM boundary in order to recommend possible mitigation strategies.

1.2 Problem statement

Urban flooding has led to several global disasters and the cost of damages and incidents reported continue to increase. Urban flooding is also increasing in South Africa, where almost all provinces (excluding North West) have been declared disaster areas in the past decade due to flooding. This is the case in urban areas, such as the NMBM, that are often exposed to flooding (Zhu et al., 2010; Eliot, 2012; Ismail et al., 2012; Jongman et al., 2012; Callaghan and Power 2014; NMBM, 2016). Within the municipal area, the effects of urban flooding are expected to be further exacerbated by climate change and urban development (de Wit, 2016). Climate change associated with the municipal area is likely to result in more intense storms that will lead to higher rainfall discharge volumes in a short period. Urban development in this case, will be detrimental as land use changes and densification of populations around urban centres will increase risk of flooding incidents as well as the cost of damages (Gwimbi, 2007; Forkuo, 2011; Jha et al., 2012; Morton and Olson, 2014; Chang and Huang, 2015). The interplay between climate change and urban development alone is likely to lead to a rise in both the costs of damages incurred by government agencies and fatalities in the NMBM. For this reason, it is important to mitigate against the effects of urban flooding.

1.3 Aim and objectives

The aim of this study is to assess vulnerability to flooding in the NMBM.

In order to support the aim, the following objectives were pursued:

- To determine the theoretical framework for assessing flood vulnerability.
- To develop a methodology with the use of GIS for assessing flood vulnerability.
- To apply the method to the NMBM area and identify high risk areas.
- To suggest adequate flood mitigation strategies for high risk areas.

1.4 Study justification

Flooding has had significant negative impacts across South Africa. The benefits of the study include the identification of facilities within the NMBM that require infrastructural preparedness as well as socio-economic capital to cope with floods. It also assists in the creation of action plans for certain wards and settlements. Data acquired can provide insurance companies with preliminary data on risk profiles for businesses and residential areas within the NMBM. This study also provides maps that can influence policy on land prices and land availability as well as building restrictions in certain areas. Mapping of flood-prone areas is important, not only as a way to prevent flooding disasters but also as a way to minimise future losses incurred because of flooding. This study provides insight into map generation in order to represent flood-prone settlements, as well as how to model hydrographs in order to understand the impact of land use on flooding. Modelled hydrographs can estimate peak discharge and peak run-off during certain rainfall conditions. This can be used to plan alternative transport routes during flood events. Flood inundation maps and land use data can be used to calculate potential loss due to flooding disasters should flood events of a particular magnitude occur. This information can also be compared with current budget allocations for flood disaster management.

1.5 Study area

The study area is the Nelson Mandela Bay Metropole (NMBM) and it comprises the city of Port Elizabeth, the towns of Uitenhage and Despatch and some rural villages on their outskirts. Its geomorphic boundaries are formed by Cassie Mountain View in the north, Cape Recife in the south, Sundays River Mouth in the east, and Van Stadens River Mouth in the west. The NMBM is situated on the southern part of South Africa in the Eastern Cape along the shores of the Indian Ocean (see Figure 1.1). Its central point geographical coordinates of 33048’S, 25030’E have the same latitude as Cape Town, which is approximately 660 km to the west (Arcus GIBB Engineering & Science, 2011). The NMBM Municipality (created in 2004) is a Category A municipality, which covers a land area of 1950 square kilometers and houses a population of approximately 1.1million (StatsSA, 2011). The NMBM has a major seaport and an automotive manufacturing center located in Uitenhage. It is the economic powerhouse of the Eastern Cape Province, and one of eight metropolitan areas in South Africa. In spite of this, approximately 31% of the active population (16≥ age≤ 65) is unemployed and the majority of these people rely on social grants and subsidies on services provided by the state.

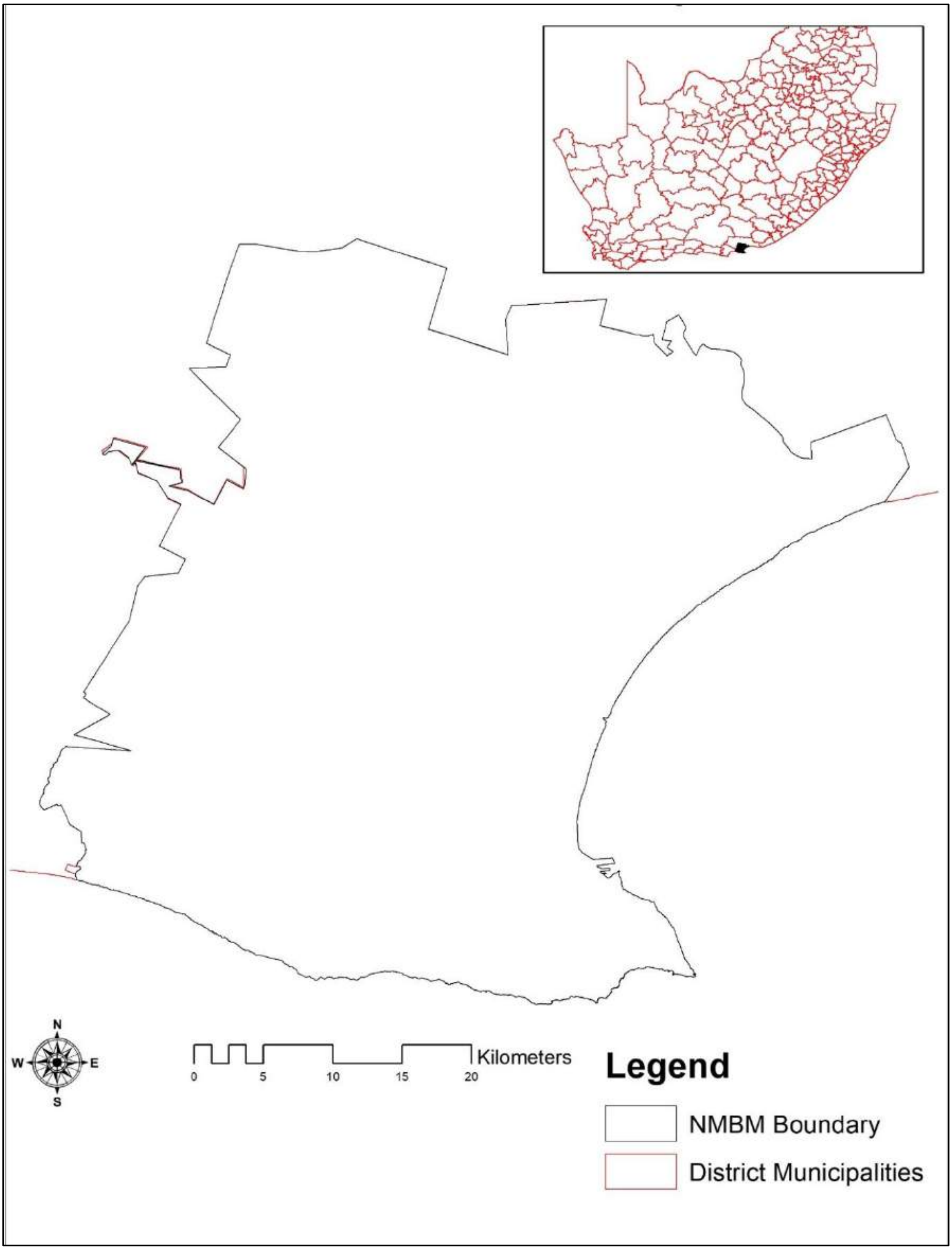


Figure 1.1 Map of area covered by NMBM

1.6 Study layout

Chapter 1: Introduction – This Chapter includes the introduction, problem statement, the aim and objectives, and the justification for the study. It also contains information on the study area as well as a layout of the research project.

Chapter 2: Literature Review – This Chapter generates a theoretical framework for understanding vulnerability to flooding in general and, specifically, in the Nelson Mandela Bay Metro.

Chapter 3: Methodology – This Chapter explains the methodology used for this study. A number of techniques were utilised, including GIS to display spatial and non-spatial data leading to the generation of areas most vulnerable to flooding.

Chapter 4: Results and Discussion - This Chapter displays the research results and provides a summary of the maps generated by the methodology.

Chapter 5: Synthesis – This Chapter creates an understanding of the results based on the literature discussed in Chapters 2 and 3. The first section consists of a recap of concepts revolving around vulnerability and urban flooding. This is followed by the section which provides a synthesis of the results generated in Chapter 4 and also includes future mitigation suggestions for the NMBM. Finally, in the last section recommendations are made for future research on flooding preparedness and capacity building.

Chapter 2: Urban flood dynamics and assessment

2.1 Introduction

In the first Chapter, a brief history on the damages associated with flooding and the frequency of flooding globally and in South Africa was presented. These two aspects provide an adequate picture of the current situation regarding urban flooding as a phenomenon, but they are not the only focus of this research.

In this Chapter, existing research is used to create a relatively comprehensive approach to identifying urban flooding occurrences and assessing potential flood vulnerability. The first section begins by defining the current status quo regarding urban flooding. This is followed by the second section which describes the causes and consequences of differing magnitudes of flood vulnerability. It is vital to obtain a clear understanding of urban flooding before developing steps to prevent or limit future damage associated with their occurrences (Lee and Vink, 201515). Understanding any harmful phenomenon forms a fundamental part of creating measures to counter its effects (Forkuo., 2011).

This Chapter also contains a roadmap for assessing flood vulnerability. In the third section, vulnerability is defined briefly and the popular theories are discussed, with special consideration to the theory used in this study. The fourth section looks at different techniques for assessing vulnerability and mapping flooding, in accordance with the theoretical framework put forward in this study. The fifth section looks at the theoretical framework behind the methodology used to map urban flooding in the NMBM. The last section of this Chapter considers the mitigation strategies that are implemented in developing countries and that can be applied in the NMBM.

The following section forms the first part of a roadmap for creating a basic understanding of urban flooding.

2.2 Urban flooding: causes and consequences

There are several definitions of urban flooding in the literature (Sharif et al. Holmes, n.d.), so it is important to have a basic definition that will be used consistently throughout this study. Here, urban flooding is understood as a combination of two definitions. The first assumes that flooding is a general and temporary condition where 8.093 or more square kilometres of normally dry land, or two or more properties are inundated by water or mudflow (Michel-

Kerjan, 2010). The second defines floods in terms of their statistical occurrence and such that a hundred-year flood is a flood having a magnitude that occurs in a location on average once every hundred years. This means that in any given year there is a one percent statistical chance of an occurrence of said flood (Baum and Godt, 2010). Although both definitions are parsimonious about the differences between processes affecting rural and urban areas, it is assumed that this allows both definitions to encompass all urban and peri-urban areas in the NMBM.

In this study a distinction can be made between rural and urban flooding based on the fact that the urban environment has many more settlements and built up areas in comparison to rural areas (CNA, 2011). Built up surfaces and settlements have an influence on the magnitude of floods (Chang and Huang; 2015, Zhu et al., 2010),especially in situations where such environments have inadequate flood defence mechanisms for areas situated on floodplains. In some areas inadequate flood defence mechanisms come about as a result of development in high risk areas, such as areas under the 10 and 50 year flood zone (Dalu et al.., 2017). In the case of planned development, struggling flood defence mechanisms may result in, for example, the breach of a dam or overflowing of outdated drainage systems (Dozier, 2013).

Irrespective of the cause, the end result is an increase in potential damage to buildings, utility works, housing, household assets, income losses in industries and trade, loss of employment to temporary workers, and interruption to transport systems (Hughes, 2010)). This multifaceted nature of the damage results in some people being affected more severely than others. Therefore, it is important to interpret the results of urban floods in ways that pay attention to the sectors and people affected (Aerts et al., 2011). In order to interpret the results in the appropriate context and to provide a review of key terms, it is necessary to outline the types, causes and consequences of urban flooding (Dhital and Kayastha, 2012).

This study considers three types of floods that affect urban areas and the NMBM specifically. These are riverine floods, flash floods and coastal floods. Understanding their different characteristics, causes and consequences can allow for the application of the most effective strategies to counter their effects.

In recent years the origin and degree of urban floods has begun to alter globally and locally, with flash floods, and acute riverine floods becoming the most frequent (Bourman, 2010). In some cases, this has been a result of urbanisation which has significantly increased flood run-offs through more built up areas (Macdonald et al., 2011). In other cases, it has been the result of changes in the macro climate and the creation of microclimates which have given rise to more intense localised storms which cause precipitation rates to surpass infiltration rates (Molnar, 2001). Whatever the causes, the increases in the population around urban centres is causing billions of people globally to be vulnerable to floods every year. Therefore, urban flooding is becoming more dangerous and costlier to manage because of the sheer size of the population exposed within urban settlements (Macdonald et al., 2011). Defining the type of flood by its characteristics is useful in developing measures to reduce the impacts to communities. Currently in the NMBM, riverine floods are the most common and occur as a result of increased stream flow.

Riverine floods are triggered by rainfall in upstream areas which causes runoff to exceed the capacity of natural or artificial channels downstream. The excess water overflows the banks of the watercourse and spills out into adjacent, low-lying floodplain areas (Borrows and de Bruin, 2006). The failure or mismanagement of flood defence mechanisms upstream can also lead to riverine flooding. Urban areas situated on the low-lying areas in the middle or lower reaches of rivers are particularly exposed to extensive riverine floods (Sakijege et al., 2012). This is because, in most major river basins, floodplains are subjected to annual flooding and the deposit of sediment along stream paths (Depetris and Gaiero, 1998). This is further aggravated by urban expansion over some of the floodplains, which reduces the area into which streams can geologically overflow (Kabanda and Palamuleni, 2013).

An example of riverine flooding is evident in the case of Southern China (1960 – 2012). Here, flooding has occurred as a result of torrential rain which causes streams to overflow the banks of the Yangtze River. This has led to thousands of fatalities and the displacement of millions of people because of their location in low lying floodplains, as well as inadequate flood protection measures (Pittock and Xu, 2011; Chang and Huang, 2015, Chang and Huang, 2015).

Flash floods are also very common in urban areas. Flash floods are the product of the rapid release and accumulation of run-off waters from upstream areas. They occur because of heavy rainfall, cloud bursts, landslides, or failure of flood control works. Flash floods are characterised by a sharp peak which occurs within six hours from the onset of a rainfall event (Doswell & Maddox, 11996). Seepage reaches a maximum quickly and diminishes almost as rapidly (Archer and Fowler, 2015). Factors such as rainfall intensity and duration, surface conditions, topography and slope of the receiving basin can influence this type of flooding.

Urban areas are especially susceptible to flash floods because of the high percentage of impervious ground surfaces and buildings which cause rapid run-off and a quick rise in water levels.

An example of flash flooding occurred in 2012 along Seaview Road in Port Elizabeth, where within a few hours of rainfall, the road was completely flooded and it stayed that way for several years (see Photo 2.1 below. Also see Figure 4.32.)

Photo 2.1: Residents of the Nelson Mandela Bay Metropolitan had to wade down a flooded Seaview Road adjacent to Springvale on 10 October 2012. This was a result of more than eight hours of continuous rainfall (144mm) that fell overnight within the Metro.
Picture: Gideon Brundson

The third type of urban flood considered in this study is coastal flooding. Coastal floods occur because of an intrusion of ocean or sea water, largely due to high (spring) tides and storm surges caused by tropical depressions and cyclones (Eliot, 2012). The intensity of coastal flooding is influenced by several key factors such as coastline configurations, offshore water depth and estuary shape. Also, high tides may affect flow of rivers and drainage systems, which can lead to further riverine floods (Ismail et al., 2012). This is because tides can cause estuarine and river levels to stay high for long periods. Here, the areas located in estuarine reaches must bear the joint impacts of riverine and coastal floods due to storm surges, and tidal effects (Valle-Levinson, 2011). The storm surge usually causes the sea level to rise for a relatively short period of time of four to eight hours, but in some areas it might take much longer to recede to pre-storm levels (Jha et al., 2012; Zhu et al., 2010).

In the case of the NMBM, research has shown that a complex relationship of its system of rivers, traditional drainage features and low relief locations are expected to lead to further flooding in the future. According to de Wit (2017), low lying areas in the Metro are currently vulnerable to coastal flooding that may occur due to climate-induced sea level rise. This is expected to be as much as 75cm by the year 2100. Furthermore, coastal inundation may occur on the low-lying coastal areas because of increased tidal waves and sea levels. A combination of such factors could lead to coastal flooding which will affect estuarine habitats and fresh water supplies in areas such as the lower Swartkops River which has an important ecosystem function for Amsterdamhoek and Bluewater Bay (de Wit, 2017) River that flows through Amsterdamhoek and Bluewater Bay (de Wit, 2017).

With this in mind, the following section forms the second part of this Chapter which reports on different causes that lead to urban floods globally and locally. In this study, it is noted that floods are caused by numerous factors that act together to overflow drainage channels.

2.2.1 Causes of urban flooding

Urban floods originate from a complex relationship of hydro-meteorological factors and human factors. The meteorological influences include, but are not limited to, annual rainfall and storms. The hydrological factors include soil properties, groundwater level, infiltration rate, condition of drainage basin, channel network and slope (Jha et al, 2012; CNA, 2011). Human factors include, but are not limited to, land cover, occupation of floodplains (which hinders flows), lack of permeability (because of built up surfaces) and incompetence of flood defence mechanisms (Kabanda and Palamuleni, 2013).

Normally, flooding occurs from heavy rainfall that leads to natural watercourses overflowing due to a lack of capacity to convey excess flow (di Baldassare et al., 2010). Sometimes flooding can be induced by climatic conditions such as the El Nino Southern Oscillations (ENSO), which occur every three to eight years and are associated with cooling and wetter conditions during rainfall prone seasons (Callaghan and Power, 2014). In South Africa, there are other weather systems that bring torrential rain, one of them being cut-off low pressure systems. They are defined by how they form. The air in the mid-levels of the atmosphere over South Africa generally flows from west to east. When this flow is disturbed, a trough forms (in a similar way that a river meanders). The trough can then intensify and develop into a low pressure system. If this low pressure system gets ’cut off’ from the basic westerly flow then a cut-off low has been formed. If they are intense enough, cut-off lows invariably result in heavy rains in various parts of South Africa (Molekwa et al., 2013). These heavy rains usually result in flooding. Although meteorological factors contribute immensely to flooding, so do hydrological factors.

Hydrological factors include that different soil types have different infiltration rates and water holding capacities which can lead to higher rates of overland flow (Kabanda and Pamuleni, 2013). A lower ground water table supports deep percolation whilst a higher water table results in shallow percolation and causes increased overland flow (Jongman et al., 2012). Land use and land cover changes impact soil infiltration rates, such that run-off rates are diminished in areas where there is high vegetation cover, as vegetated areas accommodate high infiltration rates until saturation is reached (Kakembo et al., 2012). On the other hand, increased overland flow is expected for bare ground (Jha et al., 2012). Situations also exist where the ground can be pre-saturated because of long wet periods, and this can allow even medium rainfall events to cause flooding (Ashagrie et al., 2006). As a result of such pre-saturation, temporary storage areas are created and these are potential flood zones.

Storage areas such as lakes and wetlands as well as artificially created storages are subject to lower saturation rates so they flood much more easily. The slope on these areas plays an important role as a flat slope encourages accumulation of run-off especially in the case of high water tables that form as a result of underlying geology which restricts any downward percolation (Gwimbi, 2007). Storage areas also have the ability to create sediment deposition which leads to increased siltation and pollution along water courses. Siltation and pollution have to capacity to lead to blockages along drainage systems that in turn cause flows that would have normally remained in the stream to flood adjacent areas (Smithers, 2012). Similarly, the position of settlements in floodplains alters stream pathways and infiltration rates which leads to flash flooding and drainage system failures (Solomon and Viljoen, 2003; Sakijege et al., 2012; Siyongwana et al. et al., 2015).

Although urban flooding primarily occurs because of the relationship between hydrological and meteorological influences, it is important to understand some of the human factors that further exacerbate flooding. In this study, these were separated into environmental and socio-economic. The environmental considerations focus on the role of climate change and vegetation. The socio-economic influences noted in the study are urban development, land prices, built up surfaces and inadequate waste management.

The removal of vegetation plays an important but limited role as it affects annual transpiration and interception rates which increase storm flow volumes (Ashagrie et al., 2006). This is also associated with an expansion of source areas of flow such as roads and ditches which have the potential to increase peak discharge due to shortened travel times for streams (Verschoren et al., 2017). The role of the removal of vegetation is limited because as the amount and duration of precipitation increases, the influence of the plant-soil system diminishes (Friedman and Lee, 2002). This means that precipitation events that are not extreme allow for flow to be affected by the soil-plant system and watershed.

Climate change which is occurring as a result of global warming will influence flood patterns (Shao-Hong et al., 2012). Changing meteorological patterns lead to an increase in the rate of sea level rise, storm surges and more intense rainfall events which will consequently lead to urban flooding (Jha et al., 2012; Jongman et al., 2012). Coupled with poor land use, urban floods can impact on water resources by altering the hydrology and increasing soil erosion leading to increased sediment transport and deposition (Hirji et al., 2002). In some areas, it has been noted that increased rates of erosion and pollution within a watershed have blocked upstream channels and resulted in flooding as well as the creation of new drainage streams (CNA, 2011). In such scenarios, the influence of urbanisation on flooding occurs to varying degrees.

As noted before, the accelerating rate of urbanisation and urban development has a significant impact on the risk of flooding. This is because most populations have become clustered around urban areas in search of income earning opportunities (Siyongwana et al., et al., 20155; anon, n.d.). The results are more built up urban areas that are impermeable and that contribute immensely to storm flow. This is sometimes coupled with a concentration of solid and liquid waste around urban centres which in most developing cities exists without adequate disposal systems (CNA, 2011). The waste has the potential to contaminate fresh water and also has the potential to obstruct drainage systems resulting in flooding (Chatterjee, 2010). The blockages force water to flood adjacent areas, and ultimately this affects areas outside of known floodplains.

Metropolitan areas such as the NMBM also form a hub for several economic activities for the province and nation. Consequently, they house many high value infrastructures and properties. This results in a high cost of land around ‘favourable’ locations that pushes the poor to form informal settlements or reside in low cost subsidised houses in parts of major flood plains, low lying coastal areas or deltas, small basins subject to flash floods, areas below unsafe or inadequate dams, low lying inland shorelines and areas within alluvial fans (Smith, 2012). This ultimately means that the high cost of land in urban areas exacerbates the impacts of flooding (Ismail et al., 2012).

Urban flooding comes about in three different forms; these are riverine floods, flash floods and coastal floods. These three types of floods are caused by a complex relationship of hydro-meteorological factors and human factors. This has a multitude of consequences which are discussed in the following section.

2.2.2 Consequences of urban flooding

Consequences of floods are unique in urban areas due to the high concentration of people and assets found within the urban environment. The primary consequences of flooding occur as a result of direct contact with water by human beings and infrastructure (e.g. buildings, roads, dams). In this study only these were considered due to data collection restrictions for secondary consequences (such as altercations to the environment and ecosystems) and tertiary consequences (such as disruption of services).

The primary recipients of the impacts of flooding are people, the natural environment, infrastructure, and family assets (Dhital and Kayastha, 2012). These impacts eventually translate to damage to buildings, loss of economic assets, loss of human life, immediate health impacts, and loss of ecological goods (Lee & Vink, 2015). Some consequences originate from high velocity streams. Such streams have the ability to transport larger particles as suspended loads including houses and bridges after intense heavy rainstorms (Fisher, 2016). They can also lead to erosion that can undermine bridge structures, levees and buildings, causing their collapse. People who do not know how to swim are at the highest risk of drowning in areas under high levels of waterNews24 (Khoza, 2016).

In 2010, urban flooding was estimated to have killed approximately 8000 people worldwide which was a decline from previous years (Jha et al., 2012). This was apart from economic losses which continued to rise as a result of measures that were put in place to prevent flooding disasters (Dozier, 2013). One of these measures is an increase in world medical outreach programs (such as World Health Organization, Medcins Sans Frontieres and Red Cross) that attend to areas that face natural disasters. This can be assumed as a major cause of the decline in fatalities (Jonkman, 2005; Du et al., 2010). A better standard of buildings being erected is also a major contributing factor to the decrease in the loss of life during flood events (Hughes, 2010).

Buildings and their contents are affected by flooding in a variety of ways and they also have the ability to influence flooding incidences. Fast flowing floodwaters can wash away entire buildings and communities (Hughes, 2010). According to USACE (1988), the higher the velocity of the water is, the greater the damage will be. The depth of floodwater is another important factor in calculating the amount of damage caused by floods. This is because the hydrostatic head, which is the pressure caused by the weight of water being held above the maximum pressure point, will put stress on walls and will also drive floodwater through walls (Archer and Fowler, 2015). If the flood depth is predicted to be greater than 80 cm, flood proofing is not likely to be feasible on buildings. The consensus among experts is that the maximum depth acceptable for wet-proof construction should be 60 cm (Alam et al., 2015). This means that, flood depths greater than 60 cm have the capacity to result in significant structural damage to buildings.

A study by Kreibich et al. 2009, examined both water depth and flow velocity, and concluded that the latter has a larger influence on structural damage during floods (Kreibich et al., 2009). That same study suggests that if water depth is less than two meters then flow velocity alone is not a suitable consideration for flood damage modelling and assessment. Depending on the form of construction materials and characteristics of the flood, many buildings can withstand flooding but will be damaged extensively by the corrosive effect of salinity and damping, and will still require substantial repairs and refurbishment (Hughes, 2010).

The building materials and the condition of the building have an influence on the extent of damage caused by flooding (Alam et al., 2015). Masonry construction, for example, can withstand the impact of floodwaters up to a point but, consisting of porous materials, it will absorb a large volume of water and take considerable time to dry out. Timber construction can be relatively waterproof but is often less robust. Plastic, corrugated iron and soil based construction are more vulnerable to scour and erosion (Hughes, 2010). The materials used play an important role and so does the quality of structures.

Flash floods in urban environments represent the highest risks of damage to buildings (Aerts and Wouter Botzen, 2011). This is sometimes because safety standards are overlooked in order to provide cheap accommodation, and in those scenarios inadequate structures are easily demolished by floods. Floodwaters carry the debris of waste and the materials from broken buildings with them and this leads to considerable additional damage to areas downstream (Archer and Fowler, 2015). As high rainfall leads to erosion and landslides, infrastructure can become damaged (especially roads) which is often the only way of accessing communities affected by flooding. Erosion causes concentration of sediment, which is deposited when the flooding subsides (Molnar, 2001). Furthermore, the smothering of agricultural land by sediment can also be a problem for high value vegetable production, as a large quantity of such sediment is low in organic matter, such that, production may never return to its previous level, impacting human livelihoods and nutrition (Gwimbi, 2007).

There are numerous consequences of flooding and understanding these can assist the communities that will be affected by flooding. In order to supplement this knowledge, the following section discusses urban flooding and vulnerability in order to create a theoretical overview. This will define vulnerability in the context of urban flooding. This section also aims to explore techniques for assessing flood vulnerability.

2.3 A theoretical overview of urban flooding and vulnerability

Urban flooding is a natural occurrence that has the ability to affect communities differently according to their vulnerability. Vulnerability in this study will be defined as the future state of susceptibility to harm from exposure to urban flooding and the capacity to adapt or lack thereof (Adger 2006; Birkmann et al., 2013). It can be summarised by the following equation:

Vulnerability = hazard occurrence * sensitivity to exposure – adaptive capacity (1)

In order for the NMBM to adapt to urban flooding and reduce vulnerability to future flooding disasters interventions from various sectors are required, comprising financial, technological and information resources, institutions, infrastructure, social networks, and perceptions of risk and human capital (Belliveau et al., 2006; Birkmann et al., 2013). Heltberg (2011) highlights the importance of considering the combined effect of geographic exposure, dependence on sectors sensitive to urban flooding, income and capacity to adapt. Thus, adaptation has become an important task along with the necessary processes to reduce impacts of flooding. The effectiveness of adaptive capacity is reliant on the institutions and policies put in place locally and nationally (Dozier, 2016). Flooding impacts are experienced differently by individuals and communities, but usually the case is that, those people that have contributed the least to the problem and that have the least resources to cope with it are most affected (Samuels, 2018). Over the years various theories have been developed to conceptualise vulnerability to natural disasters.

There are many approaches to understanding and assessing vulnerability, which can be grouped into three paradigms, namely risk-hazard, political ecology, and ecological resilience. Early scholars of disaster and hazard studies focused on the exposure component of vulnerability. They were mainly interested in identifying who is exposed and what they are exposed to. In theory, if there was no exposed population, then there was no vulnerability. In the 1940s, the physical and engineering sciences defined our approach to dealing with natural hazards (Mileti, 1999). The work of White (1942) was some of the firsts to look at disasters from a social science perspective. White challenged the bigger and stronger technological approach to flood control, and focused on what makes people settle in dangerous areas in the first place. His work, along with that of Burton et al. (1978) led to the risk-hazard approach for understanding vulnerability.

The risk-hazard approach focuses on understanding the impacts of natural hazards on an exposed system. Vulnerability, in terms of the risk-hazard approach, is defined as the outcome of the combination of hazard risk and the potential for loss to the people that are exposed to the risk. This approach has been criticized for its focus on impacts of the hazards instead of on the causal links that lead to the impacts, and for ignoring the role of institutions and politics in shaping vulnerability (Liverman, 2001; Turner et al., 2003a).

Political ecology is an approach to research on society-environment interactions that synthesizes political-economic and ecological explanations of environmental change. It often emphasizes a historical approach to studies of land degradation, natural resource exploitation, environmental management, forest and agricultural transformations. It is particularly concerned with questions of struggles over social control of natural resources and how these are shaped by ideologies, institutions, global economic forces, ideas of nature, and by the natural properties and ecology of the resources concerned. Building on a variety of antecedents in geography and anthropology, the label took hold in the late 1980s and blossomed in the 1990s (Blaikie and Brookfield 1987; Robbins 2004; Gautier and Benjaminsen 2012). Both the inspiration for the approach and its rise in popularity were related to its transgression of epistemological or paradigmatic boundaries. In the 1970s and 1980s, Anglophone universities experienced a period of unprecedented intellectual ferment in the social sciences.

In contrast to political ecology’s geographical and anthropological roots, the resilience approach has its origins in the field of ecology. Taking inspiration from general systems theory, C. S. Holling argued in 1973 that instead of being inherently stable or at equilibrium, ecosystems are in a perpetually transient state. He introduced “resilience” as a property of such a system, defining it as “the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist” (Holling 1973, p. 17).

Nevertheless, Whittaker et al. (2012) noted that they all share a common assumption: that humans are susceptible to harm from events and processes which lead to changes in their physical and social environments. According to the political ecology approach, such exposure to risk can be seen to be largely underpinned by political and economic circumstances in communities and people’s lives (Whittaker et al., 2012). This approach to the concept of vulnerability emphasises that the differential capacities of individuals and groups to anticipate, cope with, resist, and recover from the impacts of hazards such as flooding, are often determined by socio-economic factors (Blaikie et al., 2014).

Political ecology dates back to the 1970s where it originated from studies done to find the reasons behind access and control of resources as well as how these contributed to environmentalal disturbance and degradation (Bryant, 1998). In geography, this theory was closely linked to the evolution of ecological concepts used in human geography. This involved considering the influence of ethnicity and social and political power in human behaviour and its relation with the environment (Zimerer, 2006). Thus, researchers adopting the political ecology approach recognised historical processes as a contingent factor shaping current environmental change. They also viewed social and economic forces as having an impact on local resource utilisation decisions, as well as that these were responsible for the differences in human capacity to respond to environmental disasters (Offen, 2004).

A typical example of such an influence that socio-economic factors have on vulnerability is noted among inhabitants of urban settlements which are usually more sensitive to floods than their rural counterparts, due to the resultant effects on their livelihoods (Birkmann et al., 2013). Similarly, whilst commercial farmers may suffer bigger financial losses due to flooding than small scale farmers, the latter are generally more vulnerable because they have fewer resources (or less capacity) to survive the same flood (Chen, 2008). This is because a disaster usually occurs as a result of the implementation of some poor development strategies, the consequent environmental degradation and the marginalisation of groups (Collins, 2008).

The concept of marginalisation has been elaborated through studies that have focused on how the least powerful social groups in third world countries are vulnerable to socio-environmental changes. Marginalisation connotes that social inequalities limit the livelihood options of certain groups, leading them to degrade landscapes and occupy hazardous environments, which ultimately constrains their abilities to cope with environmental changes (Susman et al., 1983). The idea of marginalisation was based on early political ecology studies which tried to understand why the least powerful groups and classes in a given society inhabited the most hazardous environments (Collins, 2008).

There are several variants to research in the field of political ecology; some focus on the relationship between social, economic and environmental change; others focus on international, colonialist, state and corporate intervention at a community level as well as the potential for uneven consequences and responses (e.g. conflict over resource access) that result. Some variants focus on the causes and consequences of social-environmental marginalisation as well as its remediation. Others focus their attention on empirical evidence and historic research. An example of variants that focus on empirical evidence is a study by Blaikie et al., (1994) which used a pressure and release model to trace the roots of human vulnerability to marginalization.

The assumption made by Blaikie et al.(1994) was that vulnerability was rooted in the social processes and underlying causes which were unrelated to the disaster event itself. This has been the main application of the political ecology theory to hazards, as it provides an analytical framework to understanding the root causes and consequences of disasters within a specific context. Such a framework provides an explanation of power relations and uneven resource access within a particular context (Dagert, 2001).

From the study of the political ecology theory, it is understood that poverty results from development policies that result in diminished access to natural resources. The main reason for this is policies that institutionalise and exacerbate unequal access to resources. At a local level, this is usually the result of large scale political and economic forces rooted in history (Watts, 2000). These forces include but are not limited to, economic and political processes that in the past affected the allocation and distribution of resources between different groups of people. Information reviewed (Anker, 2004; Loftus, 2005; Lawhon et al; 2007) shows that several apartheid policies established the foundation from which human vulnerability ensued in many parts of South Africa (Anker, 2004; Loftus, 2005).

Apartheid policies in the 80s had a significant impact on flood vulnerability in the NMBM as they determined the location of townships and controlled residential segregation (Kiloh and Sibeko, 2000; O’Malley, 2015). This directly contributed to communities being vulnerable to flood disasters. Generally, the most vulnerable people are the poor because they have a limited adaptive capacity. Other particularly vulnerable groups include the sick and elderly, poorly educated and isolated (e.g. remote rural communities), and women-headed households (Morton & Olsen, 2014).

South Africa is particularly vulnerable and exposed to the impacts of flooding due to its socio-economic and environmental context (Molekwa, 2013). Here, climate variability coupled with the increased frequency and intensity of extreme weather events continues to displace the poor. At a local level, flood vulnerability and poverty are interlinked because poor households are usually located in incompetently sited areas that are vulnerable to urban floods (Fox et al., 2012). Whilst poor nations and the poor as a social class are at more risk, the extent of vulnerability varies according to the ability of different groups or individuals to secure alternative resources after a flood and ensure the flow of resources to maintain their livelihood (Ali, 2007). Seminal studies have shown us that the majority of poor people have accepted the risk of living with floods, and there are many examples of communities, which have adapted their way of living to cope with floods while deriving economic and social gain (Solomon & Viljoen, 2003; Dhital and Kayastha, 2012; Sakijege et al., 2012; Siyongwana et al., 2015). Some of this research has been carried out in various parts of South Africa including in the NMBM.

Long before Nelson Mandela Bay came into being, the San, Khoi and Xhosa people inhabited the area. The San and Khoi were nomadic people who neither built permanent structures nor kept written records. The San, however, left many examples of their beautiful and meaningful rock art. The arrival of White Settlers, trekking from the West, and later landing from England, saw the beginning of permanent structures, for example, the Drostdy in Graaff- Reinet in 1786, the beginnings of Uitenhage in 1804, Fort Frederick in 1799 and Port Elizabeth in 1815 (Bukula, 2008). In 1803, Dr Johannes Theodorus van der Kemp of the London Missionary Society established Bethelsdorp, the Bay's first permanent settlement. The arrival of Dutch and British settlers led to dreadful consequences for the San, Xhosa and Khoi people who were displaced from their lands. With a few exceptions, the people were reduced to personal servitude and had no liberty to choose their employment or their masters (Maharaj and Mpungose, 1994).

With the political ecology approach in mind it is assumed that such policies directly played an important role in the geography and vulnerability of the NMBM, along with policies that resulted in unequal economic development and growth, the forced removal of Black people, the consolidation of the apartheid city and the imposition of apartheid political institutions, and the appalling inequalities in government services that apartheid delivered (Kiloh &

Sibeko, 2000). These dynamics created a legacy and responsibility for the post-apartheid government which its agencies have been struggling to recover from or cope with. In several areas in the NMBM this has resulted in the flood vulnerability of particular communities and infrastructure.

One of these areas is the lower part of Missionvale settlement that lies on a gentle slope at the edge of a saltpan lake. The geomorphology of the area is dominated by a saltpan lake that is seasonally, or sometimes annually, wet. The pan gets water through the inflow of salt water that is pumped out regularly, as well as overland flow of rainwater from from the surrounding built up area. Here, the dominant soils are clay soils which are situated in higher areas that are between 5 – 60 metres above sea level and thus allow the saltpan to retain water for longer periods. The saltpan lake is prone to flooding during periods of high rainfall, or when muddy soils become water logged and water is discharged into a local drainage system (Siyongwana et al., 2015). The bulk of the Missionvale community are poor, and the average household income of the population is below the minimum poverty line, with main sources being grants and occasional employment (StatsSA, 2011; SABC, 2011). More than eighty percent knew their houses were flood prone but preferred to stay there because it was situated close to employment opportunities, business activities, health facilities and educational facilities like the Nelson Mandela University’s Missionvale campus (Siyongwana et al. et al., 2015).

Flooding has also occurred in the past in Soweto-on-sea because of its location on a flood plain. Soweto-on-Sea (SOS) is an informal settlement situated in the flood plain of the lower Chatty River near Port Elizabeth. The Chatty River is a small seasonal river which flows into the estuarine reaches of the Swartkops River. In 1994 Mackay, van der Merwe, van Eeden, Hops and Banzana, recorded tens of thousands of people living in approximately 15000 shacks in SOS. Many of the people were unemployed with no visible means of support (Solomon & Solomon and Viljoen, 2003). The area was not formally zoned for residential use, and the local authority structures were not prepared to take responsibility for the upgrading of the settlement with minimal services. This was because SOS developed in an unsafe manner, with 3000 shacks being erected below the 1 in 50 year flood zone for the Chatty River and this fell in a restriction zone for sewerage systems (Solomon & Viljoen, 2003). Since then, the structural development frameworks (SDFs) that were implemented have shown the NMBM developing a more inclusive approach than other post-apartheid municipalities as part of the population residing in SOS was relocated through the Zanemvula project implemented in 2006 (HeraldLive, 2010).

Vulnerability to urban flooding disasters is a challenge for many metropolitan areas such as the NMBM and it is necessary to be able to assess and mitigate against its effects. With this is in mind, the following section discusses different flood vulnerability assessment techniques.

2.3.1 Assessing and mapping flood vulnerability

Assessing flood vulnerability is central to the aim of the study and in the first section this study discusses techniques for flood mapping such as modelling, statistical analysis (such as logical regression analysis) and flood frequencies. The second section, provides a generic overview of vulnerability assessments and their application in assessing flood vulnerability.

Floods tend to affect communities situated in floodplains due to numerous factors discussed in section 2.2.1. In order to reduce the risk due to floods, three main approaches have been mooted in the past with the aim of visualising the impacts of floods (Orupabo et al., 2015). In most cases flood visualisation has been based on statistical analysis, flood frequencies and flood modelling. Statistical analysis has been carried out through logistical regression analysis and can be derived in order to determine the probability and frequency of high discharges in streams (see Figure 2.3 on p24) which eventually result in flooding. Logistical regression works with odds which are simply the ratio of two possible outcomes; for example the proportion of flood presence and the proportion of flooding absence (Nandi et al., 2016). Logistic regression analysis can also be used to derive return intervals based on previous flood data if it is available.

Flood frequencies can be determined for any given stream if data is available for discharge in the stream over a period of time (Gwimbi, 2007). Such data allow for an analysis to determine how often a given discharge for a stage of a river is expected. From this analysis a recurrence interval can be determined and a probability calculated for the likelihood of a given discharge in the stream for any year (Billa et al., 2011). The data needed to perform this analysis is the yearly maximum discharge of a stream from one gauging station over a long enough period of time and recorded precipitation data for the same period of time (Archer and Fowler, 2015). The precipitation data can be used in a model and the results can be compared for accuracy using the recorded stream data.

Flood modelling is used to determine the areas susceptible to flooding when discharge of a stream exceeds the bank-full stage (Dozier, 2016). Using topographic data and precipitation data, models can be constructed to show areas expected to be flooded (Archer and Fowler, 2015; Nandi et al., 2016). This is done through the use of Digital Elevation Models (DEMs) which have the ability to show topographic data at a resolution of thirty metres by thirty metres (30m * 30m) and can be combined with recorded rainfall data for a particular area. Where there is only one rain gauge, data from that is applied across the entire study area. Usually the results generated by the model can be represented visually.

Urban flooding is mainly driven by weather events which can be hard to predict. For this reason, flood hazard predictions are usually generated from models (Nandi et al., 2016). Factors that are taken into consideration in the creation of a model include the volume of a stream, spatial distribution, intensity and duration of rainfall over a catchment area, the capacity of the water course or stream network to convey run-off, catchment conditions before the event, weather, land cover, topography and sea level (Teller, 1968; Zhang et al., 2002; Jha et al., 2012).

Flood impact visualization is used with any spatial assessment that requires information on the probability and extent of a flood, such as vulnerability assessments. Vulnerability assessments are particularly useful for understanding patterns of flood vulnerability at multiple scales (Midgely et al. 2006). Therefore, a niche for vulnerability assessments exists at the intersection of development agencies and governments, as they provide support for generating scientifically sound methods for targeting adaptation and assistance in the event of floods (de Sherbinin et al., 2014). The results of a vulnerability assessment are displayed on maps that show different combinations of flood exposure and sensitivity (Chattopadhyay et al., 2017).

Mapping of vulnerability assessments involves data integration of geo-referenced socio-economic and biophysical data, as well as the use of data derived from remote sensing. Previous studies have shown maps to be useful tools for multi-stakeholder discussions on adaptation planning (Reid et al., 2007; Nhamo et al., 2014; Elkhrachy, 2015). This is because they provide a scientific base for discussions to take place especially in cities or developing countries where geographic information is hard to come by (Morton, 2012). Changnon (2003) argued that, even without an increase in flood hazard over time, the impact of flooding has risen (and will continue to rise) because of the increased exposure of people and assets in urban areas (Baum and Godt, 2010). This requires that the spatial distribution of elements shown by the maps, clearly displays areas of concern regarding flooding (Birkmann et al., 2013). Thus, vulnerability maps form a core component for effective flood disaster management strategies.

In the next section, a hydrological model is defined in general and then the model used in the study is discussed.

2.3.2 Hydrological modelling and mapping flood vulnerability

Hydrological models allow for flood prediction based on certain parameters. Hydrology is a subject that deals with all phases of the world's water (Chow et al., 1988). There are several components and complex interactions within the hydrological system. The hydrological system can be defined as a set of physical, chemical and/or biological processes acting upon an input variable or variables, to convert it into an output variable (or variables) (Xu, 2002). A model can illustrate this process. According to Hagemann et al., (2013), hydrological models (see Figure 2.1 on p26) are simplified representations of actual systems in order to predict responses and make it possible to study the function and interaction of various inputs.

The results generated by such a model can help develop a better understanding of the phenomena operating in a catchment and changes that may affect surrounding ecosystems (Li and Sankarasubramanian, 2012). Moreover, the results provide scientific evidence for forecasting future flooding scenarios that take climate change or land use into account. It is understood, that a model cannot describe all the components of the hydrological system, as well as all the relations between them (Zhu et al., 2012). Models only have the capacity to approximate the parameters at a particular scale (Sun et al., 2002).

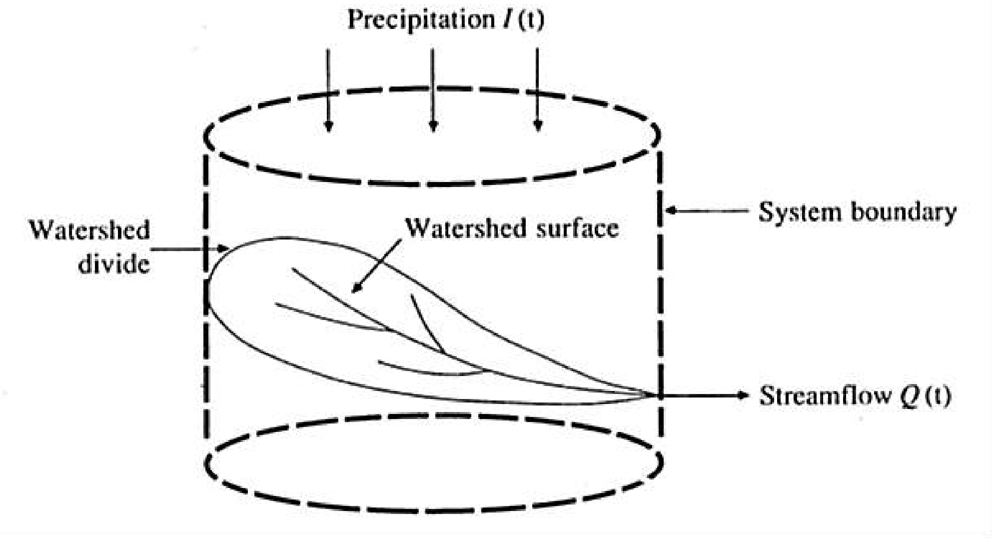


Figure 2.1: A hydrological model (Source: Modified from Xu, 2002)

Most hydrologic models have a small capacity and are limited to watershed scale. A watershed is represented with a division between topographic data and groundwater levels. It is defined as the higher terrain area that contributes to stream flow into a river network or any point of interest (Chow et al., 1988; Dingman, 1984). Hydrological models simulate the process that occur within a catchment area or a watershed (Chow et al., 1988).

The design, construction and operation of any adaptive strategies requires an adequate understanding of the variation of the catchment's runoff. Such information can be generated by identifying the magnitude of the stream flow events and their frequencies. This information can be used at the mitigation planning and design stages where it will be possible to select from alternatives of a design, construction program, and operational procedure that would produce the best output to mitigate the effects of urban flooding (Billa et al., 2011; Chattopadhyay et al., 2017).

Unfortunately, such ideal and precise information is rarely available, so it is necessary to develop plans, designs, and management techniques using a hypothetical set of future hydrological conditions. It is the determination of these future hydrological conditions that has long occupied the attention of engineering hydrologists who have attempted to identify acceptable simplifications of complex hydrologic phenomena (Teller, 1967; Xu, 2002; Nandi et al., 2016). In view of this, a number of basic hydrological models have been developed over time for flood forecasting and rainfall-runoff processes (Sivapalan et al., 1987; Zhao 1992). Over time, the models have become more accurate as they are derived based on measured topographic data.

In recent times, hydrologic models are applied through Geographic Information Systems (GIS).These have become an integral part of hydrologic studies due to their ability to represent the spatial character of the parameters and precipitation that controls hydrologic processes (Kwang and Osei, 2017). GIS plays a major role in distributed hydrologic model parameterisation as a means to overcome gross simplifications made through representation by lumping of parameters at the river basin scale (Prasad and Narayanan, 2016). The extraction of hydrologic information, such as flow direction, flow accumulation, watershed boundaries, and stream networks, from a DEM is manageable through GIS applications.

With the advent of GIS based techniques to obtain channels, cross-sections and topographic datasets have become essential in flood mapping (Yang et al., 2002; Sun et al., 2002). The cross-section elevations obtained from topographic datasets are used along with precipitation data for hydraulic modeling. The stream extent is obtainable by subtracting the topography from the interpolated water surface obtained from DEMs (Tate et al., 2002). The stream extent is used with channel cross sections to generate points, lines and polygons of areas most likely to flood. Using ArcMap and the Hydrologic Engineering Centers-Hydrologic Modeling System extension (HEC-HMS), along with recorded precipitation data, can allow models to predict the rate at which streams will discharge flows. This information is crucial for analysing the assets and the people at risk.

Layers can be created for assets, infrastructure and populations in GIS, and these layers are combined with accurate stream polygons and expected discharges. The damage to residential and commercial property by floodwaters depends on the value of the building structure, the value of its contents, and its susceptibility to damage (Oleyiblo and Zhi-jia, 2010). Property inundation levels are calculated using information associated with heights above river base, stream discharge levels, flood heights and property floor levels. Inundation levels can be modelled according to precise data on river bases. (See Figure 2.2 and 2.3 for model examples.) Flood heights can be predicted using numerical flood modeling in GIS or flood extent maps of previous flood events (Mohammadia, Nazarihaa and Mehrdadi. 2014).

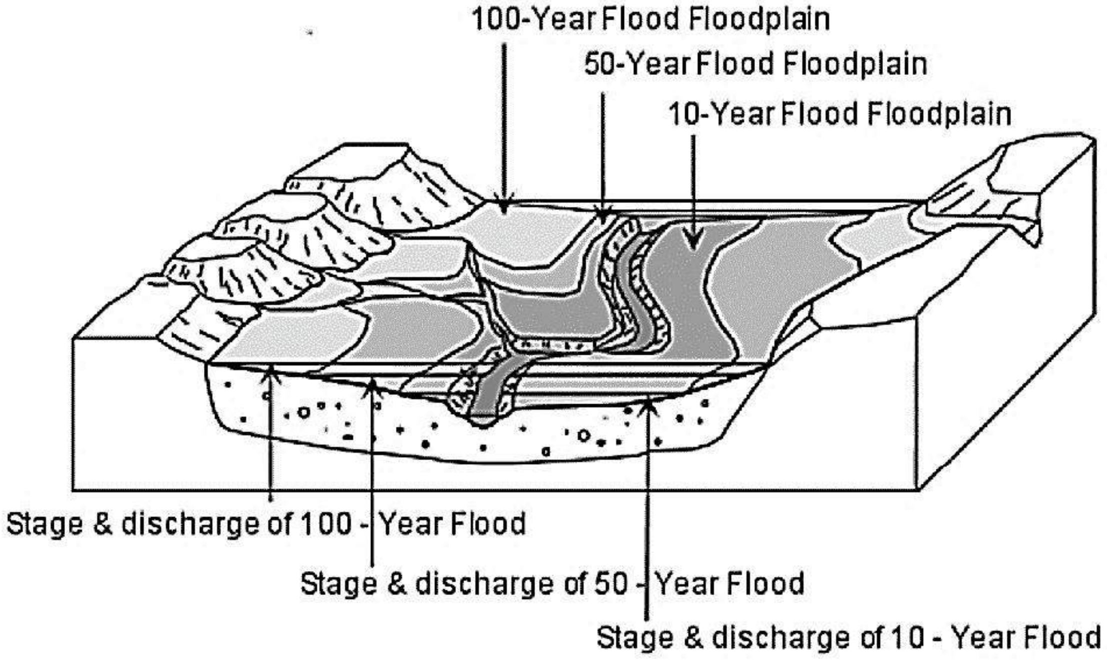


Figure 2.2 Model flood zones and discharge levels

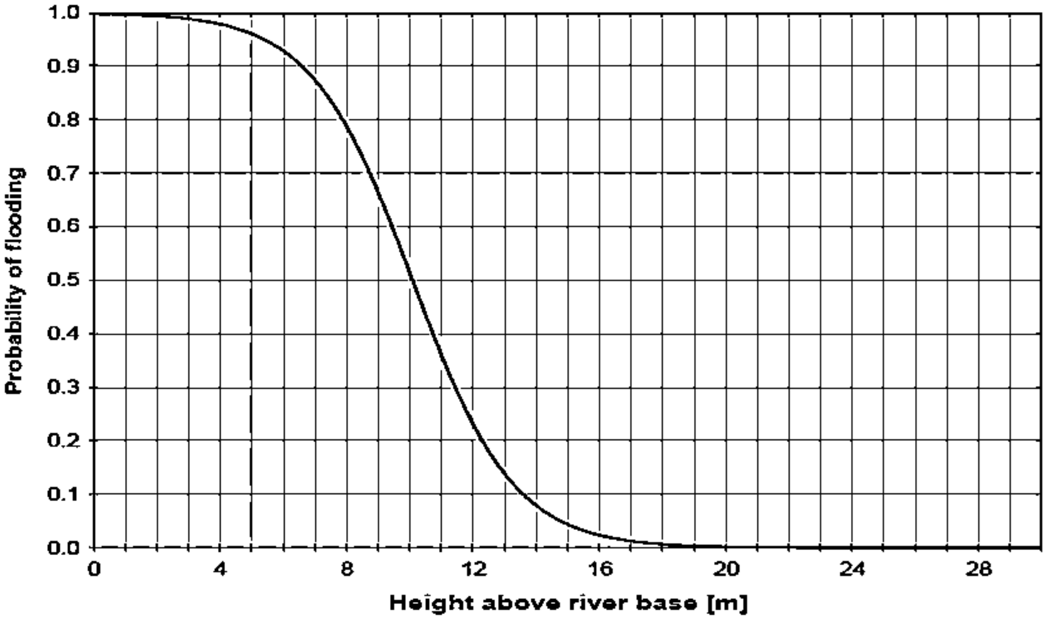


Figure 2.3 Modelled probability of flooding according to height

Flood simulation models are generally expensive to buy and require expert knowledge in order to get accurate outputs. It is important for anyone planning to mitigate against particular impacts of flooding, to understand the importance of adopting an appropriate model based on the information available for planned risk reduction and availability of financial resources. This is because not all municipalities will be able to afford expensive models for flood simulation. An example of cheap models to use, is the incorporation of ArcGIS HEC-GeoHMS (Extension) and HEC-HMS (Extension) to calculate possible flooded areas, as well as frequencies based on previous rainfall data (Oleyiblo and Zhi-jia, 2010; Mohammadi et al., 2014; Elkhrachy,2015). In this study a similar methodology was implemented and it generated data on the rate at which flooding would occur on a particular road in Seaview in the NMBM.

The following section briefly outlines several mitigation strategies implemented across the world and then those currently being implemented in the NMBM. These can also be located in Appendix A.

2.4 Mitigation of urban flood impacts

In this study, flood vulnerability was assessed as the primary goal and this was done in order to and this was done in order to derive adequate mitigation strategies. This section looks at the difference between structural and non-structural strategies for mitigating against the impacts of flooding. Finally, the section concludes by informing on the current mitigation strategies against the effects of flooding being implemented within the NMBM.

Mitigation has been defined in a number of ways over the years, but for the purposes of this work, it is perceived as the policies and activities that will reduce an area's vulnerability to damage from future urban flood disasters (Aerts et al., 2011). The need for mitigation has increased in areas prone to urban floods because of the great losses incurred and, in many locations, because of demands for development. Mitigation also poses a cost effective way of dealing with the impacts of flooding. The Federal Emergency Management Agency (2014), for example, estimates that for every $1.00 spent on mitigation, $4.00 is saved from post flood disaster management.

Some mitigation strategies include applications of technology such as GIS for planning, management schemes and public education. All these aim to reduce an area's vulnerability, but none will be successful without appropriate institutional arrangements (Gruntfest and Handmer, 2001). There are a number of mitigation strategies that can be implemented at ward (local) level and these include zoning, building codes, risk communication, evacuation plans, natural storage, levees and floodwalls, flood proofing and insurance. (See Figure 2.4 below.) All these strategies can be implemented in order to reduce the amount of risk but it should be noted that risk can never be reduced to zero.

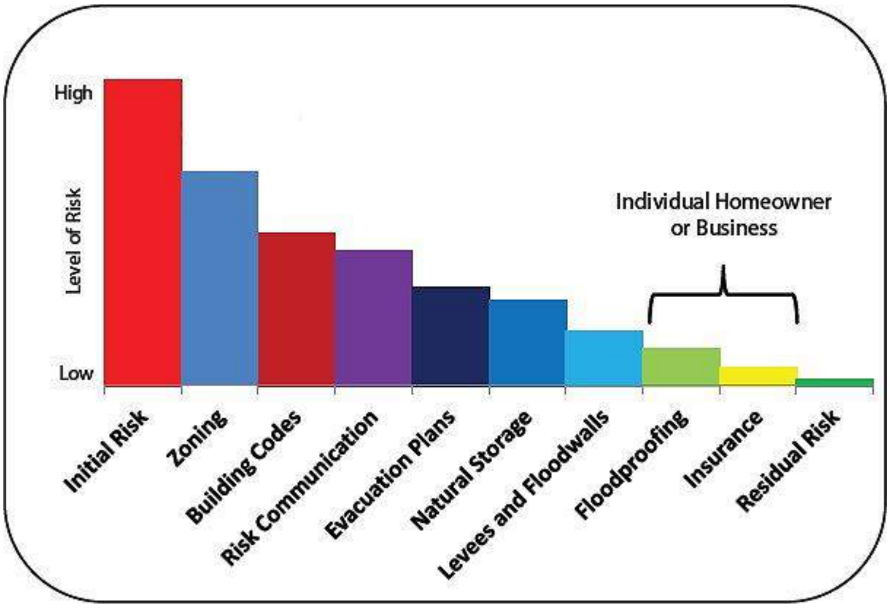


Figure 2.4 Flood mitigation strategies (SOURCE: Modified from USACE (2006)

In this study, mitigation strategies are classified into two categories: structural and non-structural strategies. Research has shown that the common strategy to manage floods has been the implementation of the former whereby civil works such as floodwalls, transversal protection works, embankments, conduits and reservoirs have been constructed to protect the built-in environment up to an acceptable risk threshold (Hai et al., 2010; Morton, 2012; Chang and Huang, 2015). Structural measures are generally designed for either controlling floods or reducing flood peak discharge (Montz, 2001; Colombo et al., 2002). Some of the methods include water retention basins, river training interventions and enhancement, rehabilitation and restoration of the river corridor, whilst reduction and delay of runoff can be attained by adequate agriculture and forestry management practices. These traditional methods have long attempted to reduce vulnerability to flooding, but this cannot be possible without the implementation of non-structural mitigation measures as well.

The need for non-structural mitigation measures in urban areas is extremely high. This is due to the increasing number of assets and population in urban areas that are exposed to flooding (Loczy et al., 2012). Non-structural measures assist with the control of flood vulnerability through socio--economic strategies rather than structural means. The broad categories for non-structural strategies are toleration, emergency response systems and insurance. Toleration simply suggests that a local municipality carries out a flood risk assessment and chooses not to do anything about the results besides relocating the people residing in flood prone areas (Colombo et al., 2002). Emergency response systems are usually derived based on results generated by flood vulnerability assessments and mapping. Emergency response systems work with a range of initiatives such as water level monitors and notification systems. Flood vulnerability maps can also be used to offset insurance calculations for communities and businesses at risk as well as life cover policies for people that reside in areas prone to flooding.

Insurance against flood damage should be an integral part of risk acceptance. However, many countries still do not consider using flood insurance, due to the high associated costs. There is a diversity of the existing solutions to flood coverage (Nicholls et al., 2007). This is mainly due to the technical difficulties involved in providing insurance cover against flooding, because of differing views on the role of the state in managing the flood risk, and diverging perceptions of the dangers posed by flooding (Dozier, 2014). The current solutions in place range from unrestricted private insurance cover to state aid for flood victims. Most developing countries are yet to engage in insurance policies but most have one or more mitigation strategies in place.

The NMBM has already started implementing some of structural and non-structural strategies as a means to prepare against future climate change (See Appendix B) (NMBM, 2016). These initiatives that have been put in place and are directly aimed at reducing the impacts of flooding are improved storm water management and roads, green buildings and more secure infrastructure, urban and open space management, improved coastal management, catchment restoration, relocation of infrastructure and communities and a disaster risk management plan (which includes an early warning system). This study therefore aims to supplement the current initiatives by providing the next step in a road map to reduced vulnerability to flooding in the Metro. In an effort to dampen escalating flood losses and to reduce rising expenditures for structural protective works and because of concerns over their environmental costs, policy should favour non-structural alternatives to protection works.

The next section concludes this Chapter by providing a brief overview of the information that has been explored in Chapter 2.

2.5 Conclusion

One of the techniques and procedures used in this research was a comprehensive literature review which looked at causes and consequences of urban flooding, mitigation strategies, hydrological modelling, GIS operations and a vulnerability assessment. The broad scope of the techniques implemented matches the complexity of the topic and aim of assessing flood vulnerability in the Metro in order to derive adequate mitigation strategies.

For mitigation strategies, this study noted that warning was not enough, and looked at a range of options, generally as well as in a location specific context. Not all measures will be appropriate in all places, and decisions must be made as to what the most appropriate ones are, in a given context. Most strategies must work together, such as emergency services measures and public information, as well as preventive activities and natural resource protection. Some may alleviate or exacerbate the problem, for example, preventive activities resulting in changing land cover patterns can influence runoff conditions by increasing or decreasing flows. Hence, aspects of mitigation are interlinked, and that complicates not only the choice of mitigation measures but also the evaluation of effects and effectiveness.

The next Chapter looks at the systematic processes for creating a methodology that was implemented according to specifications generated in the literature review. This was carried out in order to derive a low cost methodology for assessing flood vulnerability with the use of a DEM, precipitation data, a hydrologic model, population data and land cover data.

Chapter 3: Methodology

3.1 Introduction

In the previous Chapter a comprehensive understanding of the urban flood phenomenon was put forward. This included a brief status quo and information on the types, causes and consequences associated with urban flooding. The second and third section of the Chapter focused on defining vulnerability in the context of urban flooding as well as how to assess it and represent it in maps. The final section considered several mitigation strategies that can be implemented in urban areas. Some of these strategies require accurate maps, and therefore this becomes the main goal for Chapter 3, which describes a methodology for assessing vulnerability to flooding disasters in order to influence appropriate mitigation measures.

Following from the above, this Chapter formulates a complex methodology that can be used to assess flood vulnerability at a local scale. This is done in detail in section 3.3 and section 3.4. In order to create this methodology several studies were drawn upon and adapted. The first was Alkema (2003) which looked at flood risk assessment of a motorway in Trento, Italy. This paper introduced this study to the use of indicator maps such as water-level and flow velocity, to describe various aspects of flooding. The second was by Ashagrie et al. (2006) and it focused on quantifying how land use changes affect hydrological responses. This study introduced the current study to the use of hydrological models to simulate discharge levels and it also created empirical evidence for ranking land uses in order of contribution to flooding incidences.

The third study was carried out by Decker et al. (2009) and it proposed an approach for minimising the consequences of flooding through GIS and a risk based methodology. This introduced the study to the combination and use of hydrologic models, land use data and socio-economic data to asses flood risk and potential damage as well as casualties. The fourth was by Musungu et a. (2012). Here the study implemented an integration of community-based information and GIS in order to carry out a risk assessment. This study introduced the use of weights and ranking systems in order to illustrate spatial disparities of vulnerability within a community. The final study that contributed to the methodology was by Elkrachy (2015), and it focused on the generation of a flash flood map using a DEM, GIS tools and satellite imagery. The study introduced the investigation of mapping and spatial analysis in informal settlements using GIS and processes such as thematic mapping, distance mapping and multi-criteria evaluation analysis.

The next section provides an outline of the methodology implemented in this study. This will provide a simple representation of the stages and processes carried out in order to generate vulnerability maps.

3.2 Methodology outline

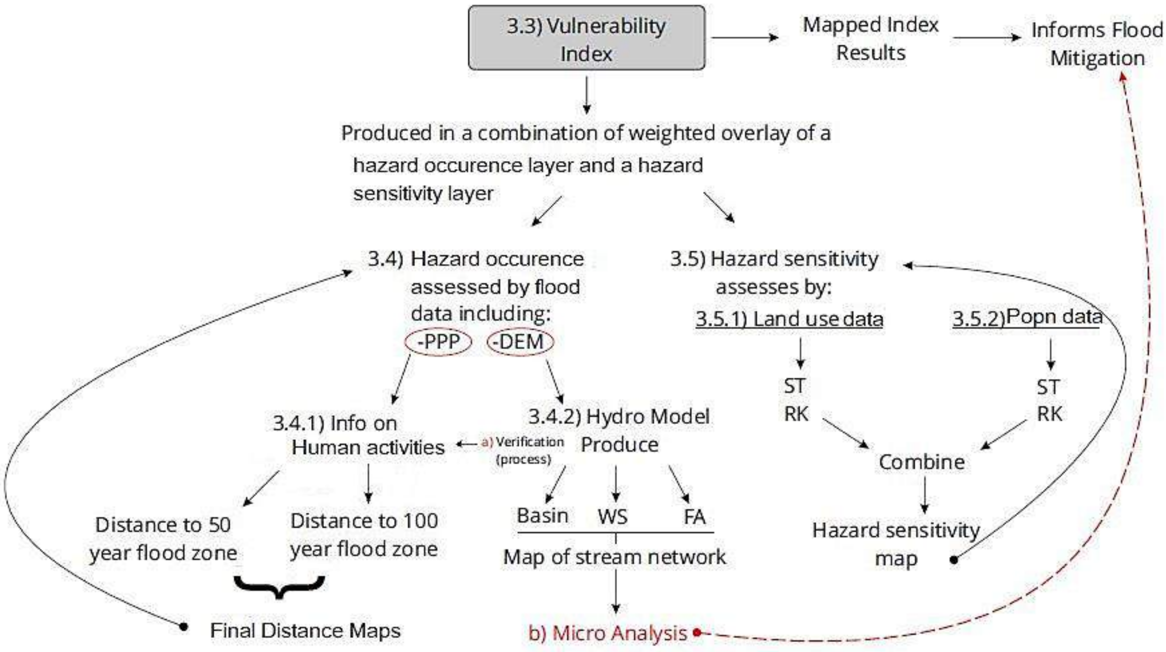


Figure 3.1: Methodology Outline

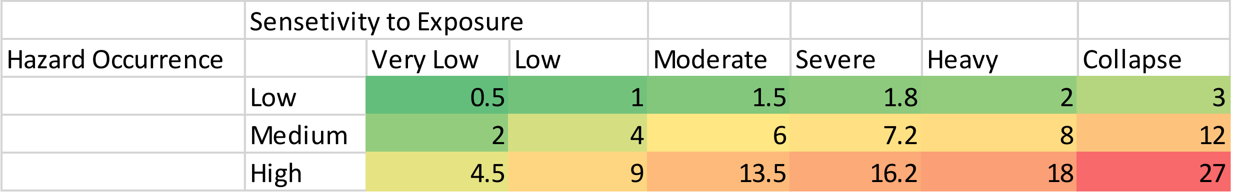
In the following section the methodology used is outlined briefly. It includes the production of a vulnerability index for the NMBM, a discussion of the purpose of the index, the roadmap to creating maps and an illustration of the methodology outline. The methodology carried out in this study follows the steps and processes illustrated in Figure 3.1. This begins from the final result, which is the vulnerability maps, progressing to the indicators that are used to represent the components. The final result of the study is developed using a vulnerability index that compresses large amounts of data on hazard occurrence and hazard sensitivity through standardising, overlaying and intersection of layers as well as a multi-criteria evaluation analysis. The indicators for hazard occurrence and sensitivity were selected based on the political ecology theory discussed in section 2.3. Hazard occurrence in this case, is potentially flooded areas in the NMBM that were calculated using a hydrological model, a DEM and previous flood data provided by the NMBM GIS Department. Hazard sensitivity in the methodology represents socio-economic factors (land use and population density) of vulnerability that were turned into layers using GIS and georeferenced in order to be accurate spatially. The last part of the outline is the hydrological model which was created through several GIS operations.

3.3 Developing a vulnerability index for the NMBM

Each community has its own coping mechanisms and it is important to generate strategies that keep this in mind. Disaster management strategies should always be driven to assist the most vulnerable communities first and then the rest second (Basnayaka et al., 2011). Only through such an approach can communities reduce the rise in damage costs and people affected by urban floods. In order to locate the most vulnerable communities, certain indicators can be used to measure potential sensitivity and potential hazard occurrence. Once these factors are considered, one can create an index which provides insight on vulnerability.

Indicators (hazard and sensitivity) are combined in order to identify the most vulnerable communities and infrastructure according to equation (1) on page 17. This can be represented through an index that condenses large datasets and still displays the effects of a hazard such as flooding on a particular community and land cover type. A vulnerability index is used to combine data by standardising it and also by creating a ranking system (i.e. from worst to best or least to most). Once data are standardised and set out as a matrix it is possible to rank the worst and best situations, in this case, most vulnerable to flooding and least vulnerable. For the maps created in this study, the following index (see Table 3.1) was used to map hazard occurrence and sensitivity to exposure.

TABLE 3.1 Vulnerability Index



	Sensetivity to Exposure						
Hazard Occurrence		Very Low	Low	Moderate	Severe	Heavy	Collapse
	Low	0.5	1	1.5	1.8	2	3
	Medium	2	4	6	7.2	8	12
	High	4.5	9	13.5	16.2	18	27

Vulnerability scale:

1. Very resilient : 0 – 1.5
2. Resilient : 1.5 - 3
3. Average : 4 – 7

4. Susceptible: 8 - 12
5. Very susceptible : 13 – 25

The first stage in developing a vulnerability index is to represent areas that are prone to flooding based on some scientific method. The next section generates a simple methodology for representing areas that are prone to flooding through return intervals (See Figure 2.3) created using a DEM.

3.4 Hazard occurrence within the NMBM

In order to calculate the area flooded in the NMBM, several steps were taken using ArcMap. The first was to develop a hydrological model, and this was used to verify the 100 year flood zone and, 50 year flood zone provided by the NMBM. The hydrological model was also used to simulate discharge and to model a hydrograph in HEC-HMS for a micro-analysis, particularly paying attention to the influence of different land use types on flood occurrences.

3.4.1 Channel distance and human activities

The polygons for previously flooded areas provided by the NMBM needed to be verified and this was done using GIS, and streams defined in the previous section. The model can easily be exported to ArcMap as a shapefile and be compared with data provided by the NMBM. Once data have been verified they can be used to create a hazard occurrence thematic layer that shows distance of settlements and infrastructure from the stream channel starting at zero, then a 50 year return polygon and eventually 100 year return polygon. Areas outside the specific polygons and wetlands were not considered to be vulnerable. This data were used along with the hazard sensitivity layer to create a vulnerability index.

3.4.2 A hydrological model for the NMBM

The first stage of developing an accurate hydrological model requires several processes to ensure that there are no errors or miscalculations - in the case of this study, requiring data processing and terrain pre-processing.

Data processing

30m × 30m resolution DEMs of South Africa were downloaded from a GIS (SA) database. The DEM was then clipped to the NMBM boundary and used to create a hydrologic model with the help of HEC-GeoHMS (see Figure 4.1). HEC-GeoHMS is an ArcGIS extension that was developed by the United States Army Corps of Engineers for displaying surface hydrology in a GIS environment (USACE, 2006b). Using DEM terrain data, HEC-GeoHMS produces a stream network, sub-basin boundaries, and connectivity of various hydrologic elements in an ArcView environment through a series of steps called terrain pre-processing and basin processing. This process allows for the visual representation of catchments and rivers configured in each watershed.

Terrain pre-processing

Determination of a hydrologically correct DEM and its derivatives, mainly the flow direction and flow accumulation grids, requires some use of drainage path calculations. This is necessary in order to precisely depict the flow of water through the catchment, therefore the hydrologically correct DEM must have a resolution sufficient to capture the details of surface flow. Problems often arise when the drainage area has a coarse resolution. These problems can be overcome if proper care is taken in the terrain pre-processing stage to produce a fine resolution of the drainage area. In order to obtain this, the 30m x 30m DEM was used to delineate various components of the catchments used for this study and the following steps were taken:

Filling sinks

A sink is a cell with no clear or defined drainage direction which leads to all surrounding cells to have higher elevation, resulting in stagnation of water. To overcome this problem, the sink must be filled by modifying the elevation value. Once the sinks in a DEM are removed by breaching and filling, the resulting flat surface must still be interpreted to define the surface drainage pattern. This is because there is no flow on flat areas by definition and the next step in the procedure requires that flow direction be assigned. The elevation of pit cells is simply increased until a down-slope path to a cell becomes available with a constraint that states that flow may not return to a pit cell.

Flow direction

The flow direction was derived from the filled grid based on the premise that water flows downhill, and will follow the steepest descent direction. It provides the flat filled surface with a slope to enable water flow freely downward without having to be impounded or trapped. This was done by assigning a slope to the filled grid DEM until the steepest descent direction was achieved (see Figures 4.2 and 4.3). Water can flow from one cell to one of its eight adjacent cells in the steepest descent direction.

Flow accumulation

Based on the derived flow direction grid, the flow accumulation was calculated. A flow accumulation grid was calculated using the flow direction grid. This is because the flow accumulation records the number of cells that drain into an individual cell in the grid. The flow accumulation grid is essentially the area of drainage to a specific cell measured in grid units (see Figure 4.4). Thus the flow accumulation grid is known as the core grid in stream delineation.

Stream definition

The threshold area was assigned to the flow accumulation grid in order to obtain the stream flow path. The stream flow path can be defined by a number of cells that accumulate in an area before they are recognised.

Model application within the NMBM

In this study a model representation of floods was used to determine the potential impacts of flooding on settlements and other infrastructure. The model also calculated future flooding conditions based on a digital elevation model and processes discussed above which recreated a hydrograph and simulated peak discharge for a particular drainage point in the NMBM. The model was combined with rainfall data provided by the South African Weather Service (SAWS) in order to create recreate storm conditions in a hydrologic system. Several parameters such as surface roughness, lag time and soil curve conservation service number were used to create the most realistic flow conditions in the hydrologic system and the results were used to inform mitigation strategies.

In this study basic principles were used to correct the data generated by the DEM with layers provided by the NMBM GIS Department to represent accurate return intervals (Fenwick, 2005). Each return interval created in this study is standardised and ranked according to influence on flooding (see Table 3.1) for use in the vulnerability index.

Table 3.2 Hazard occurrence

Hazard occurrence	Return period	Hazard ranking
Little or no occurrence	>100 year flood zone	1
Some occurrence	100 year flood zone	2
High occurrence	50 year flood zone	3

3.5 Hazard sensitivity within the NMBM

Incorporating socio-economic factors into the vulnerability index

It is important to analyse some of the social, economic and political factors that contribute to the vulnerability of an area. With this in mind this section aims to discuss socioeconomic factors that were used to generate the vulnerability index. These factors are population density and landcover.

3.5.1 Population density in the NMBM

Population density is the number of people per unit of area, usually quoted per square kilometre, excluding areas of water. The quick growth of populations has been increasing the number of people affected by floods. This occurs because many slums located along the tidal creeks and the riverside are highly exposed to flood risk. Flooding, coastal storms and cyclones, as well as sea level rise, are among the current climatic threats experienced by many coastal cities such as the NMBM. Several inhabited areas in the Metro have already been identified as being highly prone to flooding, such as the 3rd avenue dip in Newton Park which houses a road located on a low-lying area with poor drainage.

It is assumed that the more people there are in an area exposed to flooding the higher the vulnerability score. This is further exacerbated by a lack of disaster management strategies or the existence of strategies that take a blanket approach for areas when it comes to flooding. Population density data, along with land cover data, can be used to represent sensitivity to flooding and can be used to locate people and areas which require the most assistance during flood events (Hughes, 2010).

Table 3.3 below summarises the sensitivity ratings used for population densities in this study. Note the rankings assigned are specific to the NMBM and may not be applicable to other areas.

Table 3.3 Population density

Severity Rating	Population Density (per sqkm)	Sensitivity ranking
Low	1 – 1999	1
Medium	2000 – 8000	2
High	>8000	3

3.5.2 Land use in the NMBM

Pressure from urban development, land use and land cover change has affected ecosystem services such as the production of food and water; the control of climate and disease; nutrient cycles and oxygen production; spiritual and recreational benefits for some urban environments. This has also contributed in urban flooding vulnerability (Whittaker et al., 2012).

Assets accumulated on land are commonly used to represent the sensitivity of an area to a particular hazard. In this study, sensitivity can be assessed by combining the land cover type and population density. In the last two decades in the NMBM from 1991 to 2013, land cover has transformed dramatically due to socio-economic activities and extraction of natural resources. Unlimited or unwanted exploitation of natural resources reduces their sustainability limit, and this has become a cause of serious concern for the government and the people (Camarasa-Belmonte et al., 2011; Dalu et al., 2017). Land use plays a major role in how overland flow is transported and therefore plays a major role in flooding as certain land use types increase run-off and others reduce it.

Table 3.4 below summarises how different land cover types were assigned a specific sensitivity rating.

Table 3.4 Land Cover

Land cover	Sensitivity rating
Waterbody	0.5
Bare Land	1
Agriculture	1.5
Forest	1.8
Mangrove	2

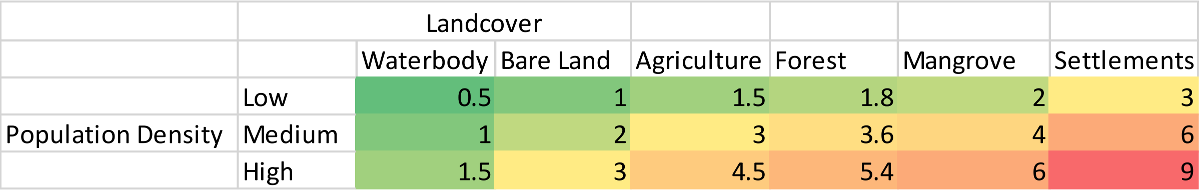
Settlements	3

Source: Modified from Mukesh et al. (2017)

This study adapted parameters from a natural and environmental vulnerability distribution study in Astrakhan, Russia (Mukesh et al., 2017). The paper classified natural and environmental vulnerability using landscape pattern from a multidisciplinary approach, based on remote sensing and Geographical Information System (GIS) techniques. A model was developed by creating thematic layers with land cover as one of the two key attributes. According to numerical scores assigned to different types of land cover, it could be classified into five levels: very low, low, moderate, severe, high and collapse. In the study area, encroachment of built up areas into unsafe environments, population growth, industrialisation and governmental policies for environmental protection are main causes for vulnerability.

Land use data is typically used to represent sensitivity and resilience according to classifications within a study area. The sensitivity to flooding of the various areas in the NMBM was classified in terms of groups as shown in Table 3.4. All individual indicators were aggregated into three groups, lowly sensitive, sensitive and highly sensitive. Specific factors that were scored, were then assigned to a feature class and used to create the sensitivity layer.

Table 3.5 Sensitivity Scale



	Landcover						
		Waterbody	Bare Land	Agriculture	Forest	Mangrove	Settlements
	Low	0.5	1	1.5	1.8	2	3
Population Density	Medium	1	2	3	3.6	4	6
	High	1.5	3	4.5	5.4	6	9

Sensitivity scale

1. Lowly sensitive: 0.5 – 2
2. Sensitive: 2 - 5
3. Highly sensitive: 5 – 9

After its creation, the sensitivity layer is used along with the hazard layer in a Multi Criteria Evaluation in order to create a vulnerability index.

3.6 Operation of vulnerability index and production of maps

Multi Criteria Evaluation (MCE) is commonly used in GIS to investigate different analyses based on a variety of attributes that the selected areas have (Eastman, 1999). MCE makes it possible to generate a comparison of alternatives and rankings of said alternatives according to varying degrees, from low to high.

There are two common procedures for MCE. The first involves Boolean overlay. All criteria are evaluated by thresholds to produce Boolean maps, which are then combined by logical operators such as intersection (AND) of layers which only combines certain features in each layer to create a new one and union (OR) of layers which combines all the features in layers combined to create a new one. The second is weighted linear combination. When there is more than one attribute that needs to be considered, (e.g. to find the area most vulnerable to flooding) each attribute is assigned a weight based on its contribution to the problem. The results are combined into multi-attribute spatial features with final scores that can be ranked (see Table 3.1). The higher the score, the more vulnerable the area. In this study the above mentioned operations were used in order to illustrate the vulnerability index as a map.

3.7 Conclusion

As discussed in Chapter 2, urban flooding poses numerous threats for any community that is exposed to it. Given the different scales with which it occurs, it is important to choose a methodology that can address challenges faced at a local level. Chapter 3 has presented the key steps taken in developing a low cost methodology for assessing vulnerability to flooding. The information in Chapter 2 and Chapter 3 provides a platform for understanding and assessing vulnerability to urban flooding. This information is used in Chapter 4 to generate context specific mitigation strategies for the NMBM as well as to inform on disaster management policy and its legacy.

Chapter 4: Research results

4.1 Introduction

The previous Chapter proposed a methodology aligned to the central aim of this study, which was to assess flood vulnerability. The methodology involved several processes in GIS and allowed for the creation of maps that could inform mitigation strategies. This section aims to represent the results generated by the methodology at a local scale, by showing the population and infrastructure exposed to future flooding. Presentation of results follows the structured approach described in Figure 3.1.

4.2 Flood hazard occurrence in the NMBM

It has been identified through several seminal studies that the NMBM is prone to flooding during rainy seasons (Mackay et al., 1994; Solomon and Viljoen, 2003; Siyongwana et al., 2015; de Wit, 2017). The results of this study have been derived based on a scientific methodology for identifying communities that are vulnerable to future cases of flooding. In aid of this, the methodology generated in Chapter 3 provided some insight on differing levels of vulnerability amongst communities in the metro. The sections that follow in Chapter 4 describe the final results generated from this. The first of which is section 4.2.1 which illustrates the process of creating an accurate hydrologic model.

4.2.1 Using a DEM to create a hydrologic model for NMBM

GIS was used to define potentially flooded areas in the NMBM on maps, in the form of a 50 year return interval, a 100 year return interval and known wetlands. GIS was also used to model a storm hydrograph for the NMBM. Large, catastrophic floods have a very low frequency or probability of occurrence, whereas smaller floods occur more often. The larger the number of years in a recurrence interval, the smaller the chances of experiencing that flood in a particular year (Aerts et al., 2011). Before the flood interval layers were created, the Digital Elevation Model had to undergo some pre-processing in order to remove any errors (see section 3.3.1), to delineate stream channels and in order to create polygons for flood zones. Figures 4.1 to 4.5 show the results of the creation process for a hydrological model for NMBM with a specific drainage point.

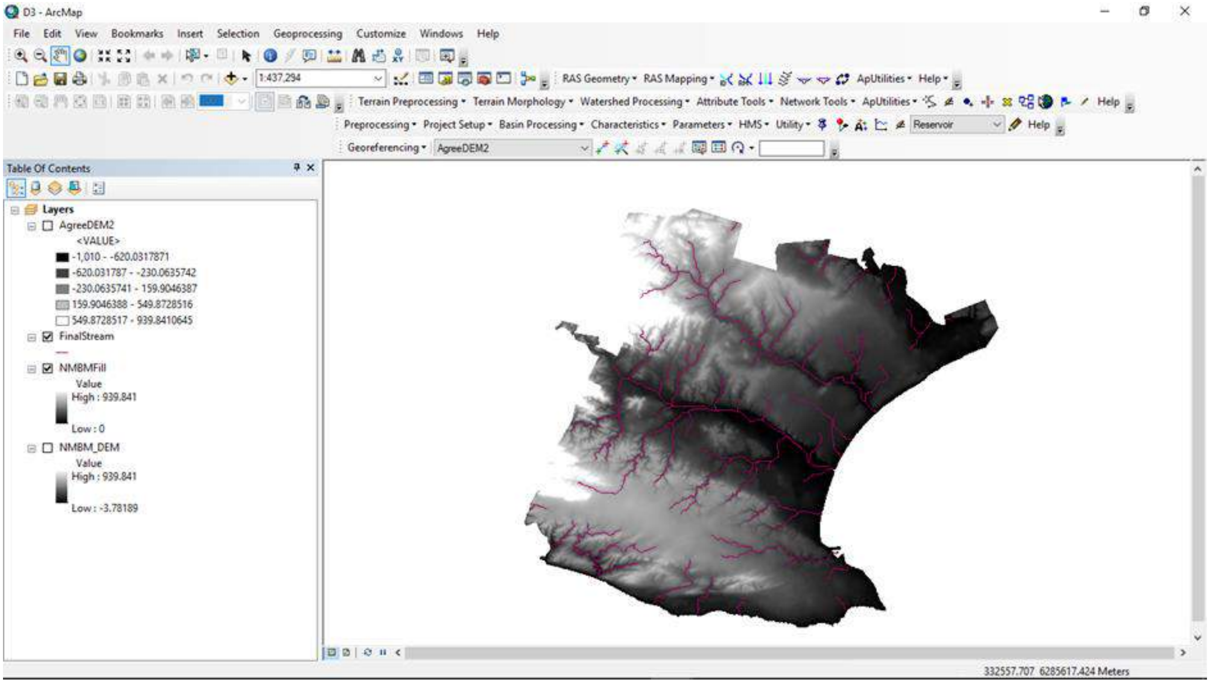


Figure 4.1: Pre-processing of a DEM using a HecGeoHMS extension in order to derive accurate central stream lines and channel reaches through cross sections.

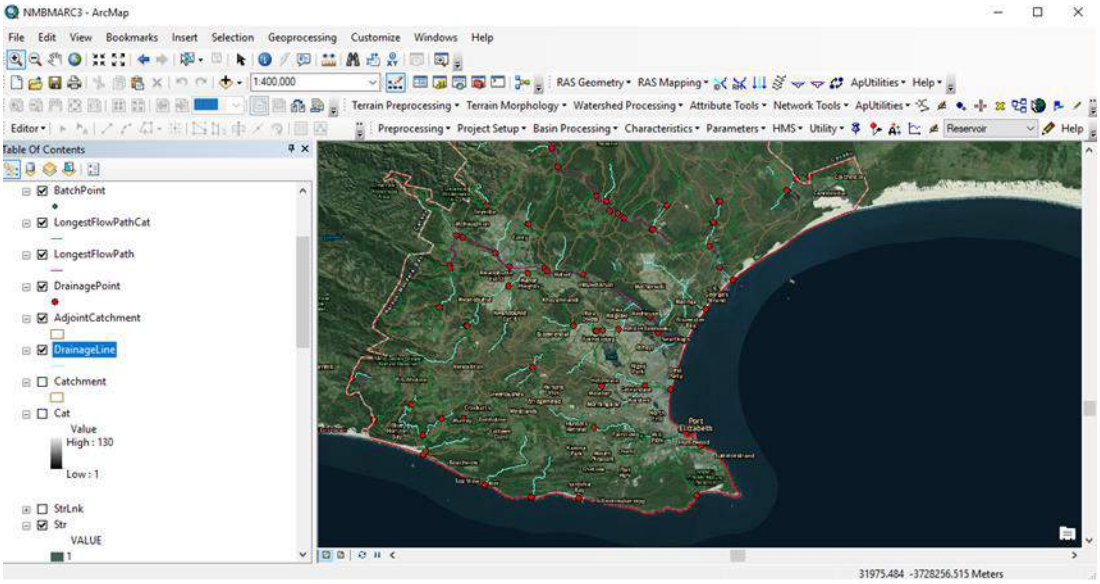


Figure 4.2: Calculating watersheds and streams within the NMBM using DEM in HECGeoHMS

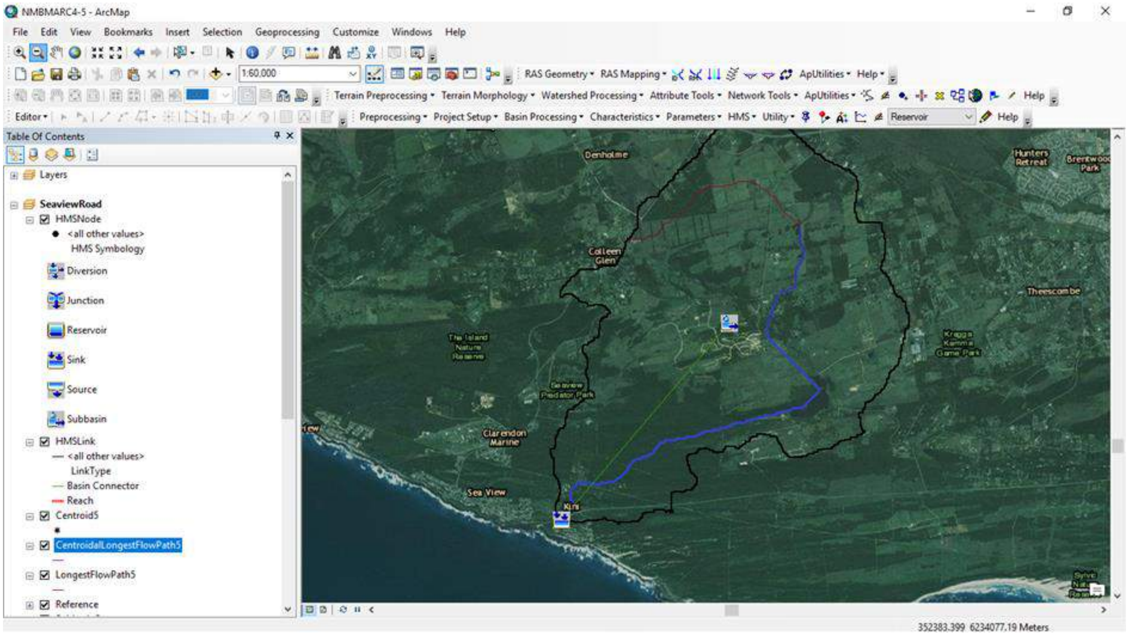


Figure 4.3 Isolating the watershed for analysis (drainage point at Seaview road)

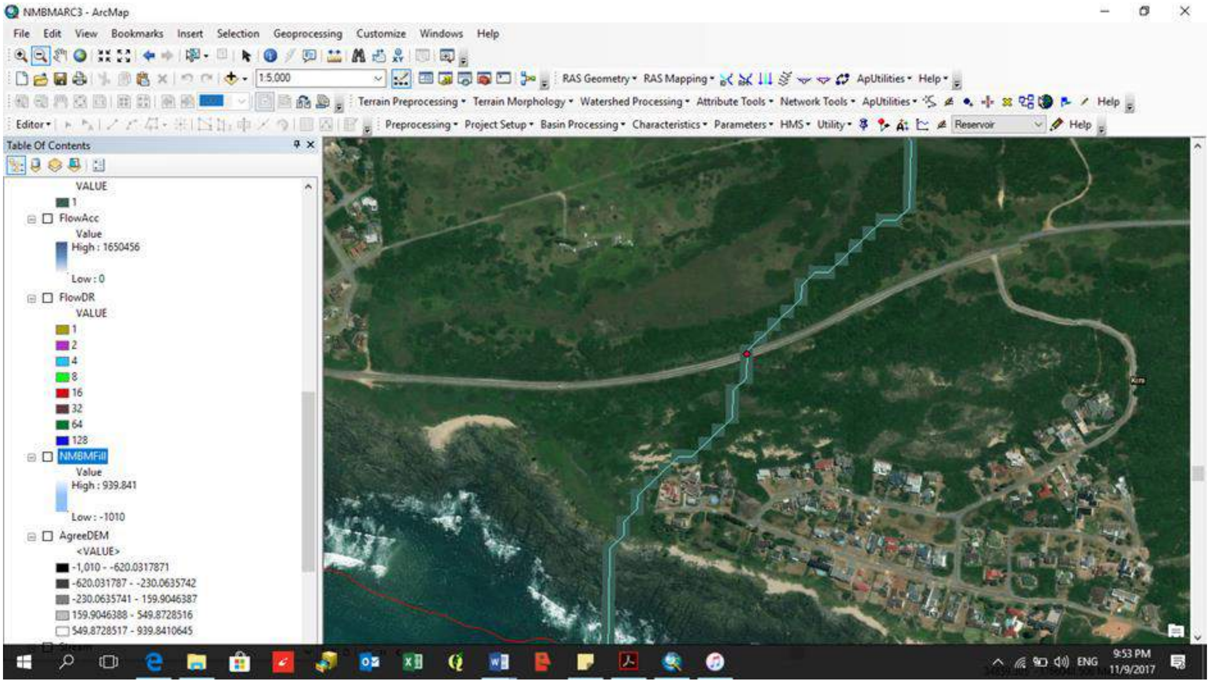


Figure 4.4: The drainage point selected for analysis in the hydrological analyses in HECHMS

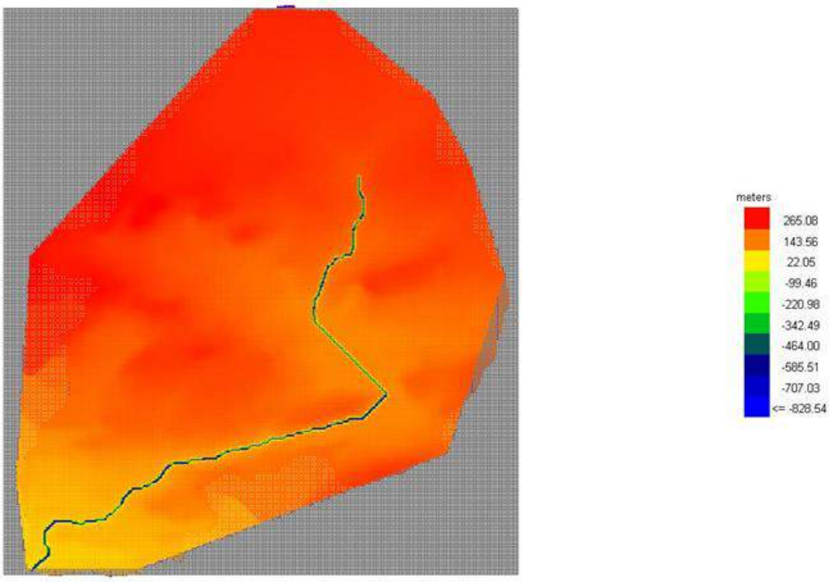


Figure 4.5: Elevation profie of entire watershed in HEC-HMS

The Soil Conservation Service curve number (SCS-CN) loss method is used to estimate runoff for a selected watershed in the study area. The response of sub basin to runoff is the lag time, time from centroid of rainfall to peak runoff. This time is determined by the basin shape and size, land cover, soil type and topography. In this study the drainage point (see Figure 4.4) was selected along Seaview Rroad as this made it simple to calculate the Manning's coefficient and fast lag time. Manning's coefficient is used to calculate surface roughness and since a road was selected this meant that the value was relatively high at 0.016 (Engineering ToolBox, 2004). Lag time is an essential input to the most common hydrograph models as it calculates the amount of time for the whole watershed to contribute to the outflow or the amount of time for the water to reach the outlet from the furthest point from the outlet. The lag time for an ungauged stream must be estimated from the physical characteristics of the stream and its watershed.

TThere was also only one rainfall gauge available for the whole NMBM area and this was used for the model. In this study HEC-GeoHMS (US Army Corps of Engineers, 2013b) and HEC-HMS (US Army Corps of Engineers, 2013a) software wereare used to calculate sub basin parameters and hydrological modelling. Longest flow length, centroid of basin, basin centroid elevation, and centroid longest flow path were then calculated. The meteorological model in HEC-HMS was created by specifying an hourly time series of rainfall for 20 July 2000 (see Ffigure 4.7). Data for the day wereas obtained from the South African Weather Service for days with above normal (100mm) levels of rainfall. The Muskingum routing method wasis used in order to run the model.

The Muskingum Routing unit models the flow of water in natural and man-made open channels using the Muskingum method to route the flow. The Muskingum Routing calculates the discharge within a river or channel reach given the inflow hydrograph at the upstream end. The model was run in order to calculate peak run-off and subsequent discharge volumes (Kumar et al., 2011) (McCarthy, 1938).

Figure 4.6 illustrates the drainage point selected for further study and depics the elevation profile of the watershed, with the stream in dark blue).

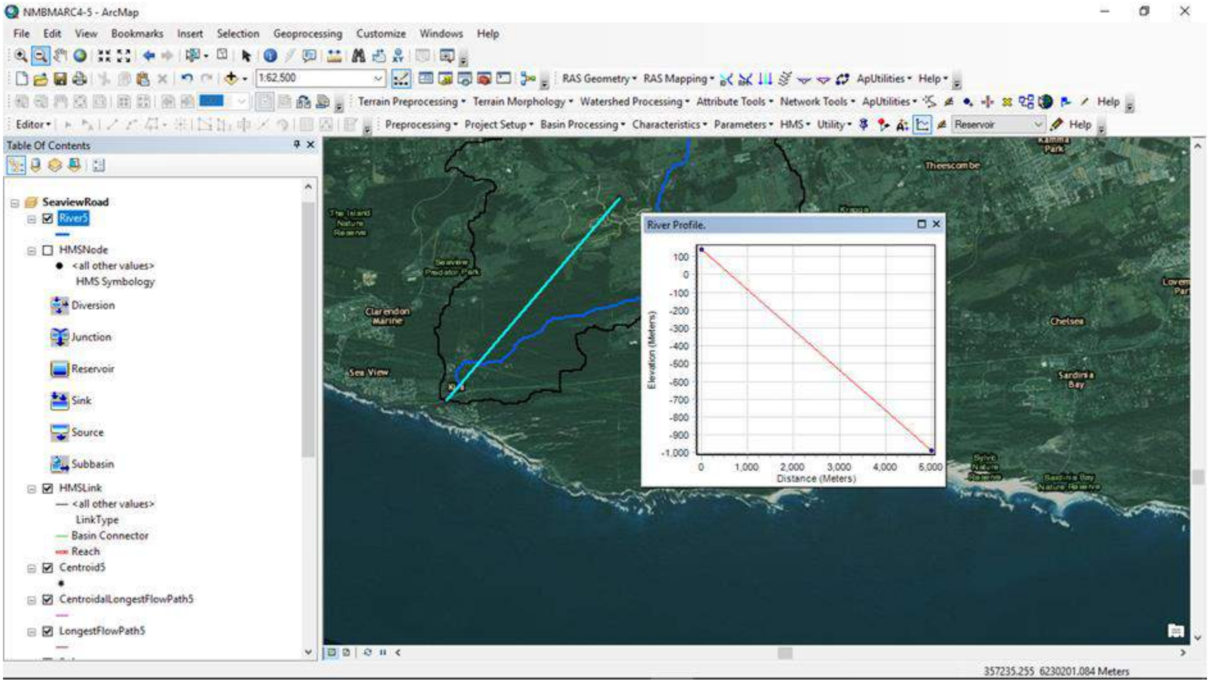
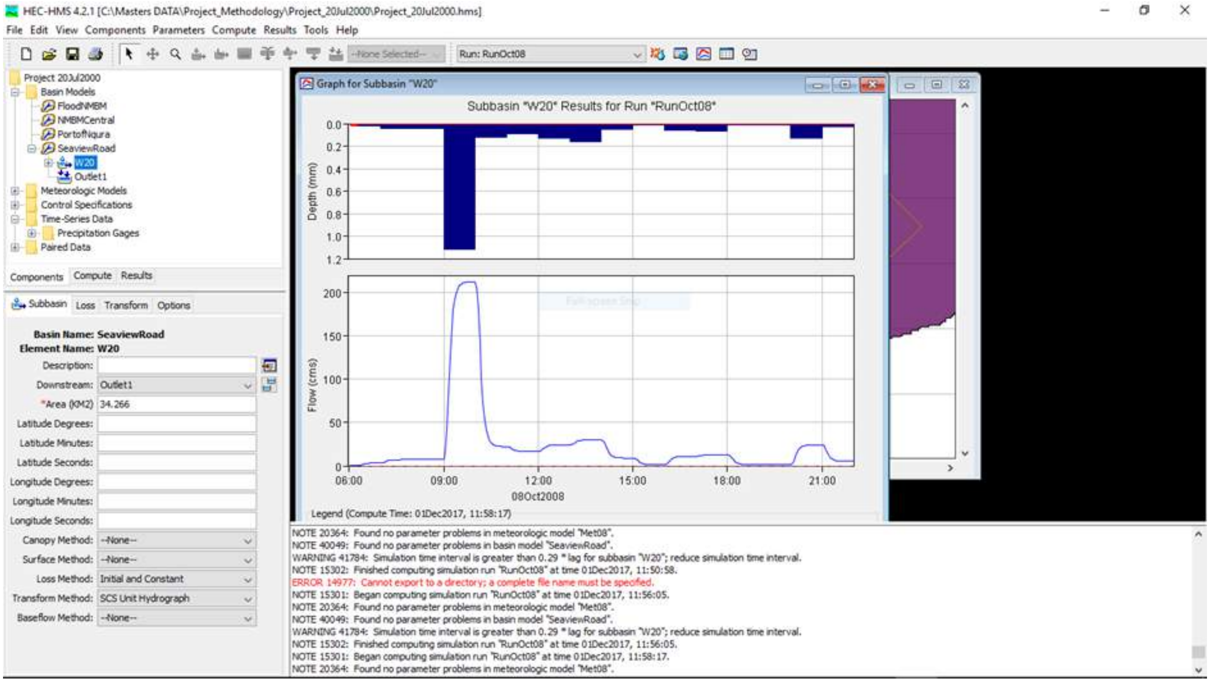


Figure 4.6: Stream elevation profile in ArcMap

The selection of a road for simulation is favourable as it allows for known parameters for the model in HMS (Manning’s coefficient for surface roughness >0.0105 and a short lag time of 7.94seconds) (Wanielista, Kersten and Eaglin., 1997). This model allows for a peak run-off time to be as well as a maximum discharge to be simulated using previous rainfall data from 20 July 2000.

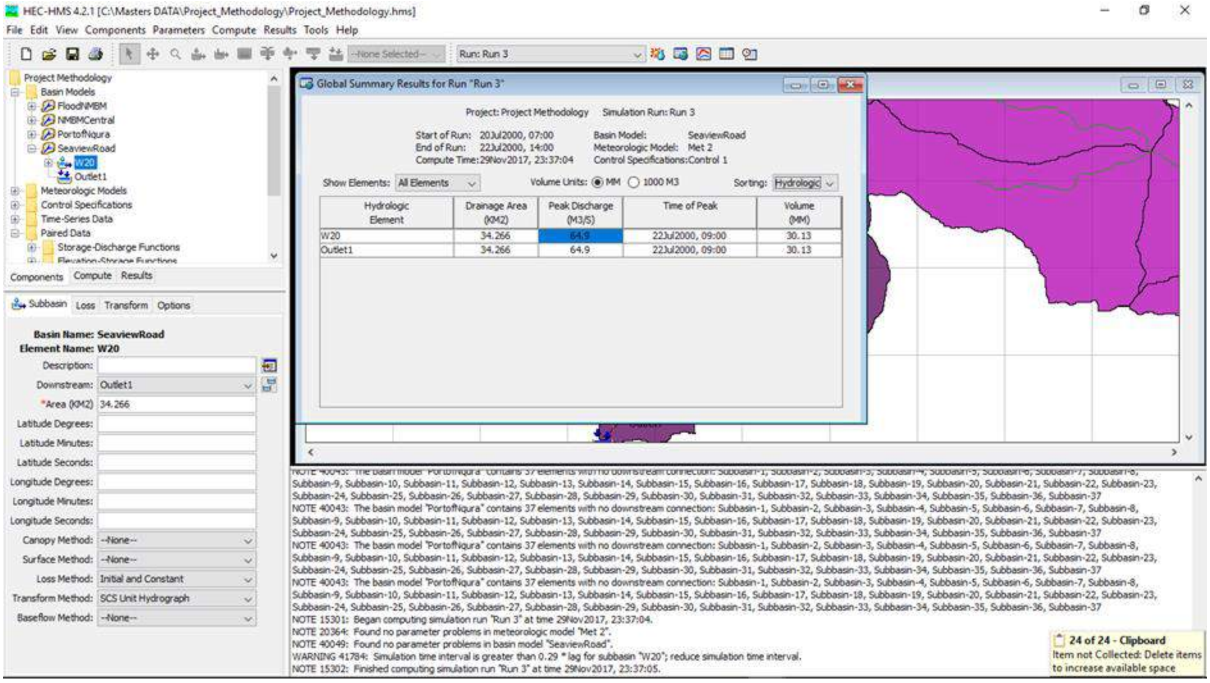
Figure 4.7 displays the results of the simulation using HMS. In Ffigure 4.8, flow accumulation is created for the lowest elevation points on the DEM and are represented by the dark blue lines on the map. Areas with dark blue lines represent areas where precipitation would collect due to the lowest elevation on the map.



Basin Name: SeaviewRoad
Element Name: W20
Description:
Downstream: Outlet1
*Area (KM2) 34.266
Latitude Degrees:
Latitude Minutes:
Latitude Seconds:
Longitude Degrees:
Longitude Minutes:
Longitude Seconds:
Canopy Method: --None--
Surface Method: --None--
Loss Method: Initial and Constant
Transform Method: SCS Unit Hydrograph
Baseflow Method: --None--

```
NOTE 20364:  Found no parameter problems in meteorologic model "Met08".
NOTE 40049:  Found no parameter problems in basin model "SeaviewRoad".
WARNING 41784:  Simulation time interval is greater than 0.29 * lag for subbasin "W20"; reduce simulation time interval.
NOTE 15302:  Finished computing simulation run "RunOct08" at time 01Dec2017, 11:50:58.
ERROR 14977:  Cannot export to a directory; a complete file name must be specified.
NOTE 15301:  Began computing simulation run "RunOct08" at time 01Dec2017, 11:56:05.
NOTE 20364:  Found no parameter problems in meteorologic model "Met08".
NOTE 40049:  Found no parameter problems in basin model "SeaviewRoad".
WARNING 41784:  Simulation time interval is greater than 0.29 * lag for subbasin "W20"; reduce simulation time interval.
NOTE 15302:  Finished computing simulation run "RunOct08" at time 01Dec2017, 11:56:05.
NOTE 15301:  Began computing simulation run "RunOct08" at time 01Dec2017, 11:58:17.
NOTE 20364:  Found no parameter problems in meteorologic model "Met08".
```

Figure 4.7: Simulated hydrograph created using the model in HECHMS, specific parameters for the discharge and rainfall data provided by the SAWS, for the point located on Seaview road



Project: Project Methodology   Simulation Run: Run 3

Start of Run: 20Jul2000, 07:00
End of Run: 22Jul2000, 14:00
Compute Time: 29Nov2017, 23:37:04
Basin Model: SeaviewRoad
Meteorologic Model: Met 2
Control Specifications: Control 1

Show Elements: All Elements   Volume Units: ● MM ○ 1000 M3   Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
W20	34.266	64.9	22Jul2000, 09:00	30.13
Outlet1	34.266	64.9	22Jul2000, 09:00	30.13

Basin Name: SeaviewRoad
Element Name: W20
Description:
Downstream: Outlet1
*Area (KM2) 34.266
Latitude Degrees:
Latitude Minutes:
Latitude Seconds:
Longitude Degrees:
Longitude Minutes:
Longitude Seconds:
Canopy Method: --None--
Surface Method: --None--
Loss Method: Initial and Constant
Transform Method: SCS Unit Hydrograph
Baseflow Method: --None--

```
Subbasin-9, Subbasin-10, Subbasin-11, Subbasin-12, Subbasin-13, Subbasin-14, Subbasin-15, Subbasin-16, Subbasin-17, Subbasin-18, Subbasin-19, Subbasin-20, Subbasin-21, Subbasin-22, Subbasin-23,
Subbasin-24, Subbasin-25, Subbasin-26, Subbasin-27, Subbasin-28, Subbasin-29, Subbasin-30, Subbasin-31, Subbasin-32, Subbasin-33, Subbasin-34, Subbasin-35, Subbasin-36, Subbasin-37
NOTE 40043:  The basin model "PortofNqura" contains 37 elements with no downstream connection: Subbasin-1, Subbasin-2, Subbasin-3, Subbasin-4, Subbasin-5, Subbasin-6, Subbasin-7, Subbasin-8,
Subbasin-9, Subbasin-10, Subbasin-11, Subbasin-12, Subbasin-13, Subbasin-14, Subbasin-15, Subbasin-16, Subbasin-17, Subbasin-18, Subbasin-19, Subbasin-20, Subbasin-21, Subbasin-22, Subbasin-23,
Subbasin-24, Subbasin-25, Subbasin-26, Subbasin-27, Subbasin-28, Subbasin-29, Subbasin-30, Subbasin-31, Subbasin-32, Subbasin-33, Subbasin-34, Subbasin-35, Subbasin-36, Subbasin-37
NOTE 40043:  The basin model "PortofNqura" contains 37 elements with no downstream connection: Subbasin-1, Subbasin-2, Subbasin-3, Subbasin-4, Subbasin-5, Subbasin-6, Subbasin-7, Subbasin-8,
Subbasin-9, Subbasin-10, Subbasin-11, Subbasin-12, Subbasin-13, Subbasin-14, Subbasin-15, Subbasin-16, Subbasin-17, Subbasin-18, Subbasin-19, Subbasin-20, Subbasin-21, Subbasin-22, Subbasin-23,
Subbasin-24, Subbasin-25, Subbasin-26, Subbasin-27, Subbasin-28, Subbasin-29, Subbasin-30, Subbasin-31, Subbasin-32, Subbasin-33, Subbasin-34, Subbasin-35, Subbasin-36, Subbasin-37
NOTE 40043:  The basin model "PortofNqura" contains 37 elements with no downstream connection: Subbasin-1, Subbasin-2, Subbasin-3, Subbasin-4, Subbasin-5, Subbasin-6, Subbasin-7, Subbasin-8,
Subbasin-9, Subbasin-10, Subbasin-11, Subbasin-12, Subbasin-13, Subbasin-14, Subbasin-15, Subbasin-16, Subbasin-17, Subbasin-18, Subbasin-19, Subbasin-20, Subbasin-21, Subbasin-22, Subbasin-23,
Subbasin-24, Subbasin-25, Subbasin-26, Subbasin-27, Subbasin-28, Subbasin-29, Subbasin-30, Subbasin-31, Subbasin-32, Subbasin-33, Subbasin-34, Subbasin-35, Subbasin-36, Subbasin-37
NOTE 15301:  Began computing simulation run "Run 3" at time 29Nov2017, 23:37:04.
NOTE 20364:  Found no parameter problems in meteorologic model "Met 2".
NOTE 40049:  Found no parameter problems in basin model "SeaviewRoad".
WARNING 41784:  Simulation time interval is greater than 0.29 * lag for subbasin "W20"; reduce simulation time interval.
NOTE 15302:  Finished computing simulation run "Run 3" at time 29Nov2017, 23:37:05.
```

24 of 24 - Clipboard
Item not Collected: Delete items to increase available space

Figure 4.8: Discharge simulated in HECHMS using the model developed and rainfall data provided for 20 – 22 July 2000

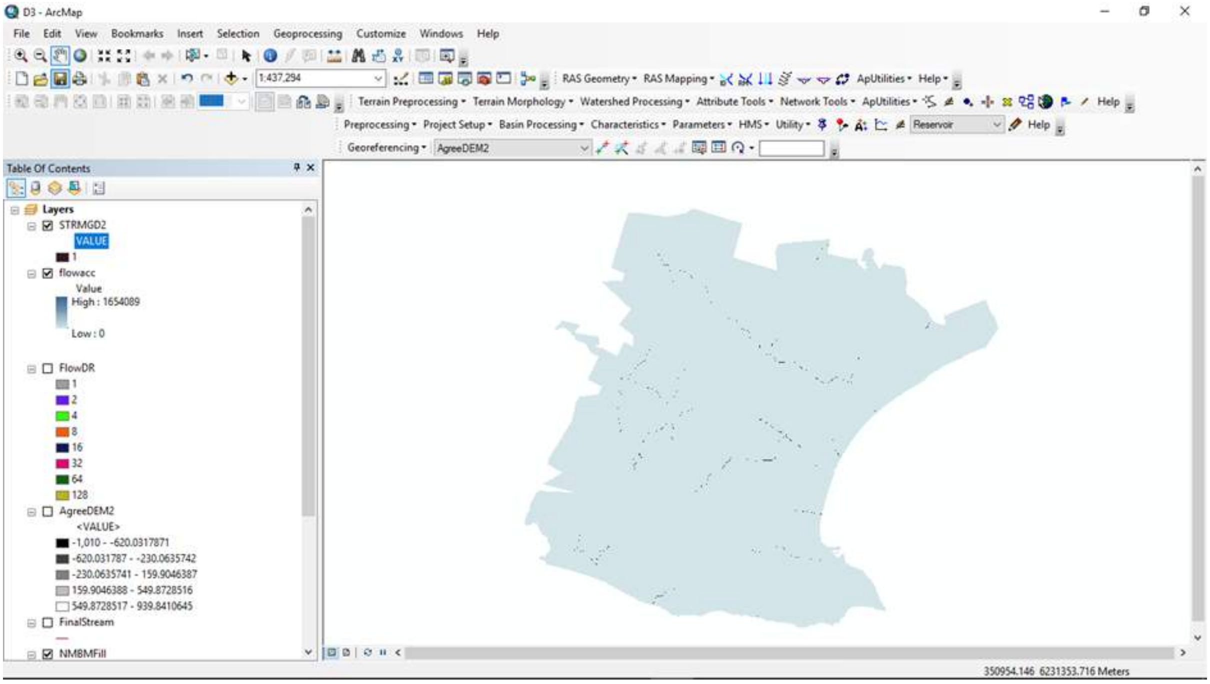


Figure 4.9: Map of flow accumulation used to create model and verify flood prone areas

4.2.2 Flood interval maps for the NMBM

It is assumed that the centre of the stream is also the lowest point within the channel, therefore the areas adjacent are considered as flood plains and should overlap with the layers supplied by the NMBM for previous floods. High resolution land cover data generated from satellite imagery, a pre-processed DEM and data provided for previous floods by the NMBM GIS department were used to create 50 year and 100 year return periods. The steps mentioned above were carried out in order to create an accurate stream line and floodplains, the results of which was Figure 4.9 above. Figure 4.9 was used to verify the data supplied by the NMBM GIS Department and the result was Figure 4.10 which illustrates a georeferenced 50 year flood interval polygon and a georeferenced 100 year flood interval polygon.

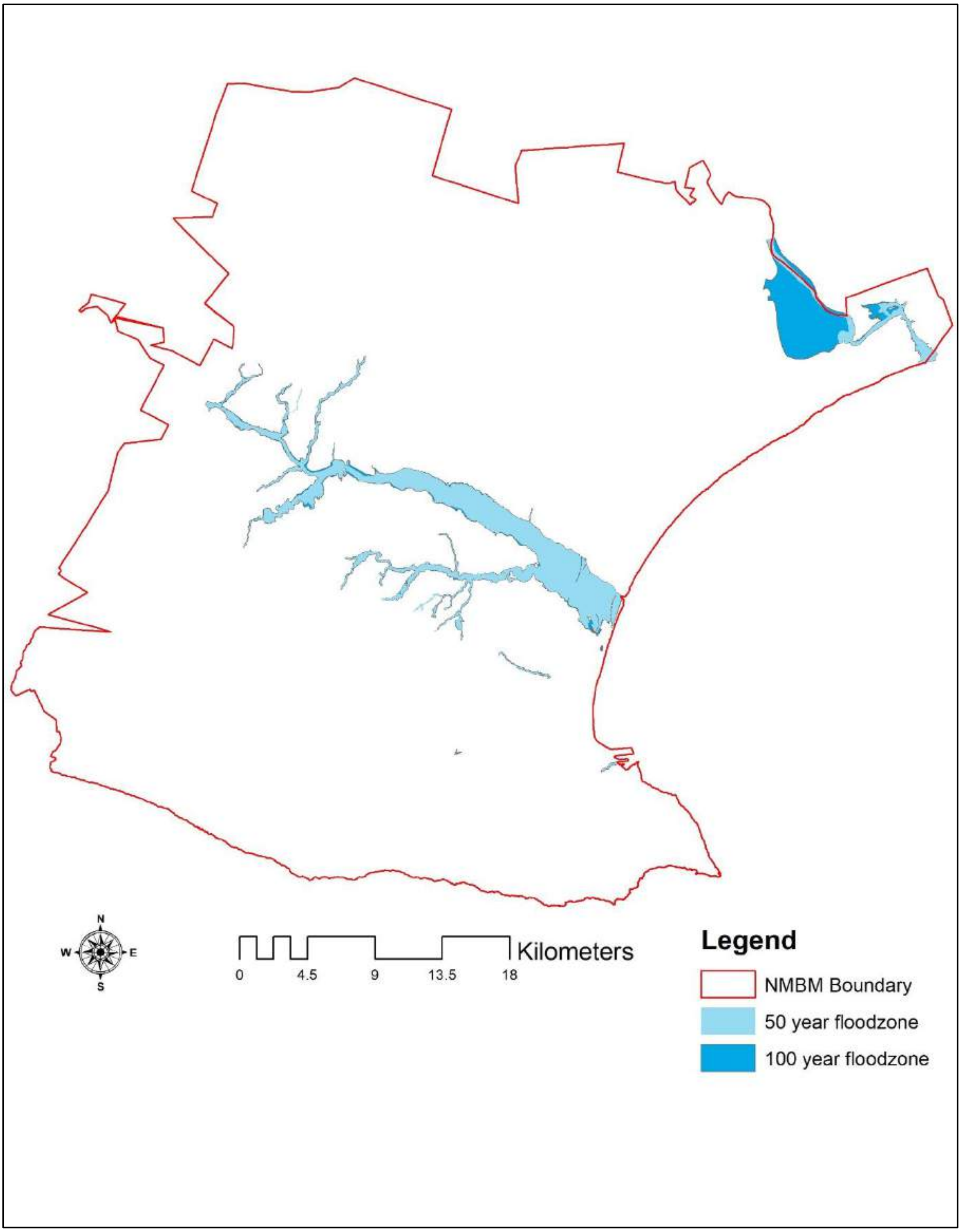


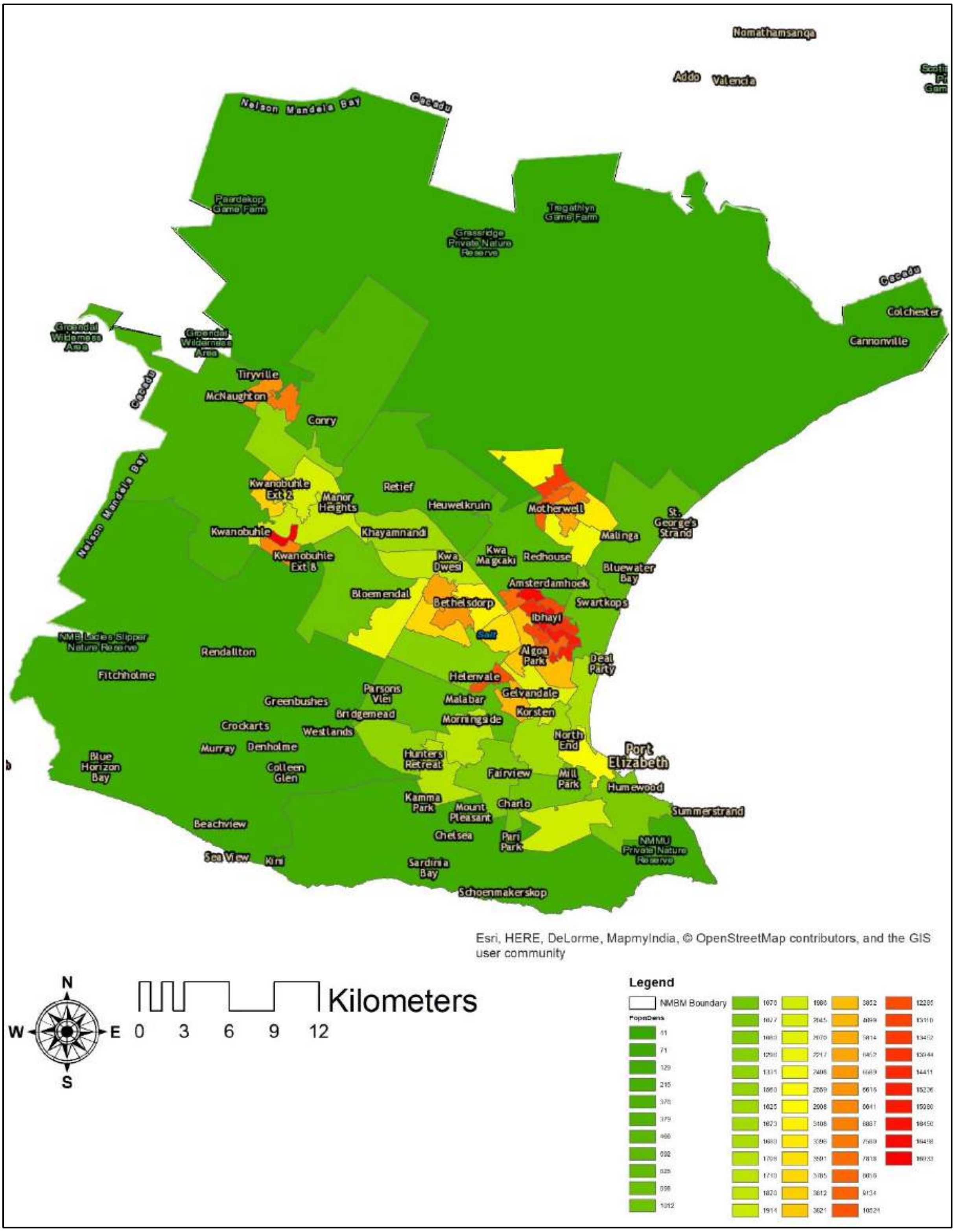
Figure 4.10: Return intervals calculated using DEM and previous flood data from NMBM GIS Department

4.3 Socioeconomic factors contributing to the vulnerability index

Sensitivity to flooding usually comes about as the combination of several socio economic factors stated in Chapter 2. These vary within and across local municipalities and are due to spatio-temporal relationships. In this study, two socioeconomic indicators were selected in order to display sensitivity of a system namely population density and land cover.

4.3.1 Population density data

Population density is the connection between humans and the environment that can be calculated by dividing the total population over the area of a location (in this case a ward which is an administrative division of a city). This is usually calculated as the number of people per square kilometre. A high population density means more people in a specific area. If that area happens to be vulnerable to flooding then that translates to more people being affected by a particular flood event at any given time. The NMBM has several densely populated areas such as the majority of the townships, namely parts of New Brighton, Zwide, Soweto-On-Sea and KwaZakhele. Other areas densely populated are Tyrenville, McNaughton, KwaNobuhle, and Motherwell as shown by Figure 4.11. These areas constitute more than 40% of the total population of the city as well as the highest number of people with a low income, education or employment.



Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 4.11: Population density map of the NMBM

4.3.2 Land use data

Land use has, potentially, a very strong effect on floods as humans have heavily modified natural landscapes (Aerts et al., 2011). Large areas have been deforested or drained, ultimately either increasing or decreasing antecedent soil moisture and triggering erosion (Kakembo et al., 2012). In environments where hillslopes have been modified for agricultural production, this has led to changes in flow paths, flow velocities, and water storage, and consequently flow connectivity and concentration times flowing to downhill areas. Therefore, land use changes through urbanisation, deforestation, and cultivation have resulted in increased flood frequency and severity in some areas (Nicholls et al., 2007). This is also due to reduced infiltration capacity, lower soil porosity, loss of vegetation, and lower evapo-transpiration.

Figure 4.11 shows the different types of land cover within the NMBM. The map shows that almost 30% of the 1950 square km of the Metro is covered by settlements. Approximately one third of those settlements are located within a 5km buffer of a stream. A number of those settlements are considered to be high density urban townships (20%) such as KwaNobuhle, Motherwell, KwaDwesi and Soweto-on-Sea, which are situated close to rivers and consist of built-up surfaces which are represented by the purple polygons in Figure 4.8. Approximately 10% of all formal residential areas are located close to streams in areas such as Amsterdamhoek, Bethelsdorp, Lower Swartkops and Uitenhage. These are depicted by yellow polygons in Figure 4.12.

- Generating a land use sensitivity ranking

In order to derive a land cover sensitivity layer, several GIS operations had to be carried out. The feature layer provided by the Department of Environmental Affairs (2013) was in raster format as a TIFF format file (see Figure 4.11). Areas of interest were ‘vectorised’ and this consisted of 175000 different polygons that were categorised according to 160000 typologies. In order to reduce the amount of landcover data processed in the study, polygons were created for areas of ‘interest’ in floodplains/flood-prone areas (see Figure 4.13). The polygons created were then ‘intersected’ with land cover data from the tiff format in order to attach attribute data such as typologies (see Figure 4.14). The new layer was standardised and ranked according to the scale stated in Table 3.3. The end result is represented below in Figure 4.15. The scale moves from green (lowest sensitivity) to red (high sensitivity), in this case the lowest sensitivity to flooding comes in the form of existing waterbodies, which have a score of 0.5. Here, settlements have the highest sensitivity out of all land cover types with a score of 3.

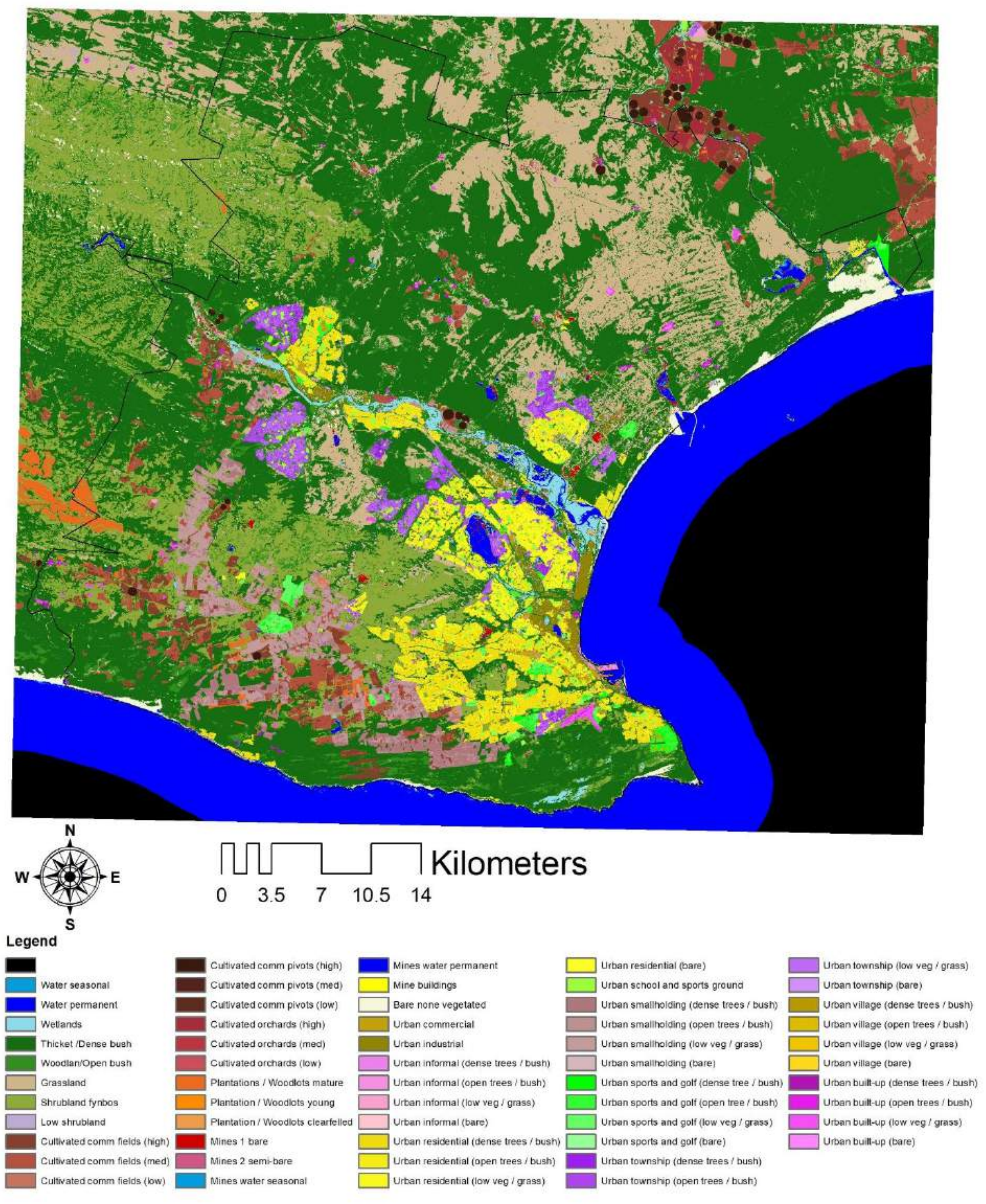


Figure 4.12: Land use map

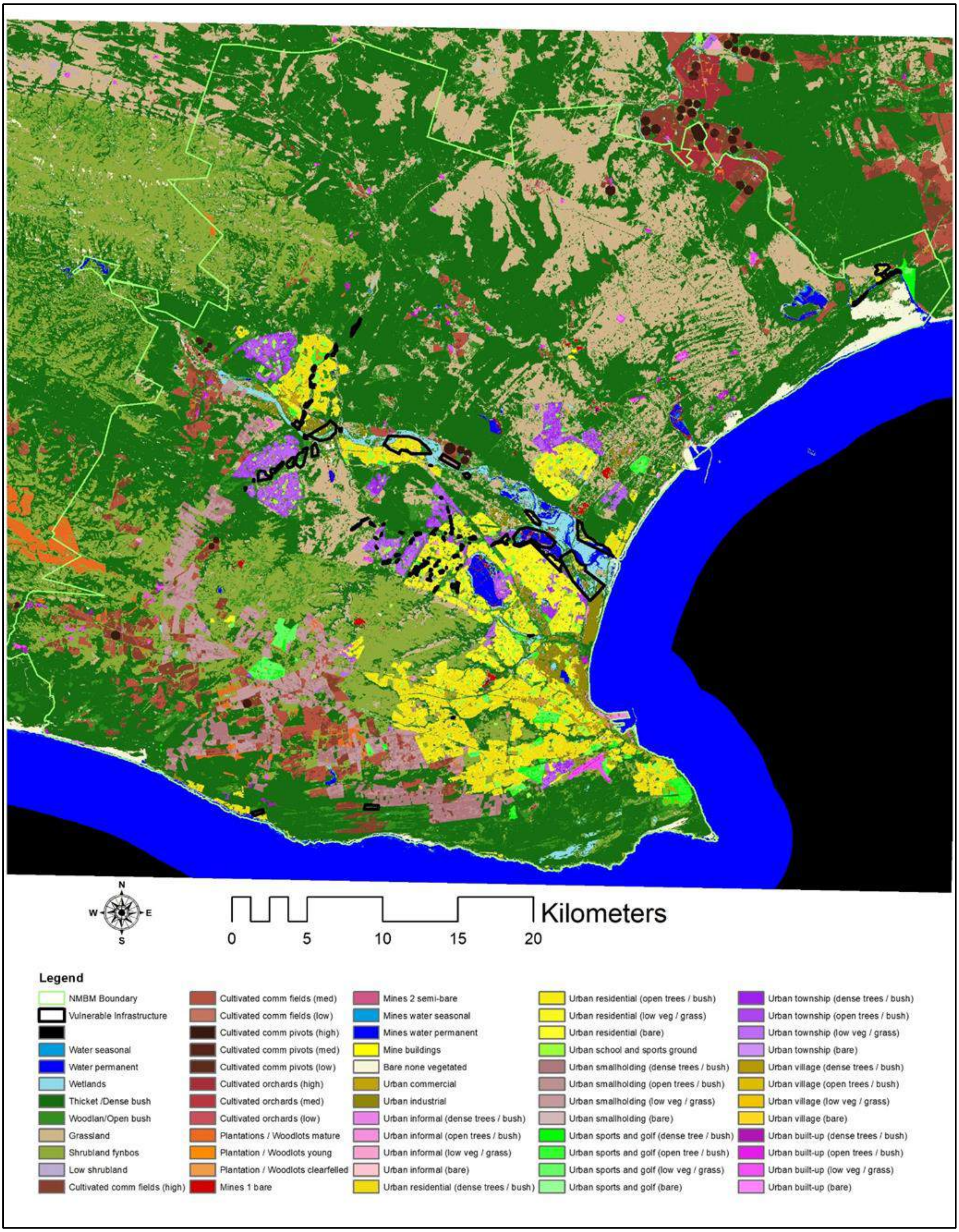


Figure 4.13 : Land use for ‘areas of interest’

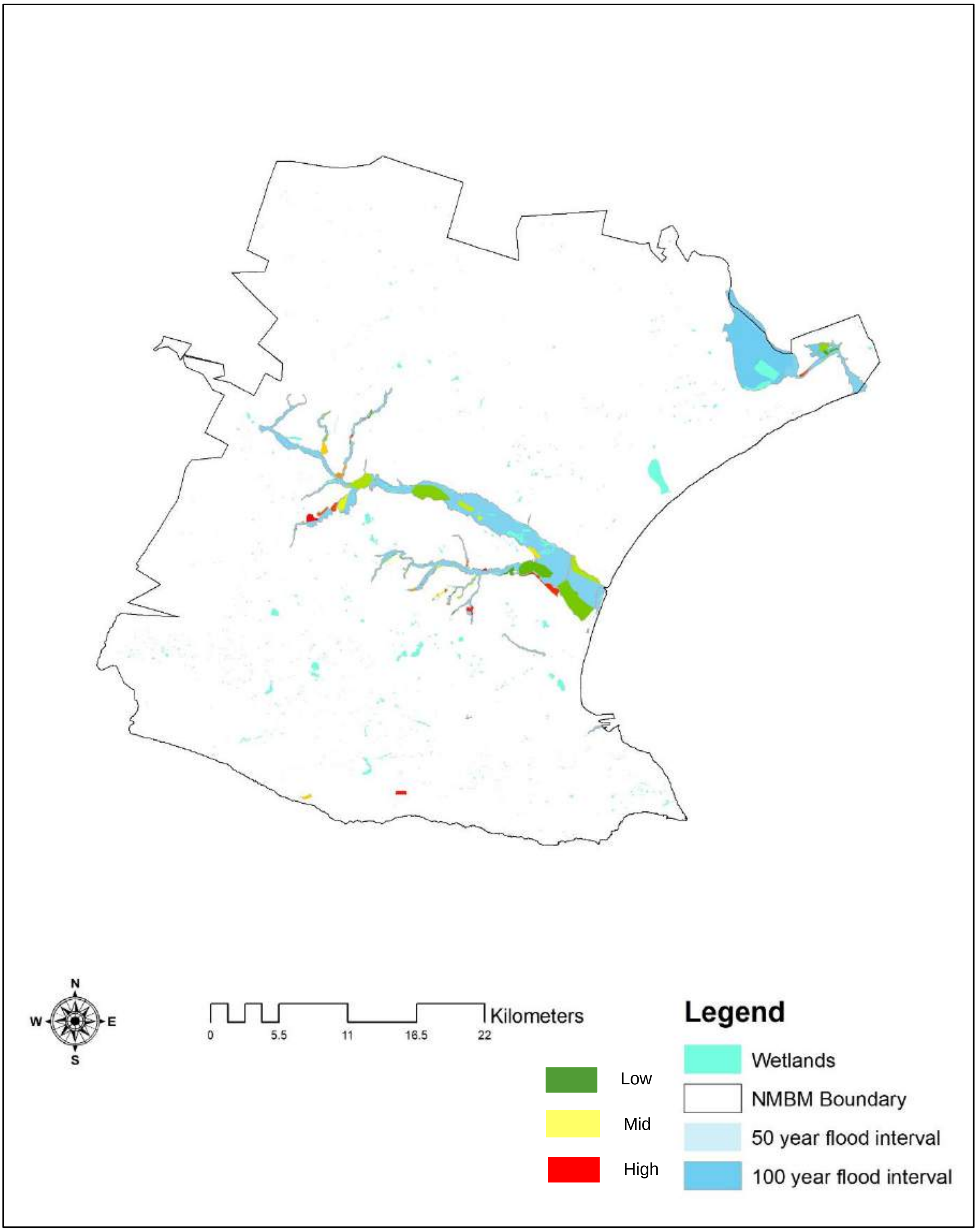


Figure 4.14 Land use sensitivity

4.4 Vulnerability index results and maps for the NMBM

Maps of areas that are vulnerable to floods are essential for flood warning and floodplain development control. In this study, areas vulnerable to flooding were identified through the use of high resolution imagery from 2018, a 50 year flood interval layer, 100 year flood interval layer, land cover layer and a population density layer. Each of these layers was assigned a different weighting and this was applied as a level of transparency. The result generated was several high quality maps that defined areas vulnerable to flooding in the future based on their current position, population density and land cover type.

In this study sensitivity was represented by the land use and population density maps. The sensitivity map was overlaid with the hazard layer in order to create a vulnerability index layer (see Figure 4.15). All areas vulnerable to flooding were further assessed visually through high resolution images which made it possible to identify buildings and assets that were potentially exposed. Such information is very useful for mitigation purposes as it informs on the types of urban structures that are in need of upgrades as well as the number of people that could require evacuation or education at a particular point in time. Furthermore, each high resolution image was also labelled with a ward number in order to make it simpler to identify the council responsible for mitigation measures.

High Resolution Maps

In order to formulate the most accurate mitigation measures, which do not leave out certain communities, it was important to generate easily interpretable results. Below are several high resolution maps generated based on the vulnerability index created in Figure 4.15 (and Table 4). These maps are located in Appendix A and they provide clearer insight (than Figure 4.15) on the houses, businesses, roads and communities vulnerable to flooding within the NMBM.

Maps of particular interest are Map 2 (Amsterdamhoek); Map 9 (KwaNobuhle ext 5&6); Map 12 (Laetitia Day Hospital); Map 25 (uitenhage industrial area). These maps highlight a contrast in levels of vulnerability and can be used to estimate potential losses and damages to infrastructure during a flood event. Amsterdamhoek contains high value assets in the form of property but has a relatively low population density per ward (466). Whereas KwaNobuhle ext 5& 6 contains low cost housing but has a relatively high population density per ward (3812). Laetitia Day Hospital and the Uitenhage industrial area are a clear highlight of high value assests that are vulnerable to future flood incidences. Flooding in such places could have disastrous impacts on a large portion of residents in the NMBM.

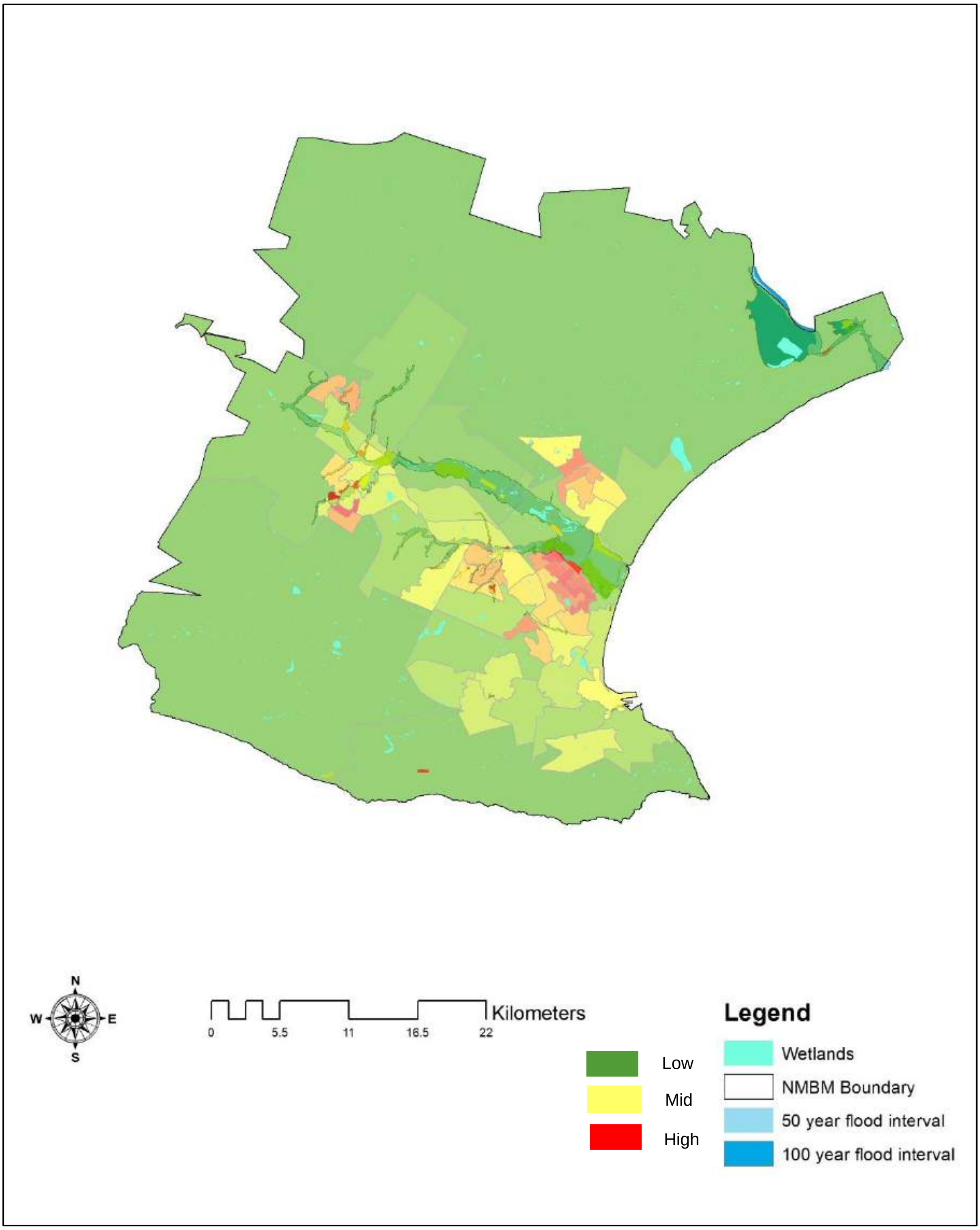


Figure 4.15 Vulnerability index results

4.5 Summary

The results of this study revealed diverse flood vulnerability configurations across the NMBM. The areas identified as flood prone were Algoa Park, Amsterdamhoek, Azalea Park, Bloemendal, Framesby, Ibhayi, Soweto-on-Sea, KwaDwesi, KwaNobuhle, Bethelsdorp, Lower Swartkops, Middle Swartkops, Redhouse, Seaview Road, Uitenhage Industrial and Uitenhage City. With the exception of Seaview Road, which is situated on a wetland, all other areas were either under the 100 year and or 50 year flood interval.

The infrastructures at risk were roads and settlements, industrial areas, a power station, a school and a hospital. The model was applied in order to recreate a storm hydrograph for a particular area in the NMBM in order to simulate peak discharge levels during a rainfall event. A road was selected as the drainage point, in order to identify the discharge levels on an impervious surface during a storm. The result was a graph that displayed a short peak and discharge time between 20 and 22 July in 2000. The location with the highest vulnerability to flooding was recognised as Ibhayi. This was due to various informal settlements identified in areas (in Figure 4.15) that lie under the 50 and 100-year flood zone, that are densely populated (13944 – 16498 people per square kilometer). Ibhayi as a whole has approximately 12285 people per square kilometer in its least dense parts and approximately 16500 people per square kilometer in its most dense parts (see Figure 4.11).

From the political ecology approach, it is evident that the people who reside in flood prone areas do so because of the context with which they find themselves. Areas such as the majority of Ibhayi, parts of New Brighton, Zwide, Soweto-On-Sea, KwaZakhele, Tyrenville, McNaughton, KwaNobuhle, and Motherwell are densely populated because of their undesirable locations and consequent cheap cost of accommodation. These areas also house a majority of the 31.8% people in the Metro who are unemployed and therefore have little or no coping mechanism to flood disasters. Poverty is still a large problem in the NMBM that has to be accounted for when deriving mitigation strategies.

Chapter 5: Synthesis

5.1 Introduction

In this study it was shown how flood vulnerability can be assessed at a local level. The study also provided an example of a hydrological model and the influence of built-up land use surfaces on flooding. In this Chapter the study looks at an overview of the research carried out in the study in a particular context. It begins by briefly going over the study in the introduction. This is followed by section 5.2 which offers a synthesis of the research results according to the theoretical framework. Finally, recommendations have been put forward for future research.

This study provided an example of how to simulate different levels of flood vulnerability in a certain area. The maps created in this study highlighted both current and future concerns regarding urban flooding. The maps produced were only snapshots and are static, based on specific inputs related to 50 year flood zones, 100 year flood zones and sensitivity (population density and land cover). Vulnerability mapping must take place at regular intervals, therefore monitoring of the implemented strategies is crucial and serves as a tracking tool to verify the effectiveness of adaptation interventions on flood vulnerability reduction.

Vulnerability maps can be used to calculate where and when aid is needed as well as which strategies can be best implemented. These strategies include zoning, building codes, risk communication, evacuation plans, natural storage, levees and floodwalls, flood proofing and insurance. In light of these strategies, there are still countries that advocate for the notion of fully containing rivers in their beds through engineering. Whether streamflow stays in the channel or not is not dependent on surface engineering alone and cannot be relied upon completely. Such strategies also have a negative connotation as they encourage unnecessary development in flood prone areas, which in turn amplifies the ambit of the losses incurred. It is important for cities to move away from this type of thinking, and to focus more on allocating resources to solving post-floods problems, and to preparing communities on how to respond to floods when they do occur.

5.2 Synthesis of results

Economic growth and development has led to densification and unplanned urbanisation in areas such as the NMBM. This has resulted in the continued upsurge of people residing in floodplains, which has consequently led to an increase in cost of damages and continued loss of human lives that is also evident in other developing countries (Jonkman, 2005). Such situations are associated with economic and political processes and the impact they have on communities, especially when it comes to mitigation measures. There are three common types of urban flooding that occur naturally, namely, riverine flooding, flash flooding and coastal flooding. Although these occur naturally, disaster impacts continue to increase because of a lack of consistent government policy on vulnerability reduction.

The development of the NMBM has brought about tremendous growth in human population with some grave consequences for the natural environment. Much of the NMBM's current land-use patterns and socio-economic characteristics can be traced back to the past, and this has led to some communities being vulnerable to hazards such as flooding. The spatial expansion associated with growths in population increased flood risk as the land cover that previously restricted the impacts of run-off was removed in order to accommodate settlements.

The case of the NMBM is not unique as the political ecology theory assumes that the implications of Apartheid policies on flood hazard exposure persist into the post-Apartheid era like in most areas where previously disadvantaged communities continue to be disadvantaged. The rapid population and urban growth from the end of this era has continued but government administrations have shown little commitment to addressing the issue. The annual population increase has overwhelmed the NMBM municipality and resulted in continued or lack of permitting for the development of unplanned settlements, some of which are established in flood prone areas.

Reviewed literature has already documented the role of political factors in the development of 'at risk' populations (Hewitt, 1983; Blaikie, 1994; Stonich, 1998; Robbins, 2004). Vulnerability to a hazard such as flooding is not only limited to the geographic characteristics of settlements or the fragility of the infrastructure but is also due to a lack of resources, unstable political system, and unstable institutional commitment to flood risk mitigation. The main factors that have contributed to vulnerability to flooding in the NMBM in the post-Apartheid era include but are not limited to: an unstable political system, unstable institutional commitment to vulnerability reduction, a continued disregard for land use planning and rapid urban development and growth which has overwhelmed government agencies responsible for service delivery (Atuahene, 2011). An evaluation of the several Structural Development Frameworks (SDFs) (NMBM, 2010; 2016) show successive attempts by post-Apartheid government agencies to address policies and residential segregation that was the result of an Apartheid legacy.

During the apartheid era, zoning and building regulations were enforced in order to regulate urban growth. In the post-apartheid era, a lack of planning and updated building regulations has resulted in a continued social stratification system that promotes residential segregation and the emergence of informal settlements (Atuahene, 2011). In the NMBM, it is assumed that the high concentration of populations in floodplains coupled with land use changes is expected to increase the cost of providing public services. This is because the poor in urban areas have been marginalised by post-apartheid governments, which have focused more on the development of rural areas, which previously housed the underdeveloped majority (Goodman, 2017).

This development approach has led to serious implications for flood vulnerability in urban centers such as the NMBM, as the neglect reduces the capacity of government agencies to cope with rapid urban growth and the associated environmental impacts. The approach has resulted in landscape change, unregulated development and sprawl, and increased vulnerability to flooding in the NMBM. It does so through an increase in environmental transformations that directly lead to more human and property losses, especially in low-lying areas such as floodplains. This is because water seeks the lowest possible elevation by way of the path of least resistance, and in Nelson Mandela Bay this means all the way to the Indian Ocean when possible.

Floodwaters usually find their path of least resistance through developed areas, particularly urban areas, because development removes natural boundaries and barriers that either absorb water into the water table or direct it to larger streams. As the land cover protecting the landscape from erosion is removed, flooding risk increases. The expansion of settlements increases impermeable surfaces that in turn increase run-off and this leads to flash flooding in some urban areas such as Seaview Road (see Photo 2.1 p14).

In this study, poverty and declining income were identified as the major causes for vulnerability in settlements in the Metro (e.g. SOS, KwaNobuhle, Motherwell, and Ibhayi). This was a direct result of economic, demographic and political processes that in the past affected the allocation and distribution of resources in the NMBM. While Apartheid had an impact on the development of the NMBM, the structure and policies of the post-Apartheid government have also contributed to people residing in unsafe conditions.

Upon a close inspection of the results of the vulnerability index, it seems the city is stuck in a fragmented property market, one servicing the largely poor black communities of the North and one servicing the largely rich and mainly white communities of the South. The population density maps show the Northern areas consisting of the most densely populated wards. It is expected that more than 80% of the future residential demand in the Metro will be for low-income housing (NMBM, 2014). The current practice of creating plots of 200 to 300m^2 for low-income housing is unsustainable from an economic and land utilisation point of view. Increased densities, on the other hand, can decrease land and servicing infrastructure costs and enhance the viability of public transport systems.

The most densely populated areas in the city are Ibhayi (New Brighton, Zwide and KwaZakhele), Uitenhage (KwaNobuhle), the Northern Areas, and Motherwell. These areas constitute more than 40% of the total population of the City. This information needs to be considered in urban planning priorities and resource allocation across the Municipality. Owing to the high human densities and variety of human activities near the Swartkops Estuary, a wide range of human threats to sustainable development and conservation exist in the area. Areas such as Amsterdamhoek are particularly vulnerable to flooding events, but due to the condition of building structures and available resources, the area has a lower level of vulnerability compared to areas such as Soweto on Sea and the northern parts of Ibhayi, which have a high level of vulnerability to flooding. Differences in land cover types can be related to the differences in the severity of damage to households as observed during this study.

Ongoing efforts to reduce high levels of poverty and to accelerate the provision of infrastructure and access to services are failing to reach par due to the large number of rural people that continue to migrate to urban areas to seek employment. Most times, they have no alternative but to settle in unsafe environments that are vulnerable to a range of threats including floods. By analyzing the results generated in Chapter 4, this study adds to research on current mitigation initiatives for the NMBM by proposing some additional mitigation strategies to reduce the impacts of flooding.

5.3 Proposed mitigation strategies

One strategy allows for the minimisation of the extent of losses incurred during the onset of flooding. The first step carried out, will be a review of current insurance policies for the flood-prone regions (settlements and city developments), so that they account for the areas located close to or under the 100 year and 50 year zones. Following the review, the most vulnerable communities should be offered subsidized rates for insurance cover on their houses and assets using funds from the disaster management directorate as part of capacity building. Claims on weather-related damages should also carry a sense of urgency in terms of processing times. On the other hand, there are several infrastructural challenges with allocation of resources through insurance, therefore it is simpler for the government to have buyout programs for areas that are flood prone and have been previously flooded. That way the local municipality does not have to keep paying through direct disaster relief and subsidized insurance.

Another strategy that could be developed by decision makers in order to prevent fatalities as a result of flooding, is the erection of warning signs in areas that have been identified as being at risk (particularly 100 and 50 year flood zones). Signs will serve as a constant reminder for communities residing in such areas. To support the signs, education on the importance of restraining from unsafe activities such as using floodwater for recreational purposes or driving on or walking on flooded roads or causeways could be added. The ideal place to start the educational classes could be at the community centers in the flood prone wards, which are easily identifiable in the maps.

At the same time, the maps generated can also be used to implement instruments such as more early warning systems, which could enable authorities to respond to floods in a timely manner, by using water level monitors and traffic redirection plans (The Citizen, 2018). It is even possible to forecast events through Global Satellite Mapping of Precipitation, which can calculate the probability of an area undergoing flash floods using possible precipitation outcomes. This type of mapping can be very useful in real time as it can also display the intensity of an event although this does not always produce accurate results in comparison to studies that look at static information such as this one. Since land use has an influence on urban flooding incidences, it is important to implement green space initiatives that reduce the amount of impervious surfaces contributing to storm flow.

It should be noted that this study has focused on only a few mitigation alternatives for the NMBM and there are many examples to draw from through research. The next section looks at recommendations for future studies aimed at mitigating the impacts of flood vulnerability.

5.4 Recommendations for future research

Future studies on flood vulnerability could use simulation models such as Flo2d (a licensed software for representing 3 dimensional flow patterns) which allow for a greater degree of accuracy in modelling floods. The diagrams below show two methods of mapping urban flood hazards. Figure 5.1 shows urban flooding polygons calculated using return periods and Figure 5.2 shows overland flow path simulations using depth analysis, storm hydrographs based on hourly rainfall data and manning's coefficients allocated per 5m^2 grid square in Flo2d.

Figure 5.1: Polygons based on return periods.

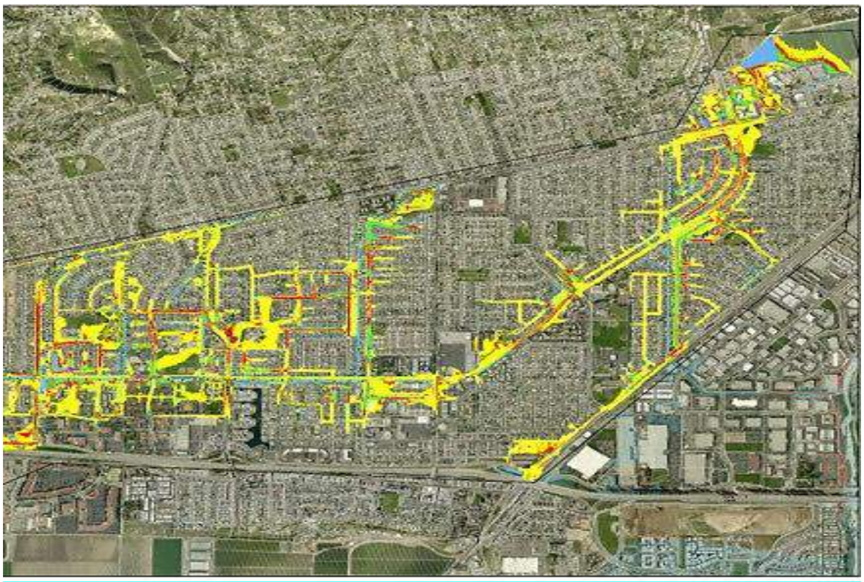


Figure 5.2: Flow simulations generated by Flo2d

Figure 5.2 displays a simulation carried out in Flo2d which visualises urban flooding through storm hydrographs (which have time stamps). In the diagram, areas where the most flow collects due to lower elevation and surface roughness show a red colour. The yellow colour depicts areas where there are flows during simulated flooding incidents created using storm hydrographs and green shows areas where little to no water would flow due to restrictions. Flow simulation data and the number of people exposed can allow for disaster management strategies such as redirection of flow paths or use of alternate transport routes during certain times.

It is also important that future studies look at the potential costs associated with flood disasters where mitigation measures have been presented. This will provide insight into the usefulness of some flood protection measures. It is also necessary that a Cost-Benefit Analysis (which is a systematic approach to estimating the strengths and weaknesses of alternatives) be carried out where several strategies have been put forward, in order to select the best options. Studies should look into the policies that have been established in the NMBM with regards to vulnerability reduction and where possible suggest ways to cater for the most vulnerable communities.

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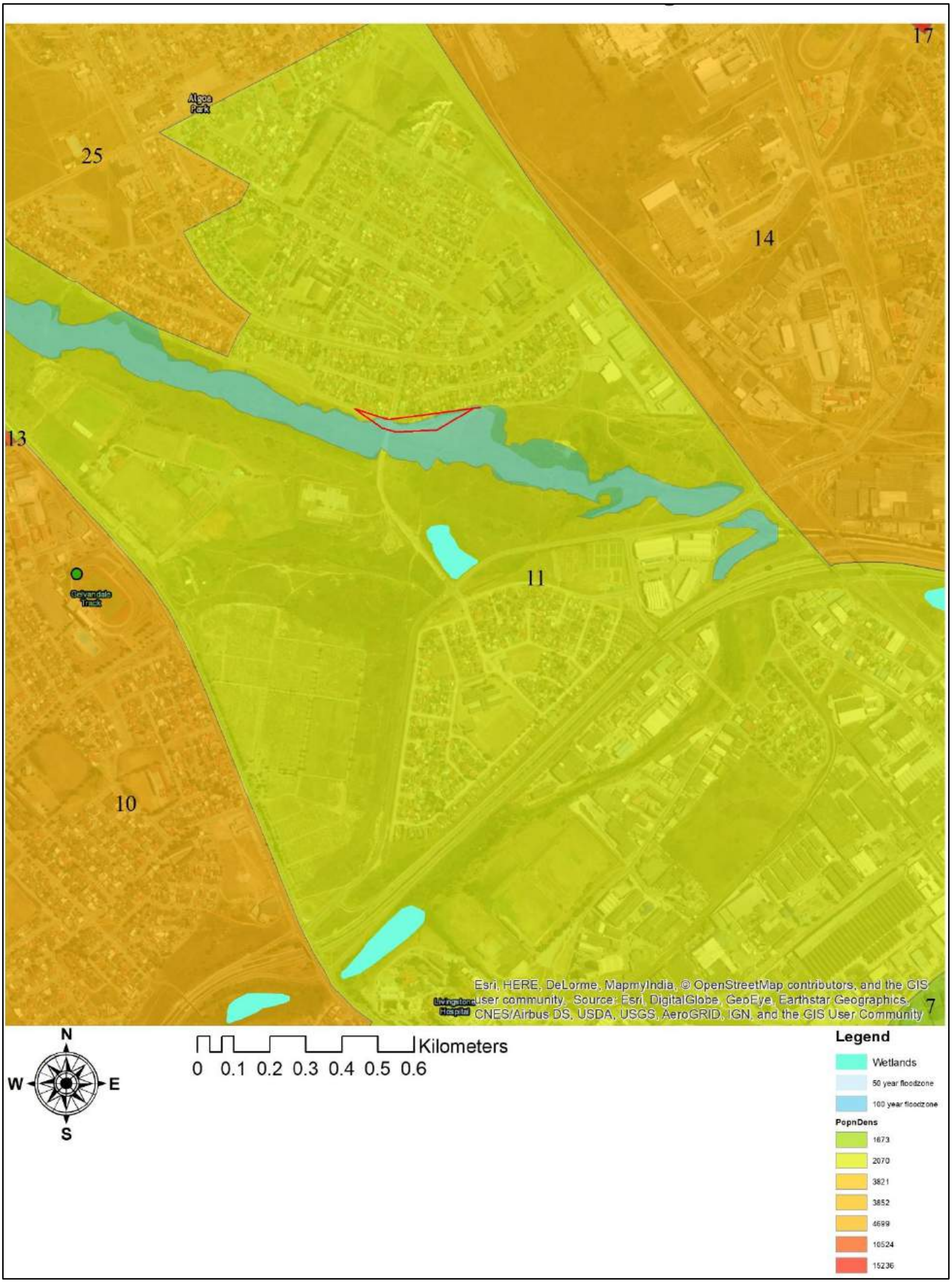
Appendix A – High resolution maps of the flood vulnerability index

List of maps



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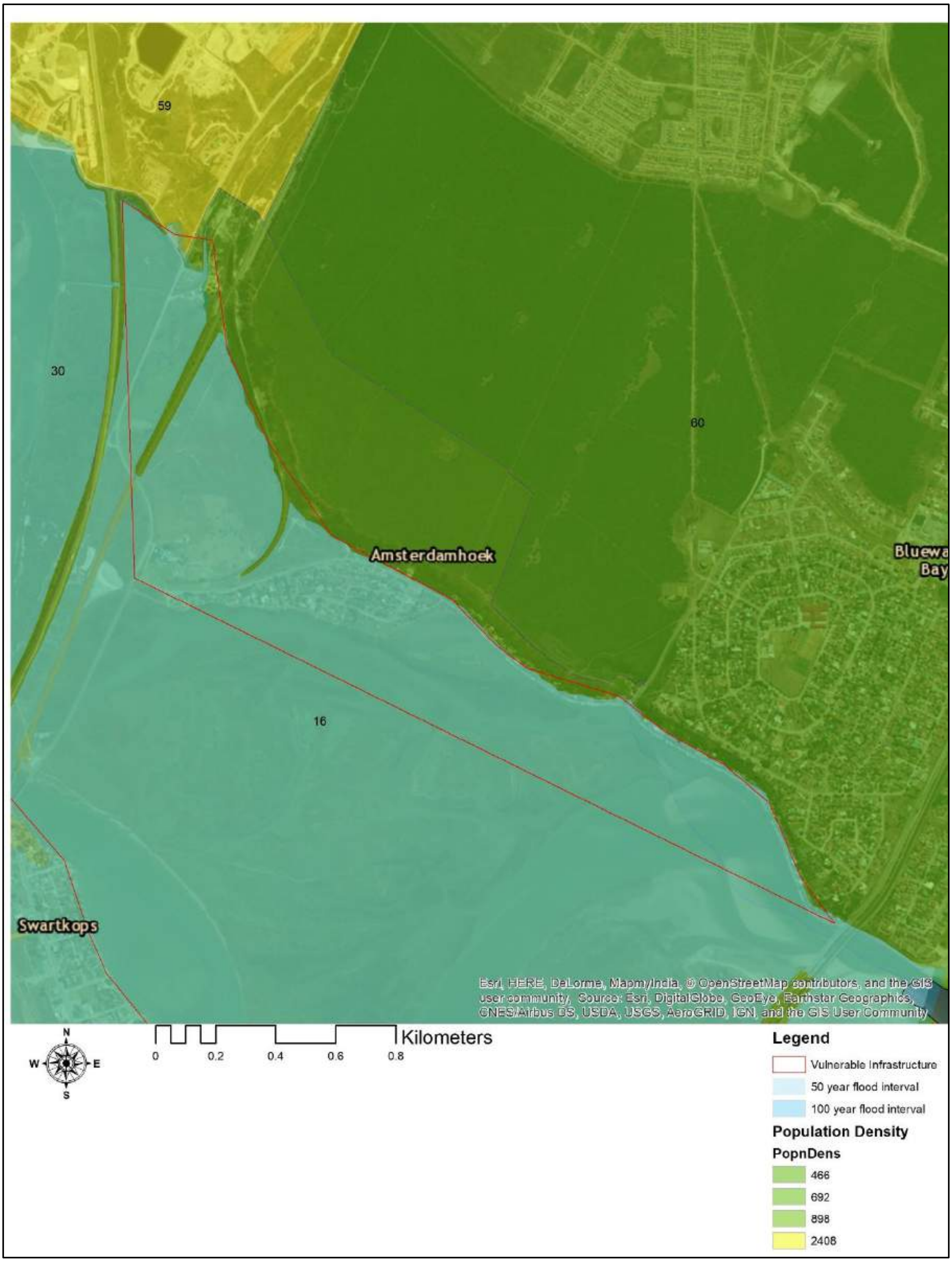
Map 1: Vulnerable dwellings and roads in Algoa Park



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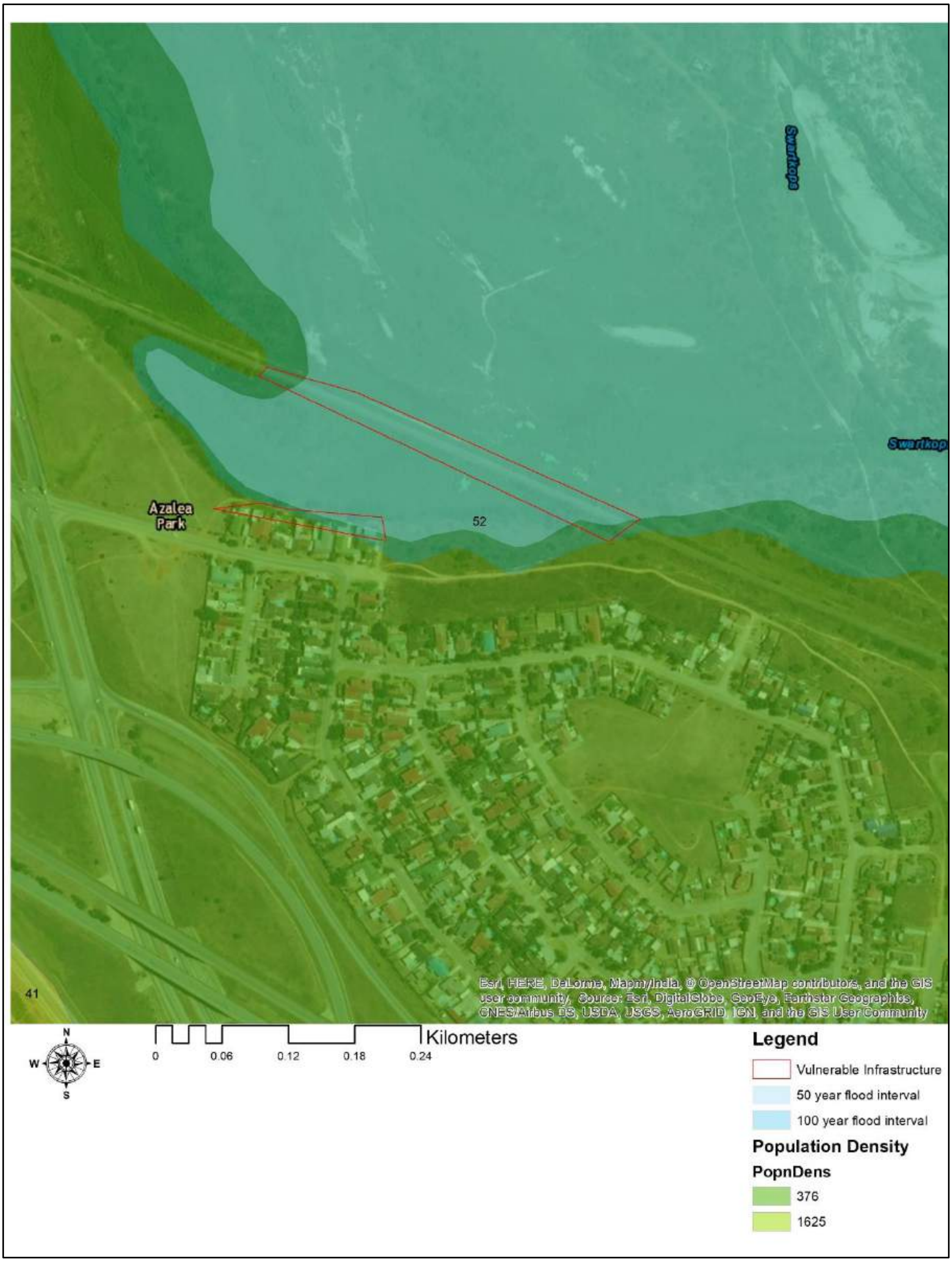
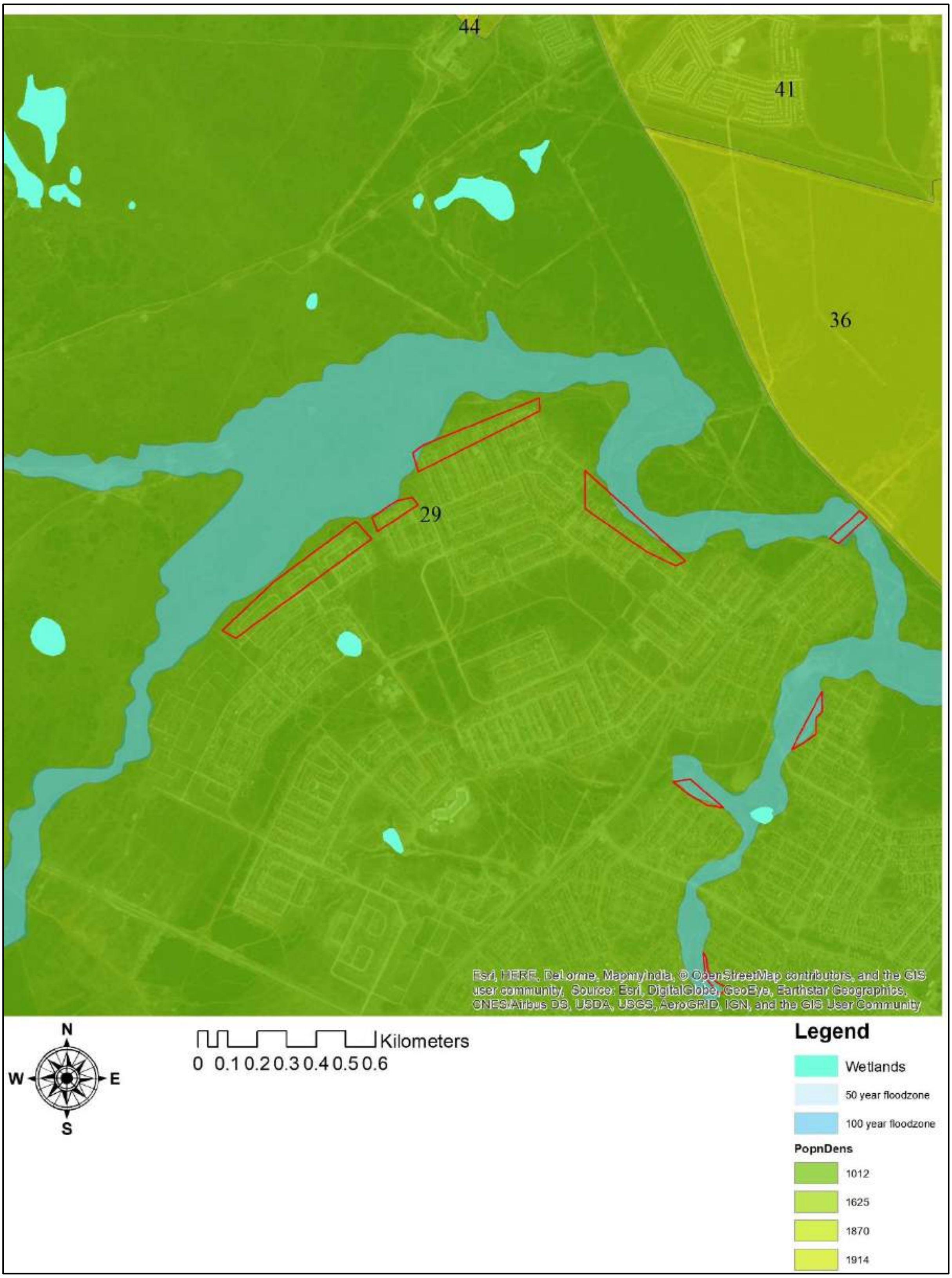
Map 2: Vulnerable dwellings and roads in Amsterdamhoek



Map 3 : Vulnerable dwellings and roads in Azalea Park



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Map 4: Vulnerable dwellings and roads in Bloemendal

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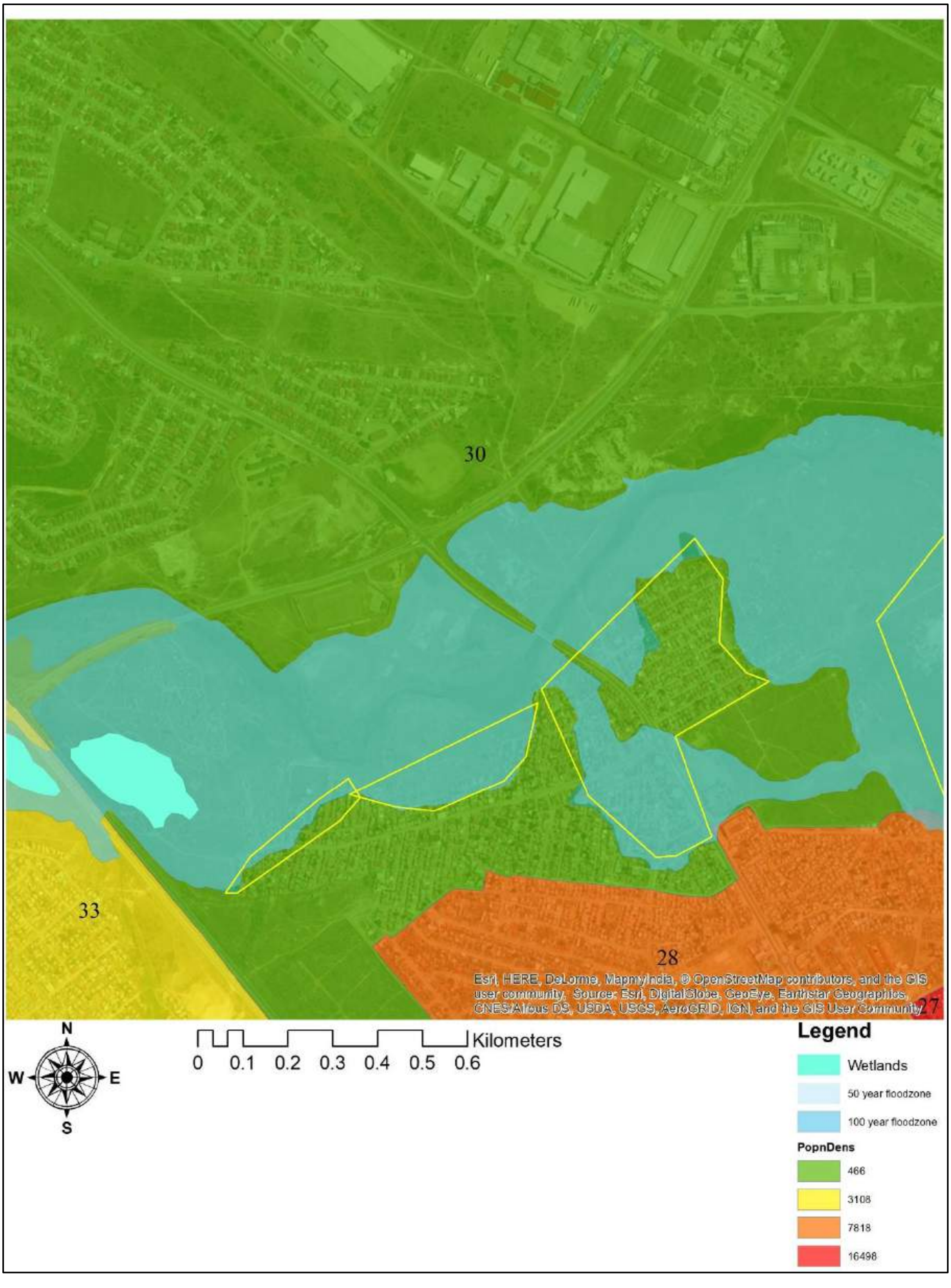
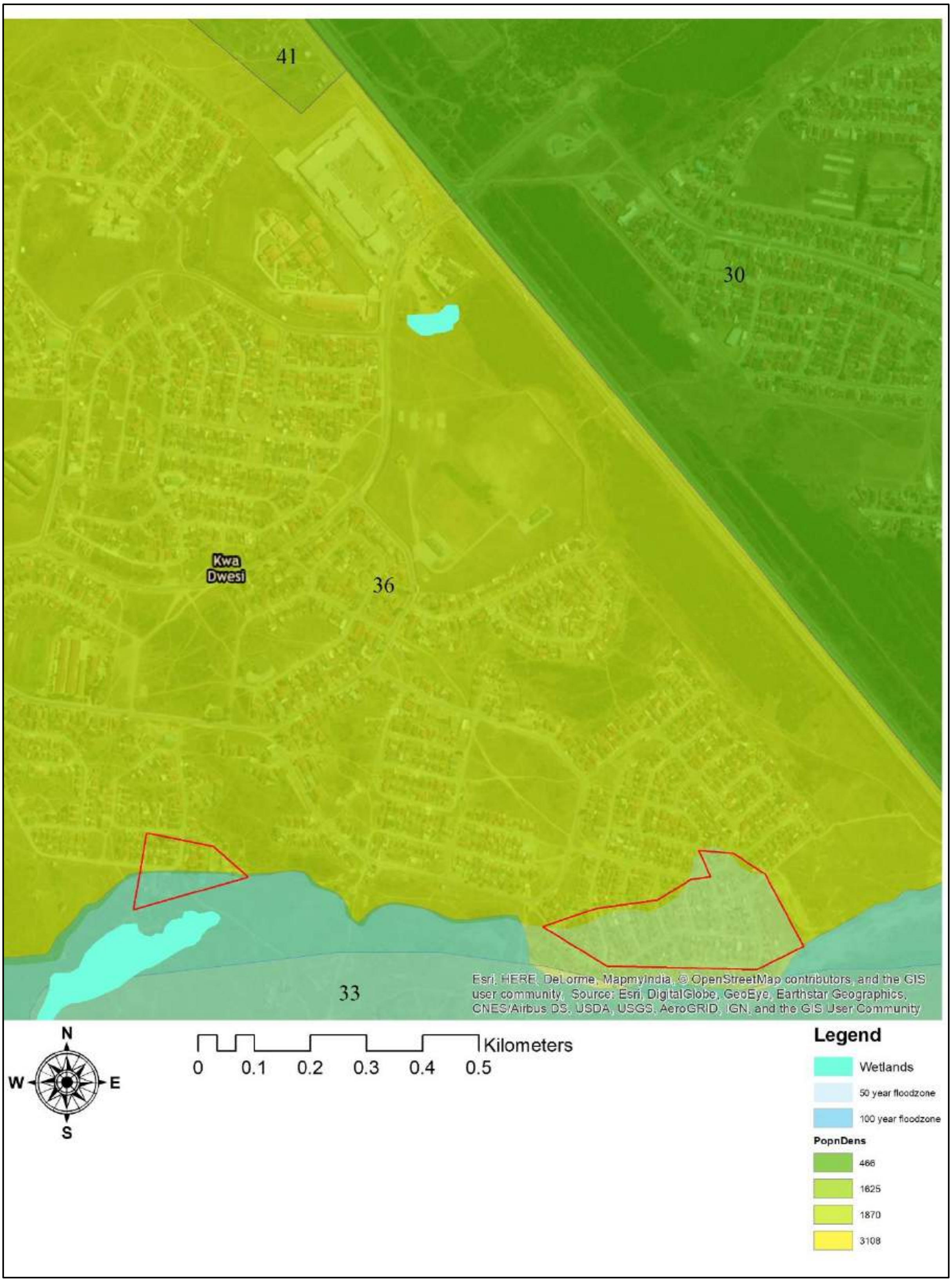
Map 5 : Vulnerable roads in Framesby



Map 6: Vulnerable dwellings and roads in western Ibhayi



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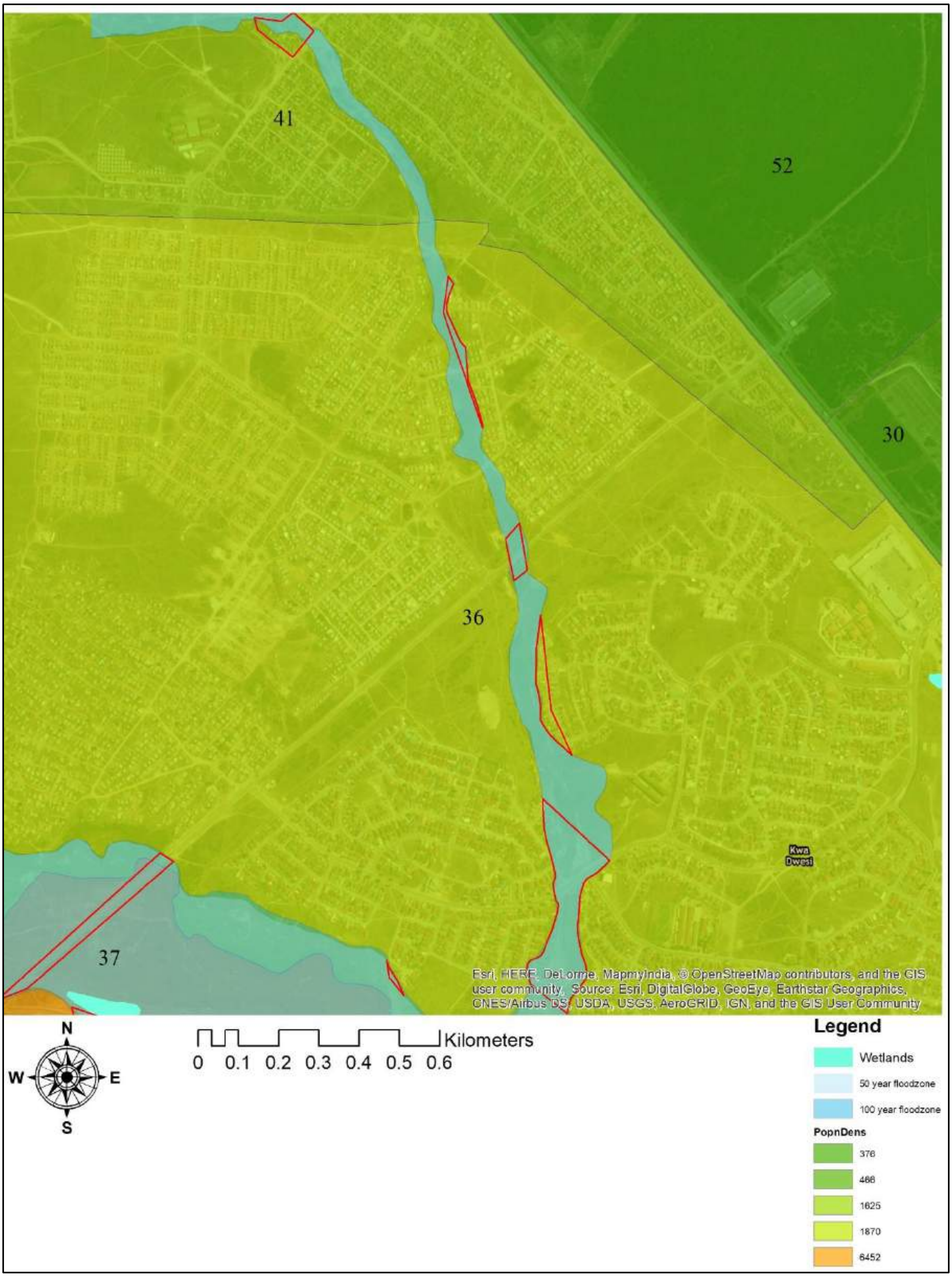
Map 7: Vulnerable dwellings and roads in Kwadwesi



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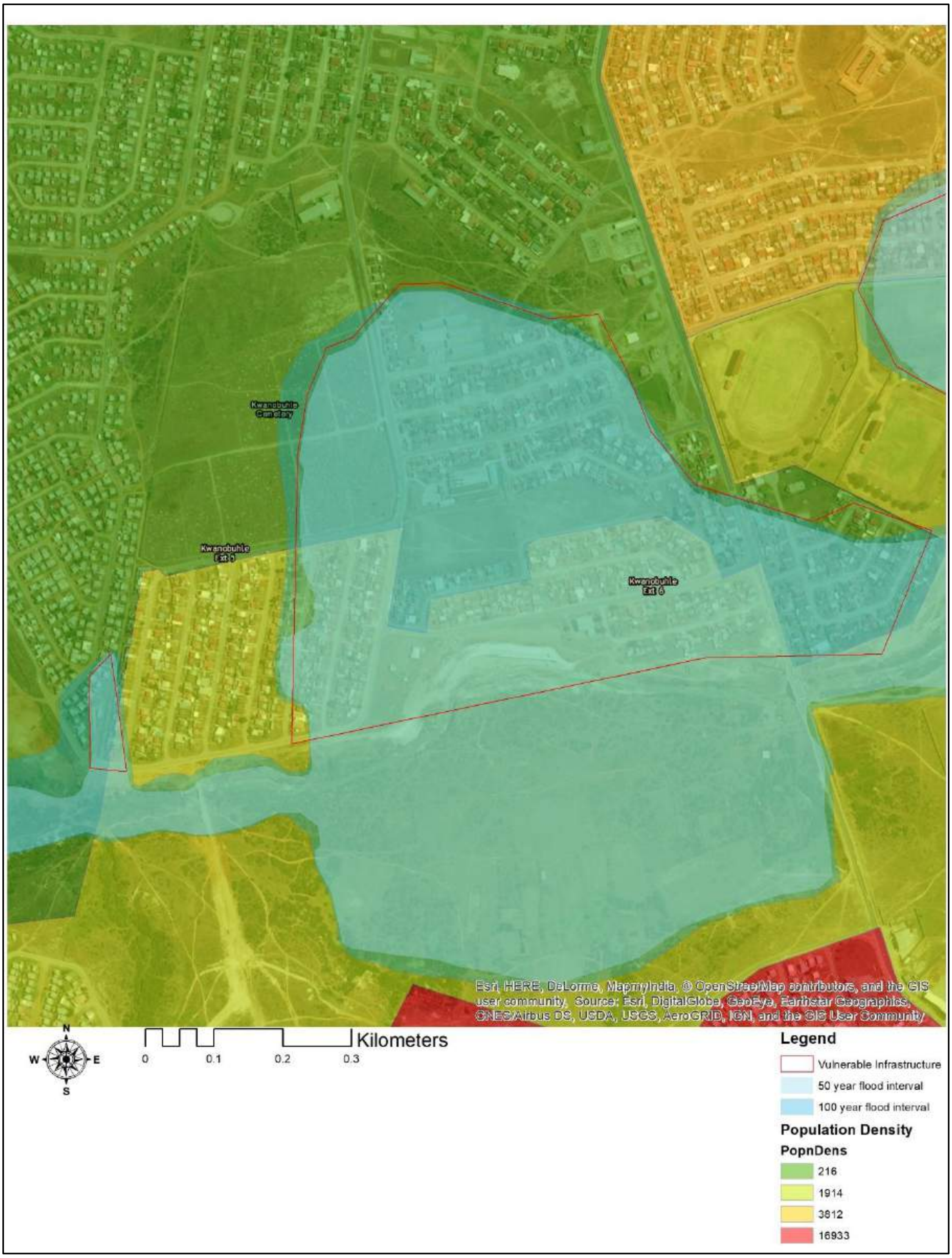
Map 8: Vulnerable dwellings and roads in KwaDwesi 2



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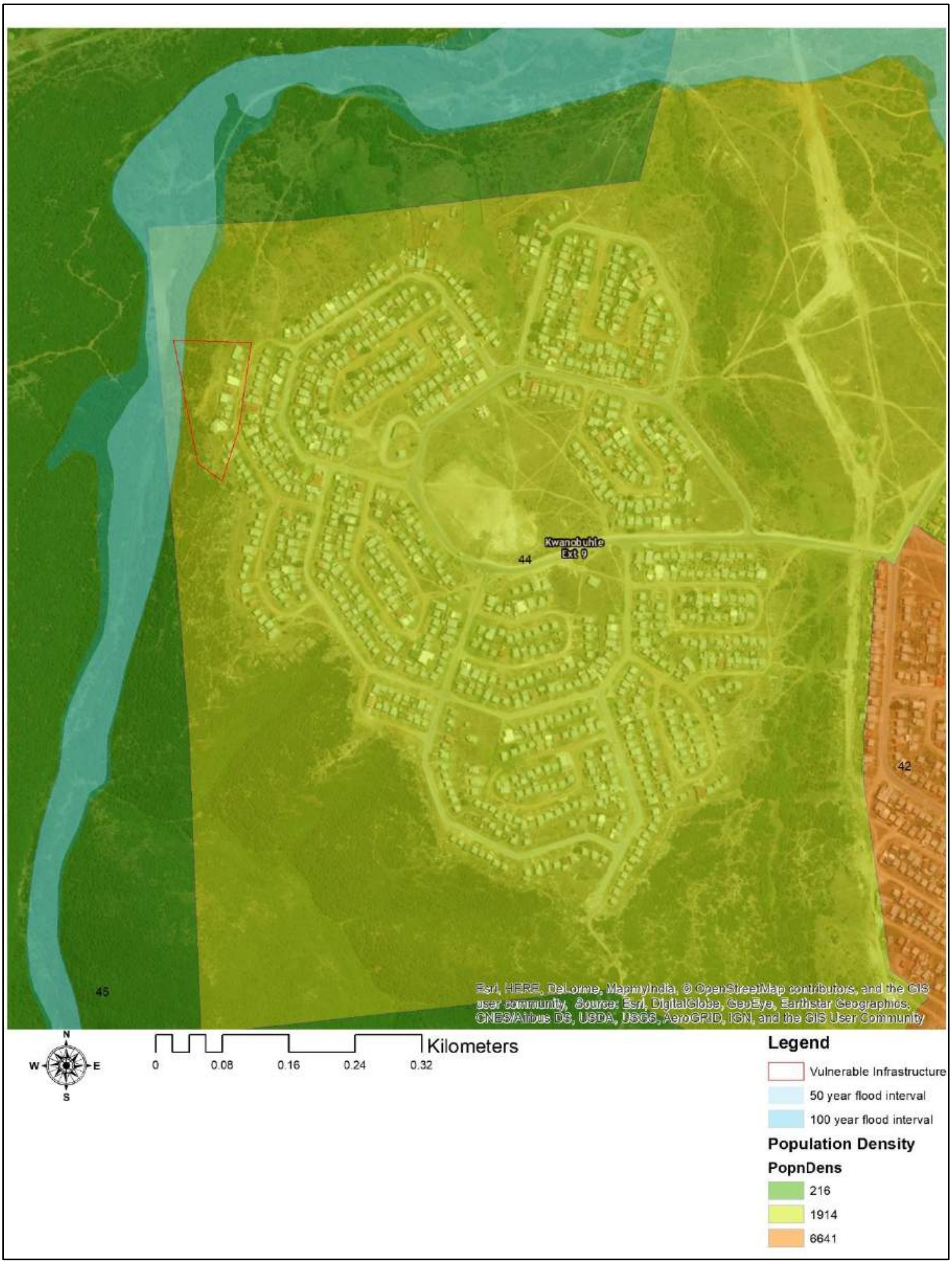
Map 9: Vulnerable dwellings and roads in KwaNobuhle extensions 5 and 6



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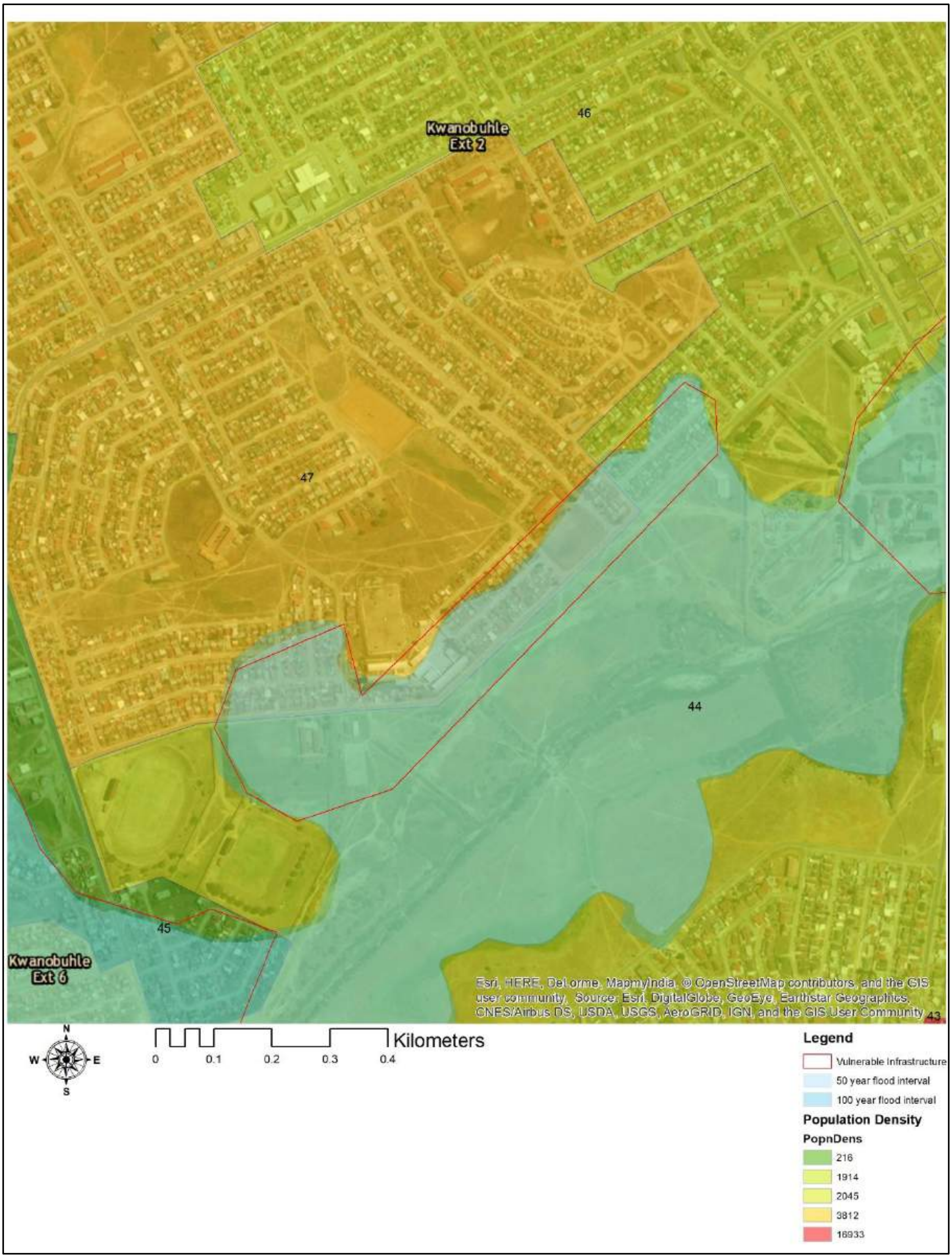

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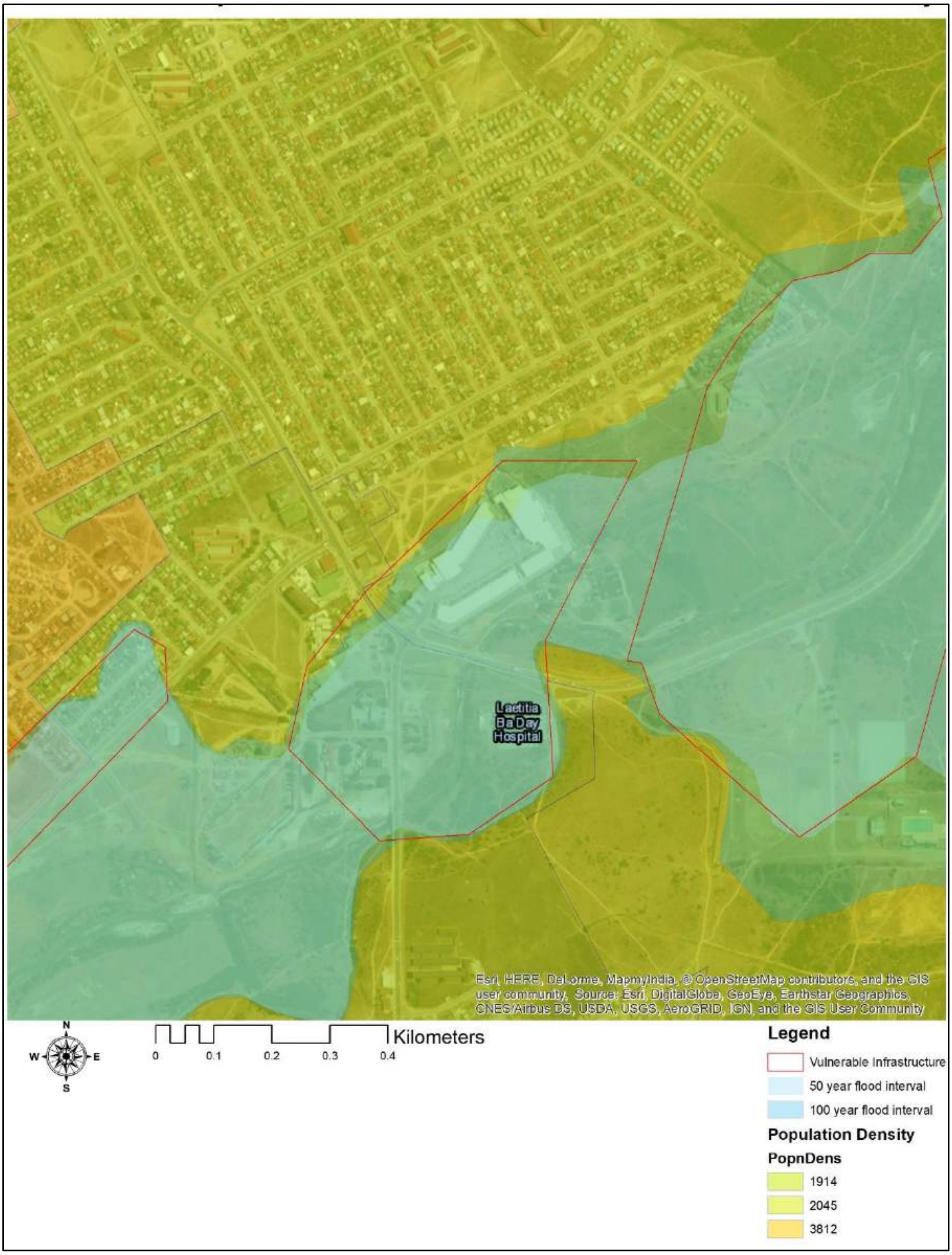

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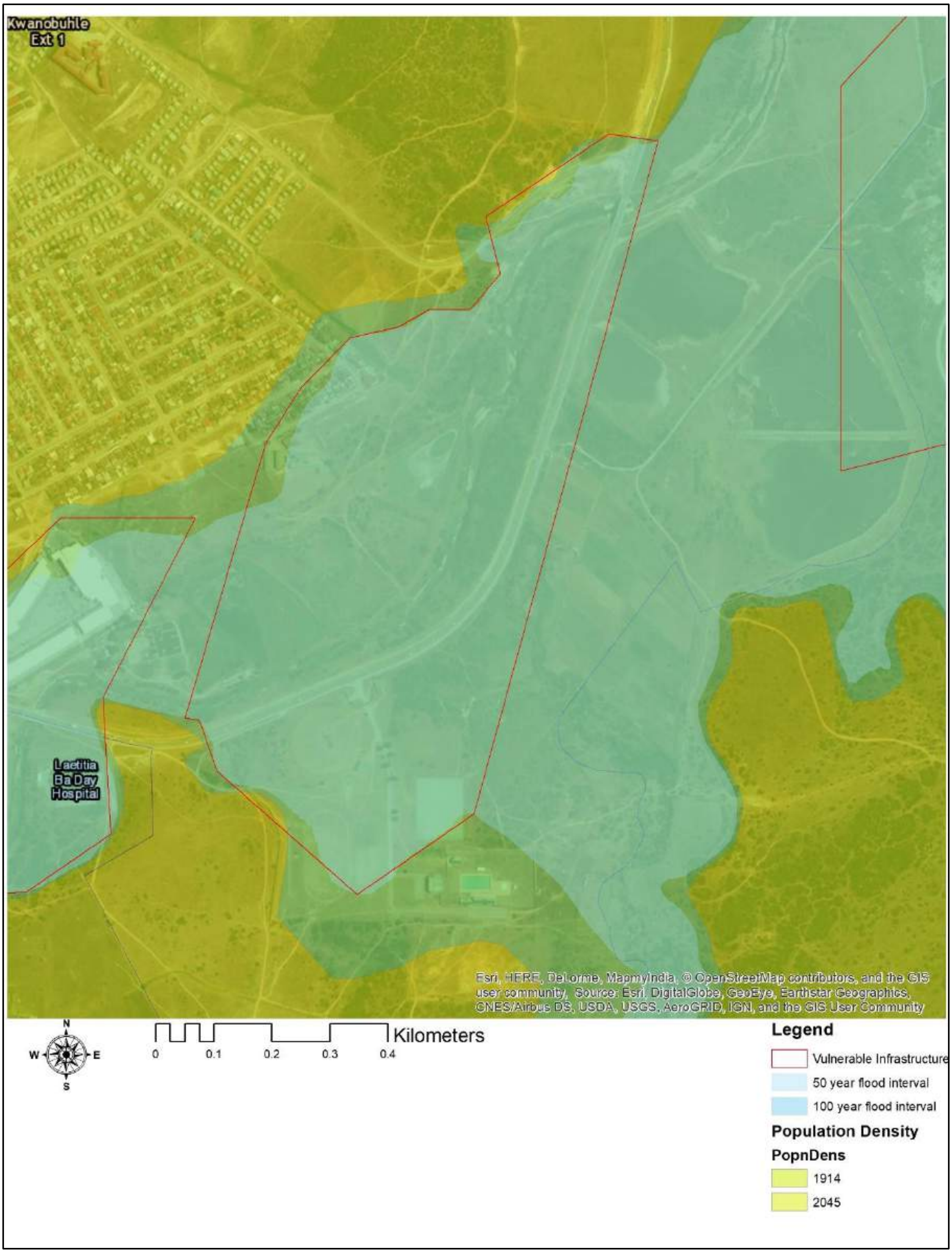

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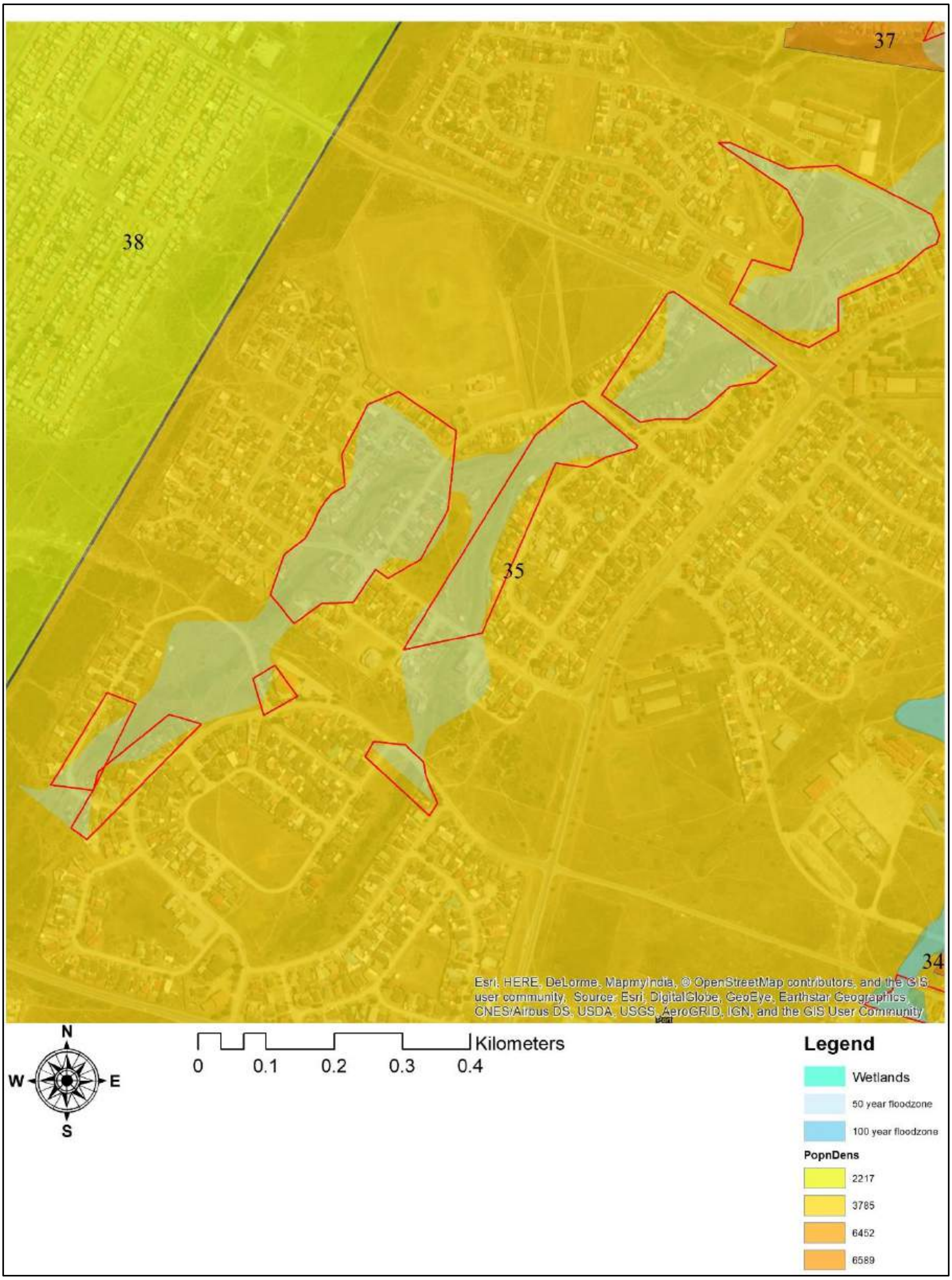

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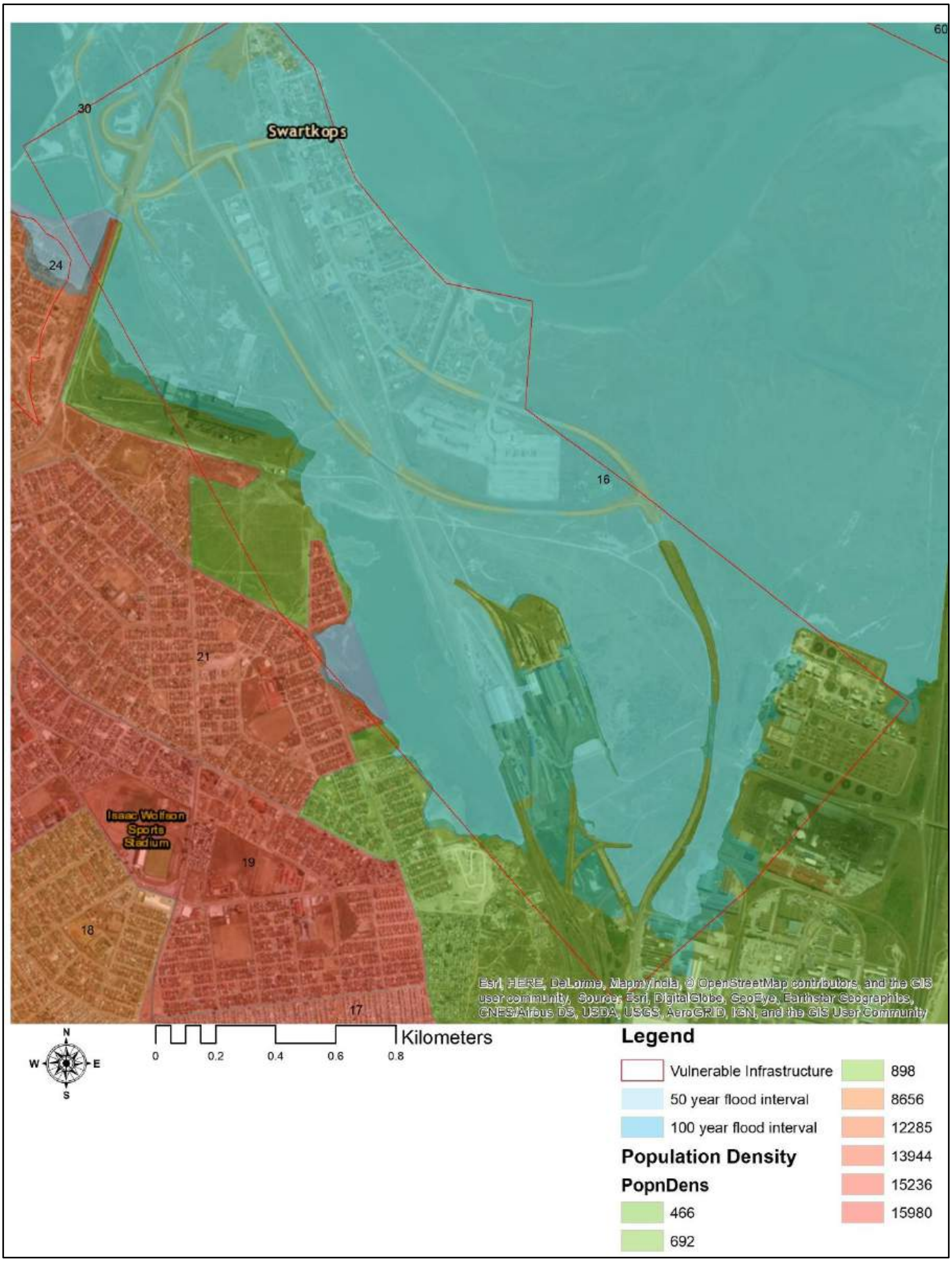
Map 14: Vulnerable dwellings and roads at Laurence Erasmus Drive



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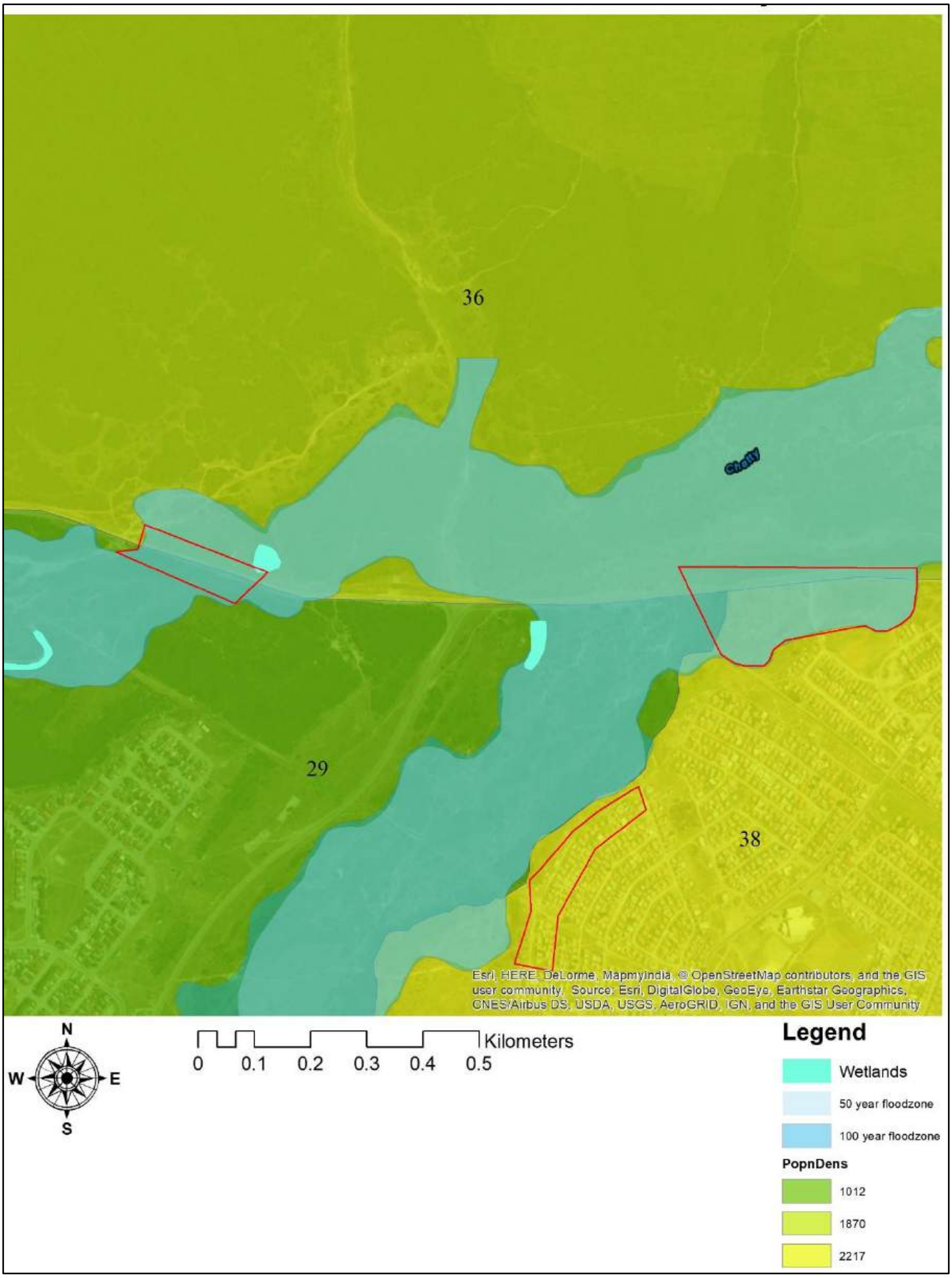

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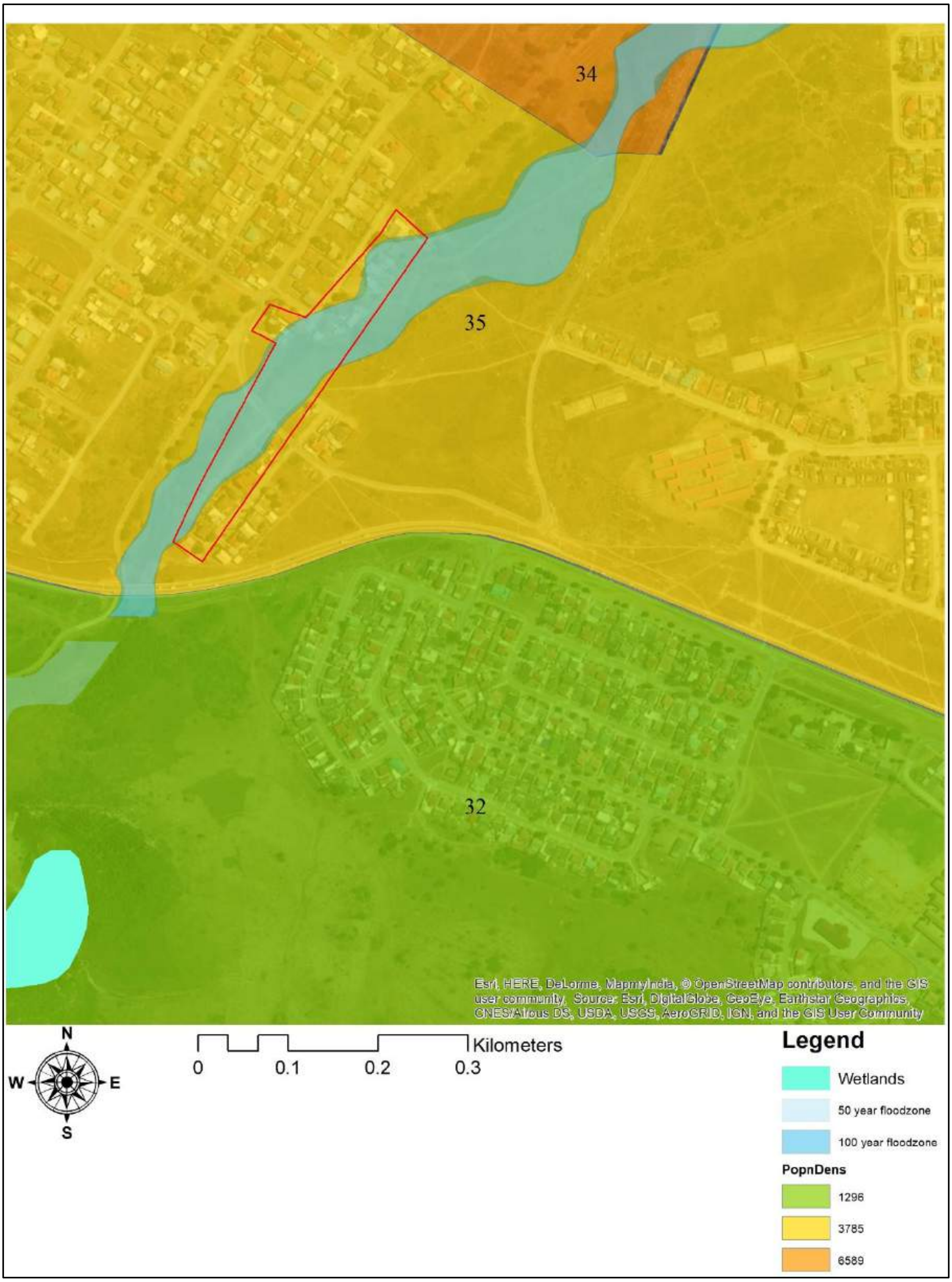

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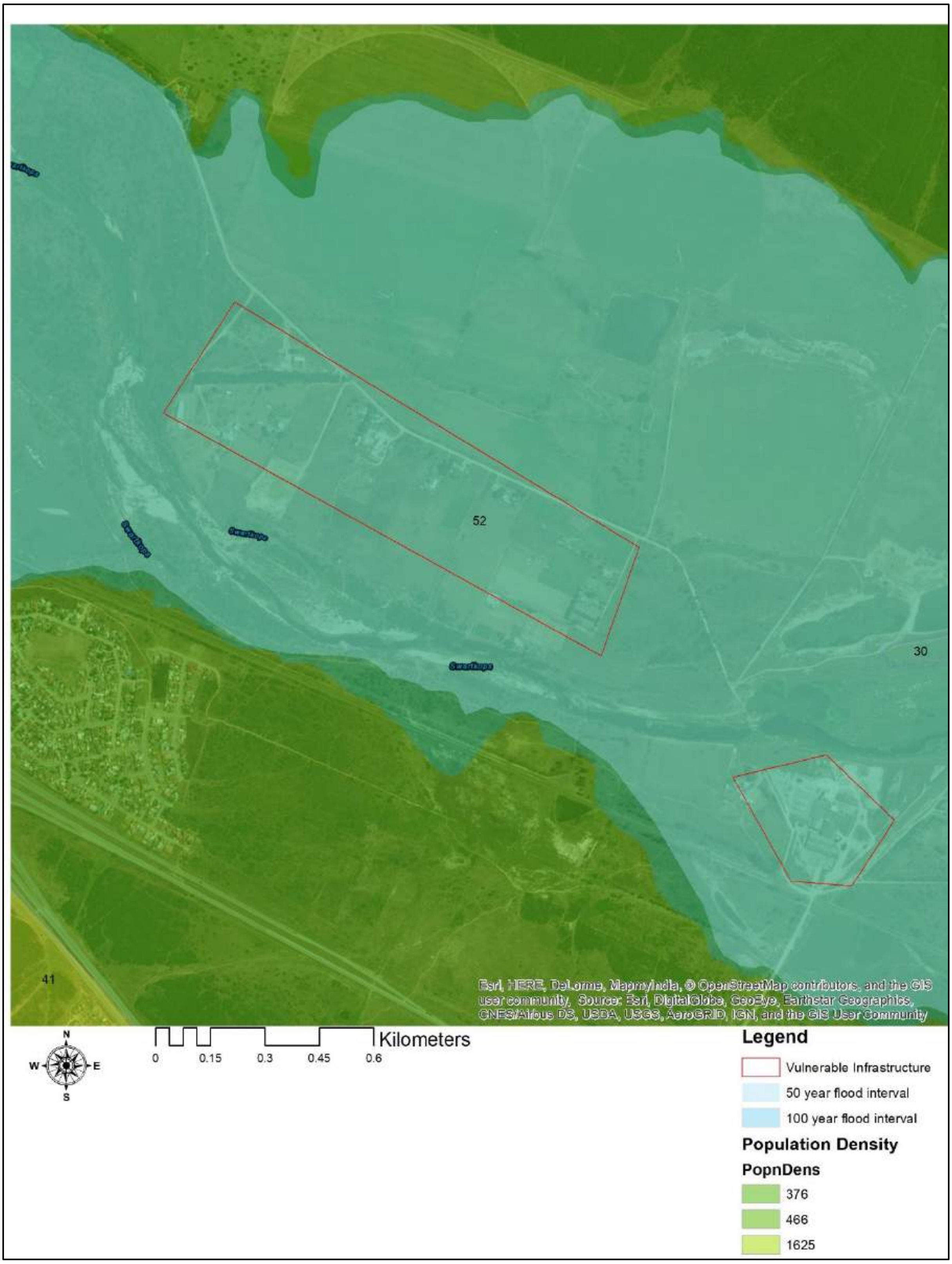

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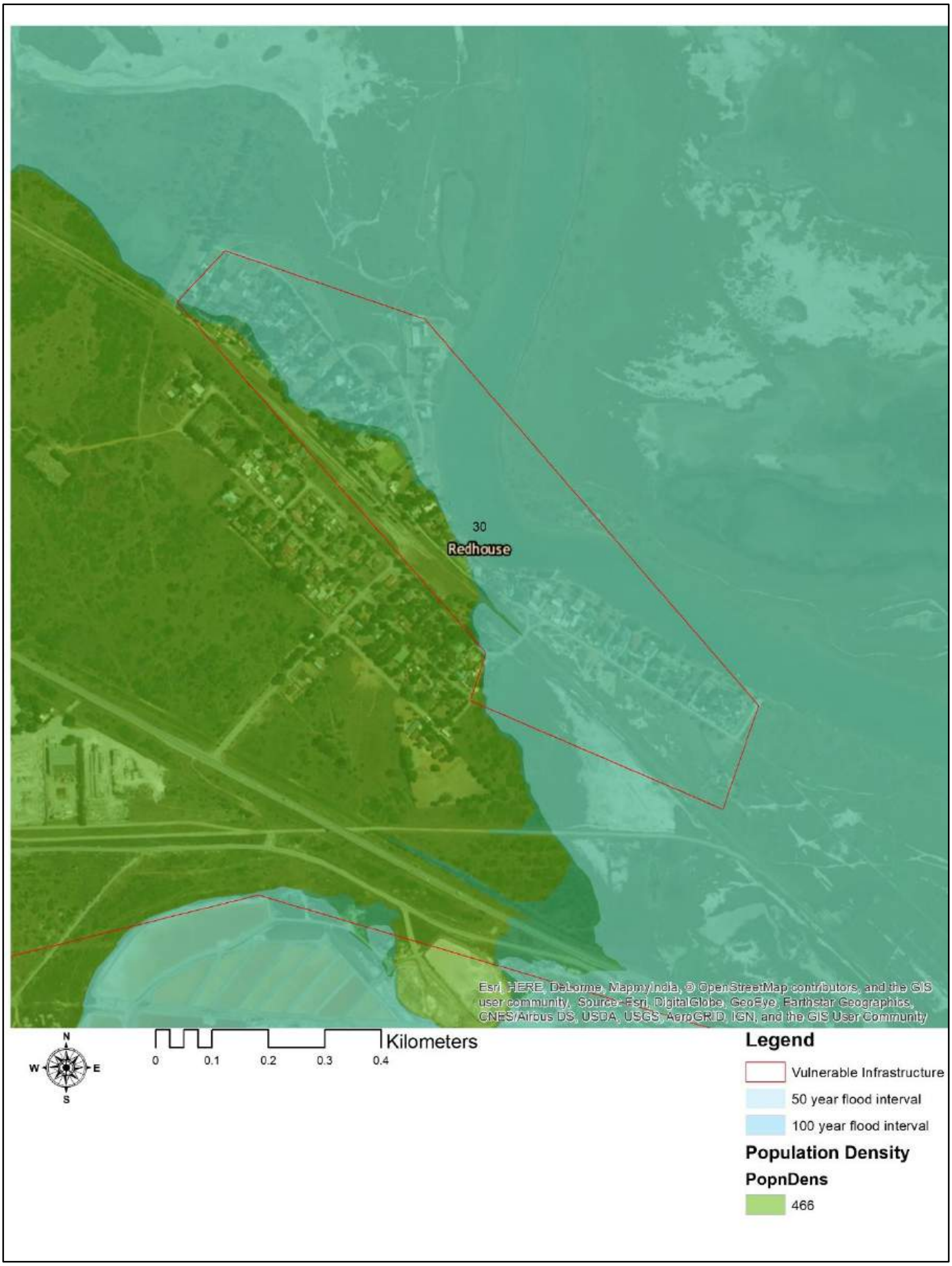

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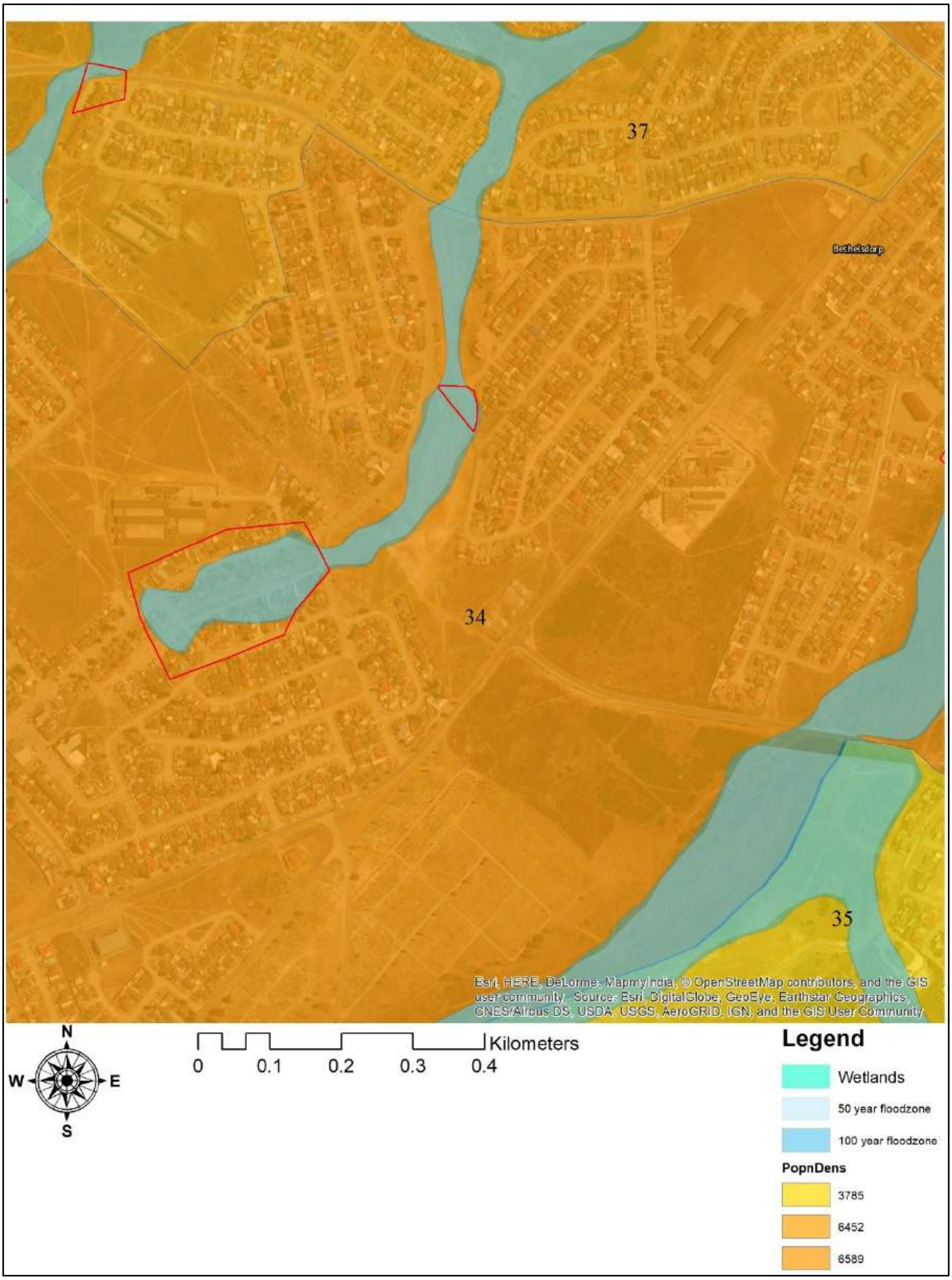

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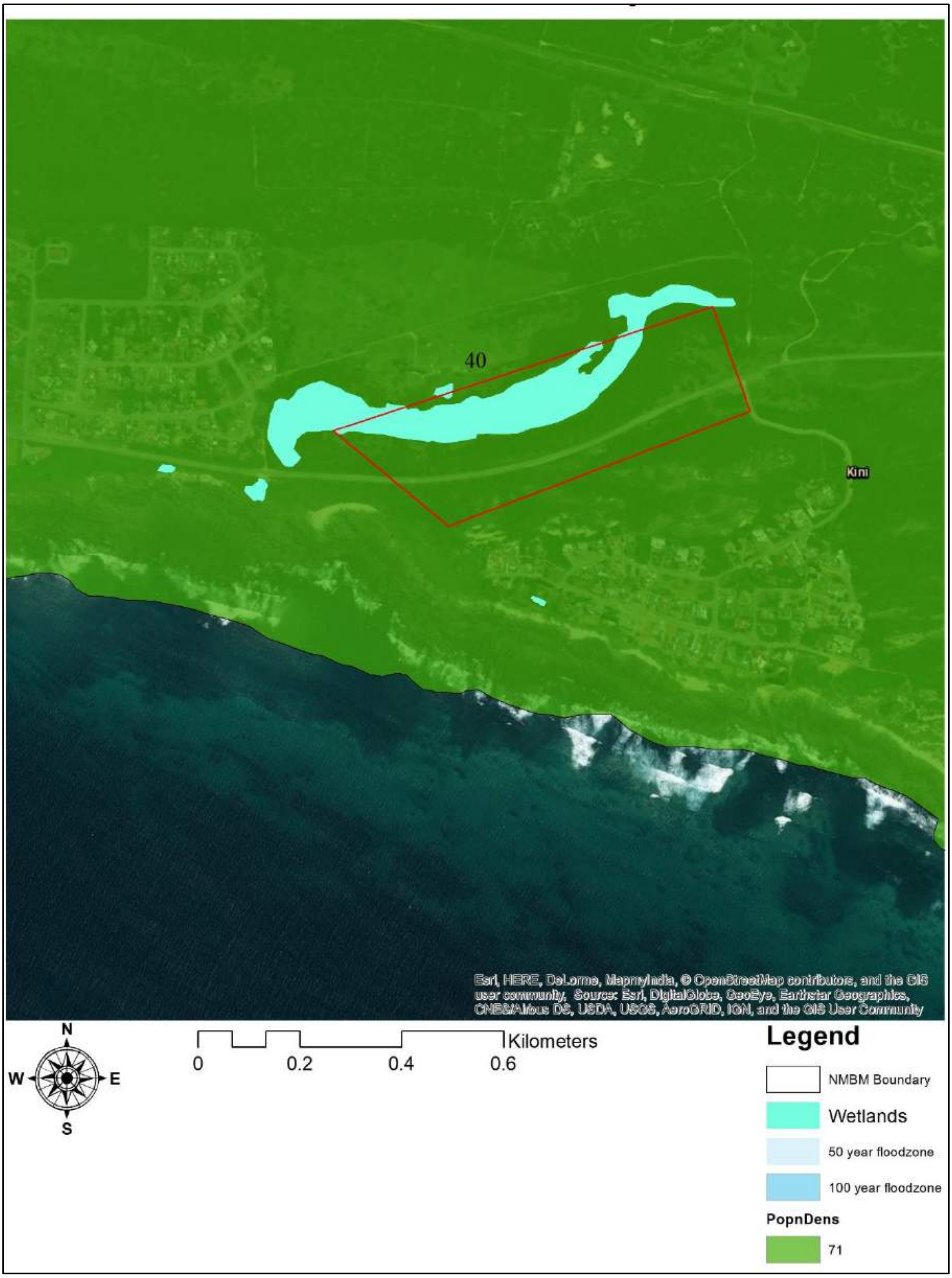
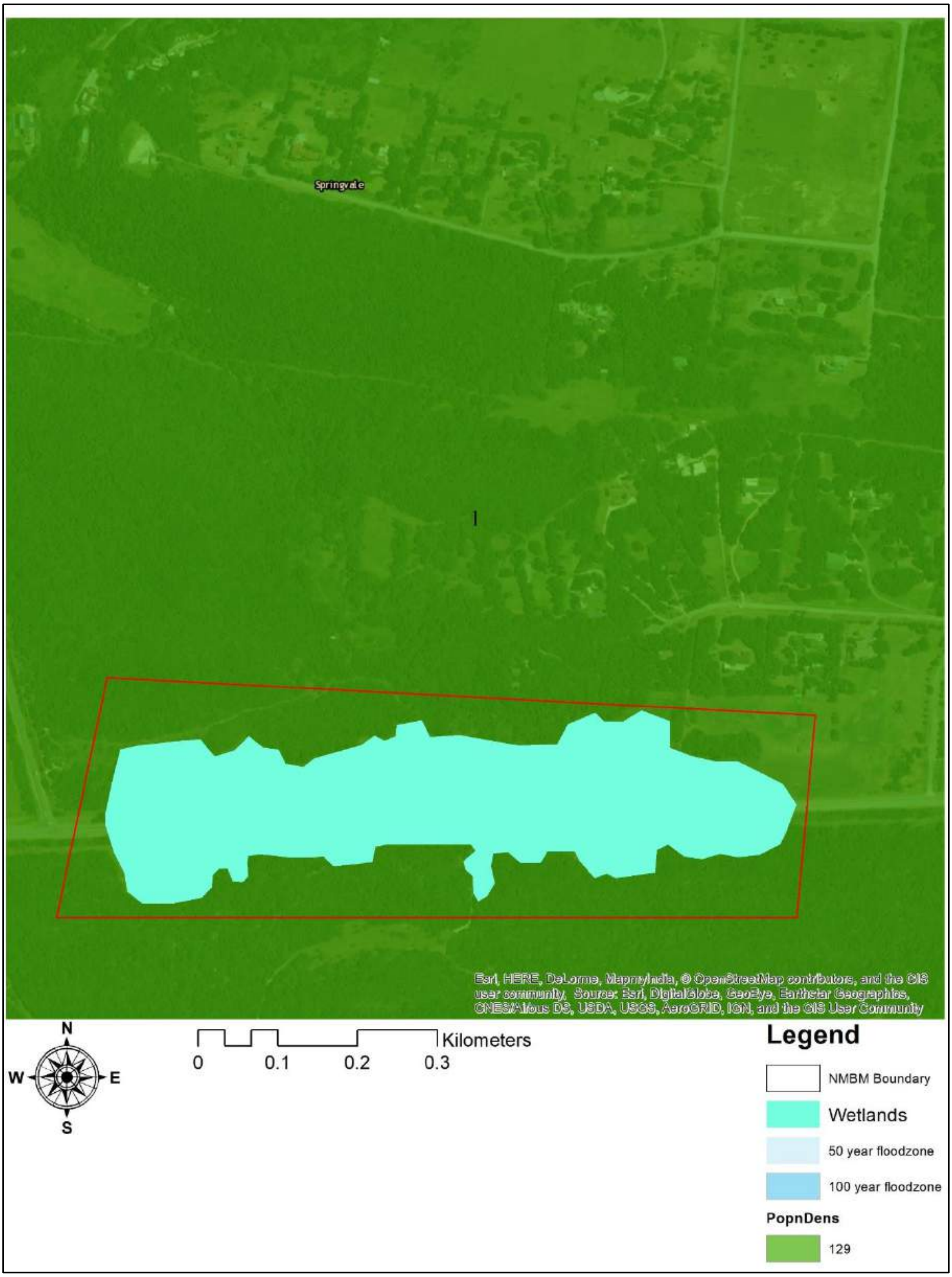


Map 21: Vulnerable road at Seaview



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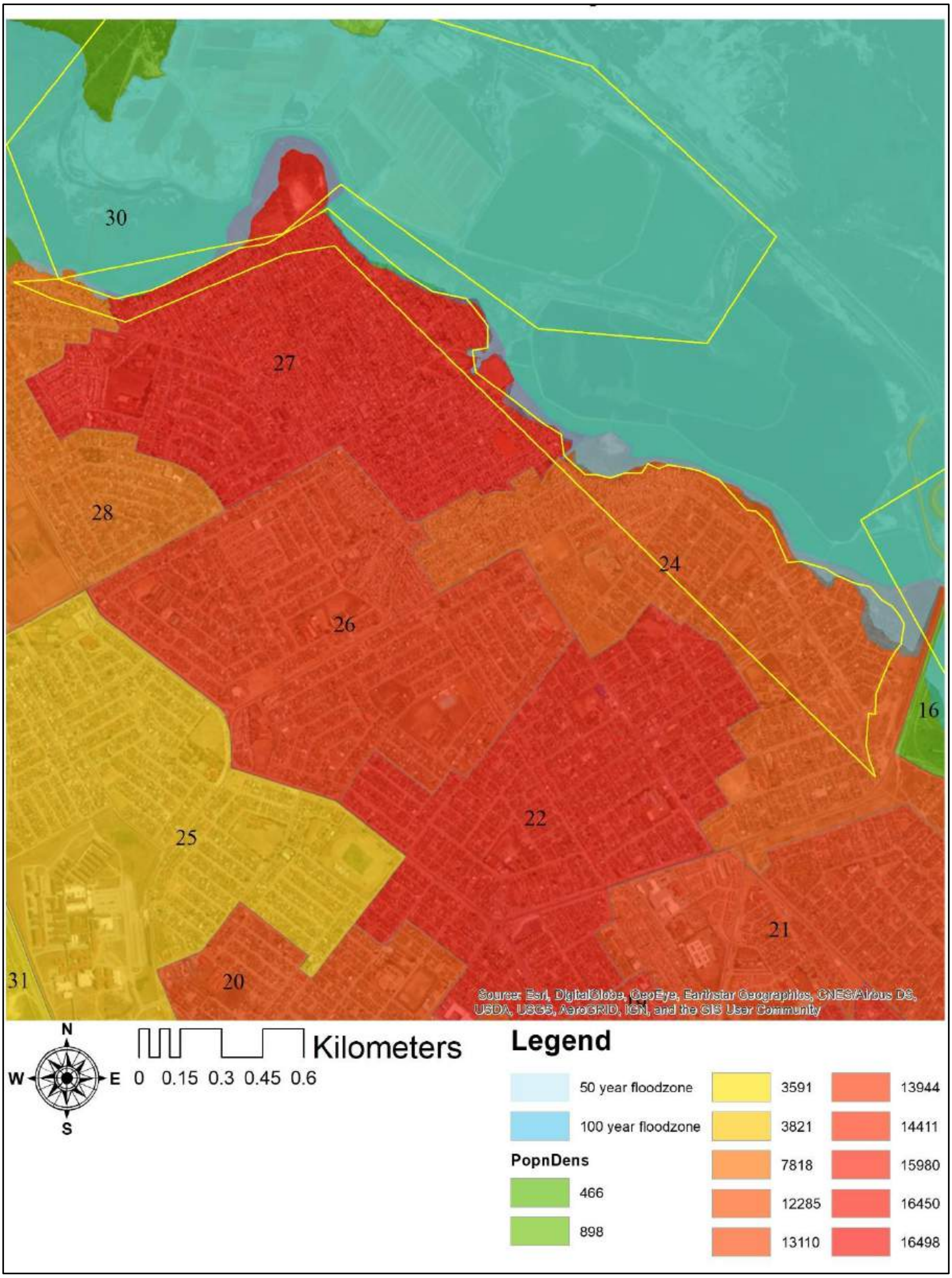

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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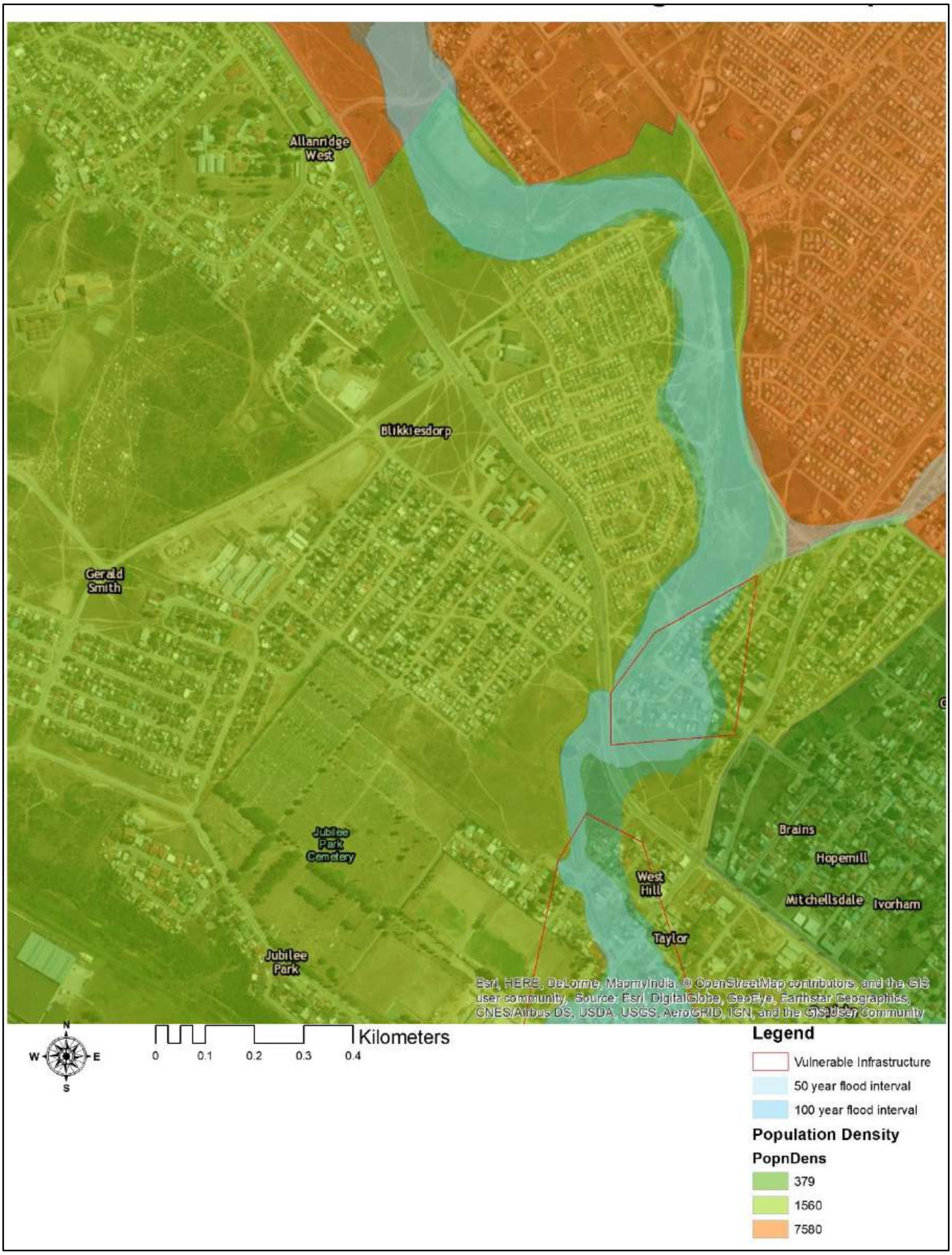

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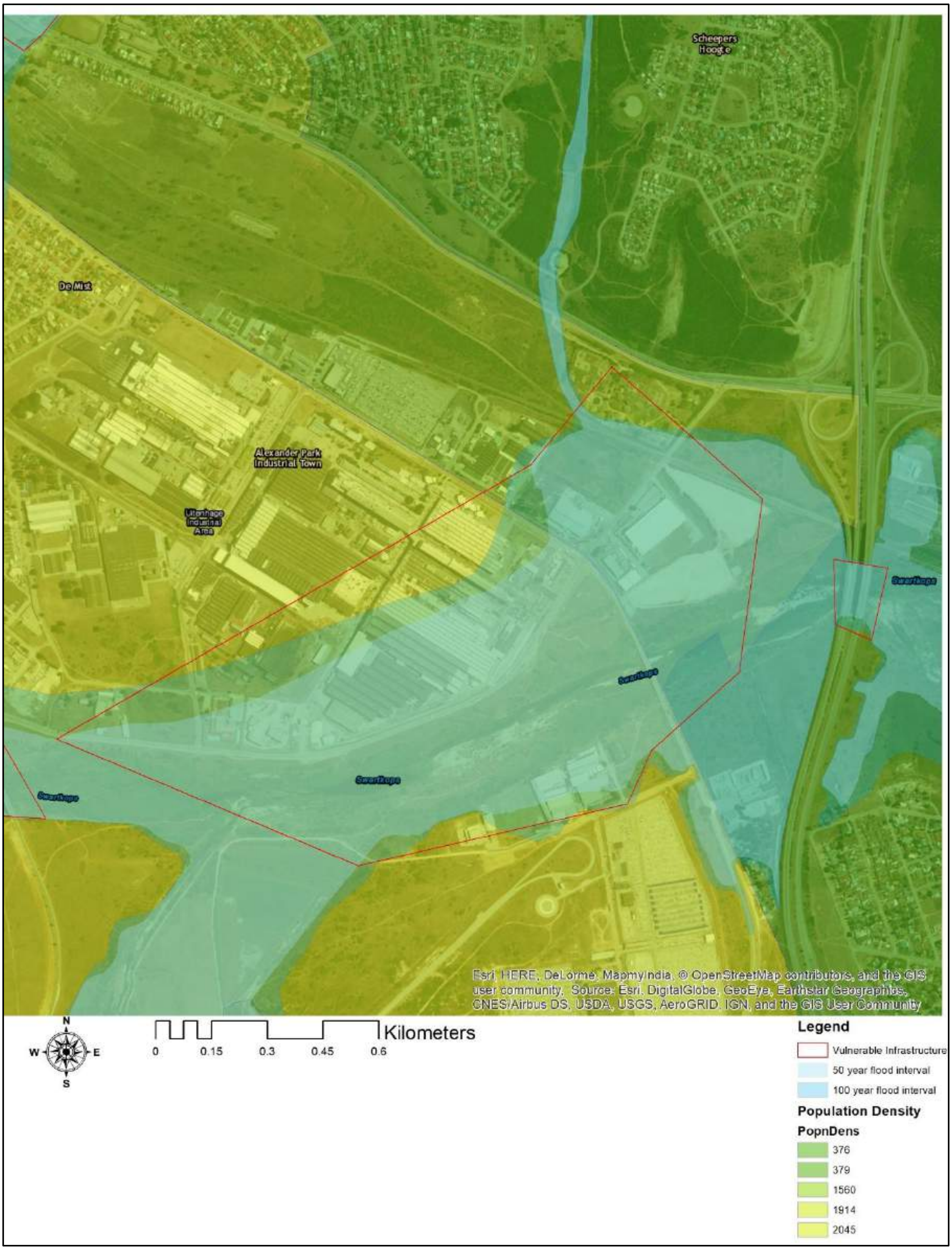

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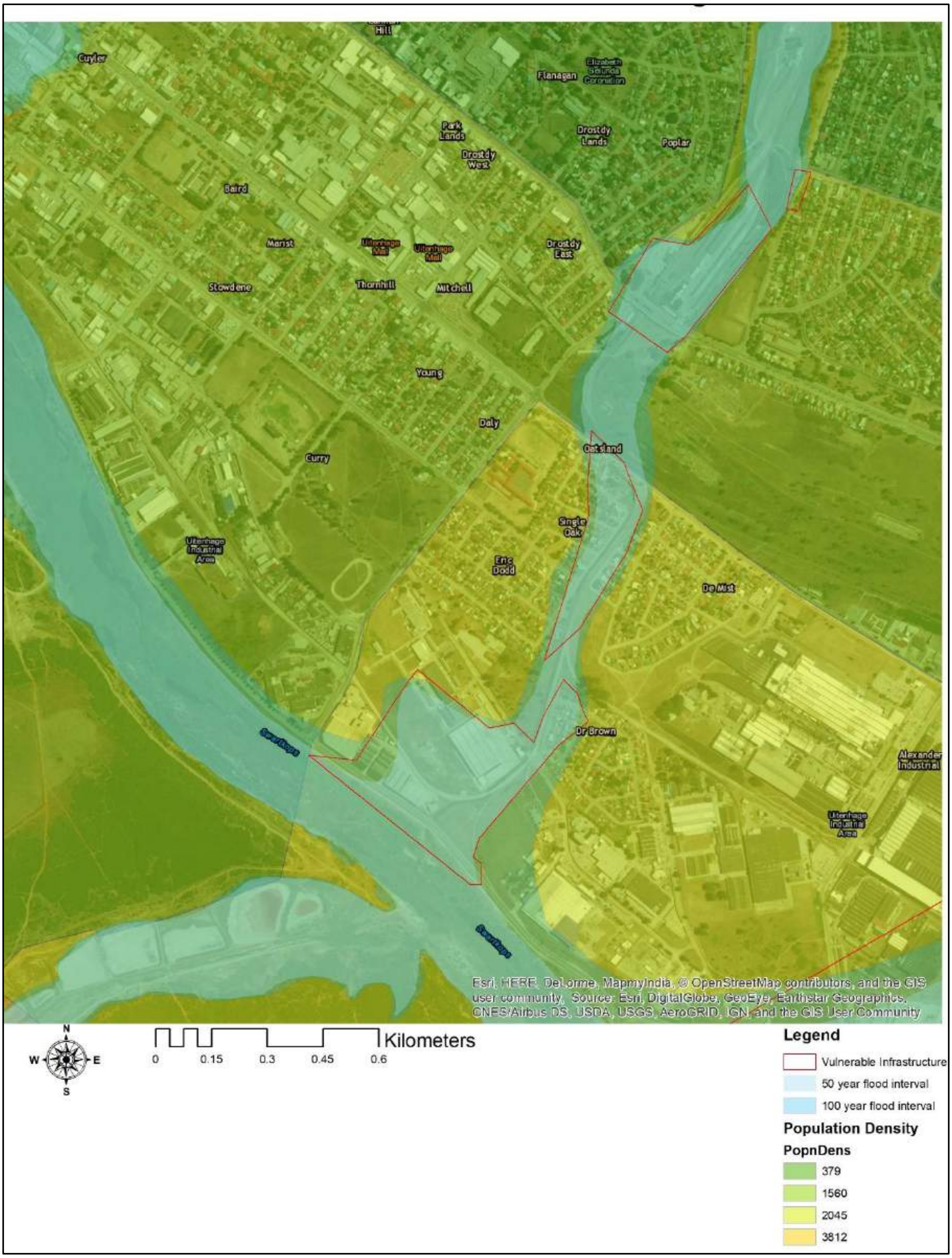

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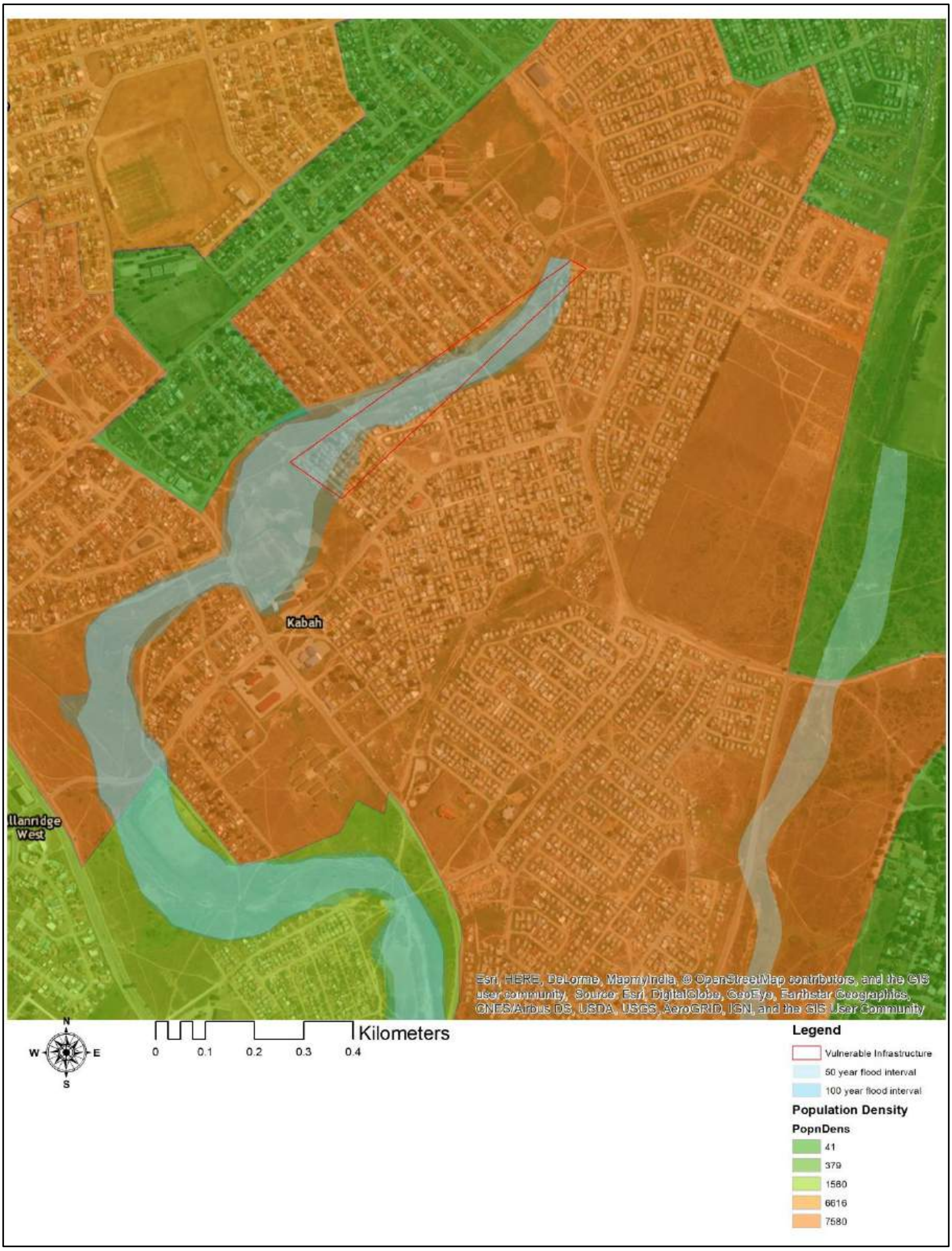

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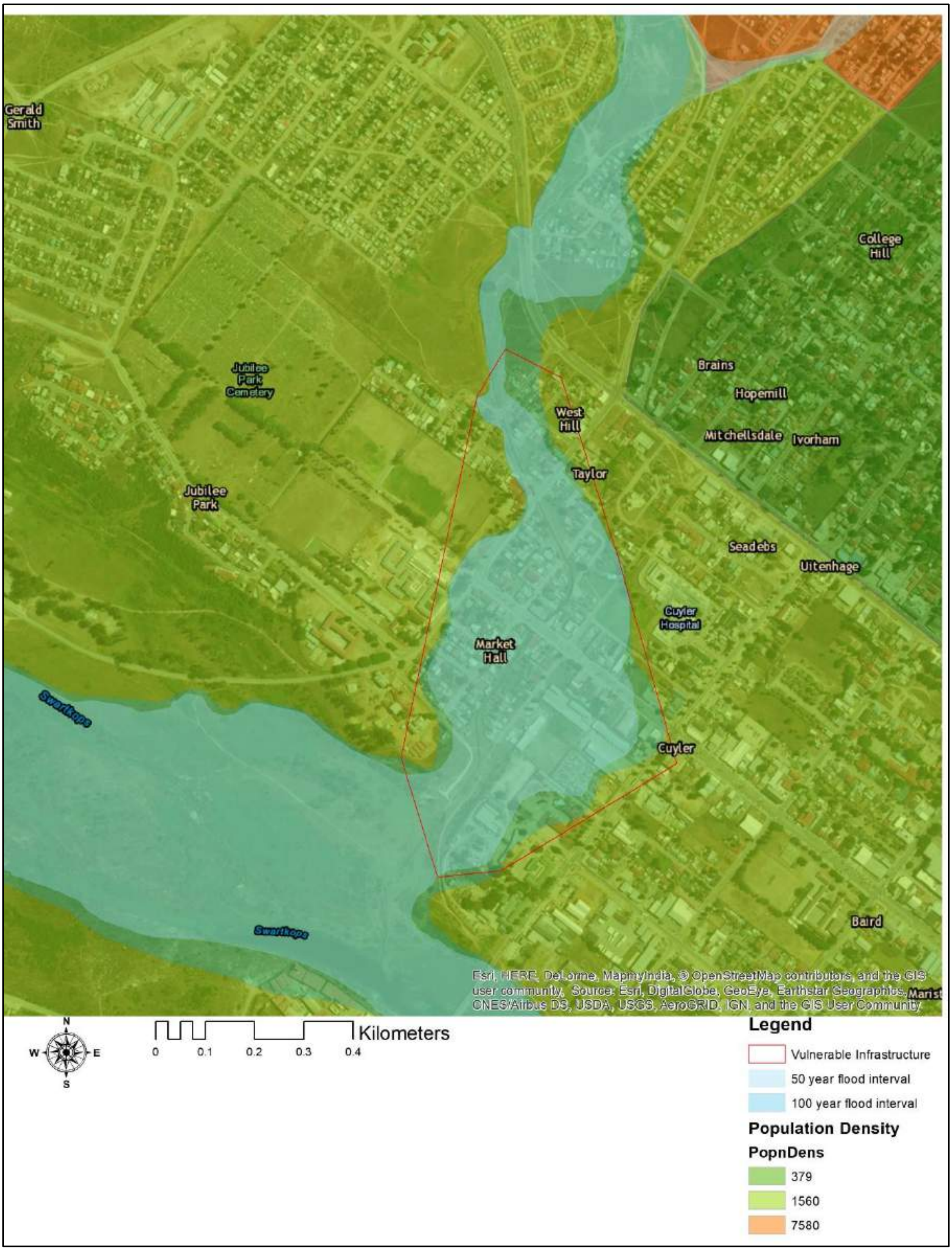

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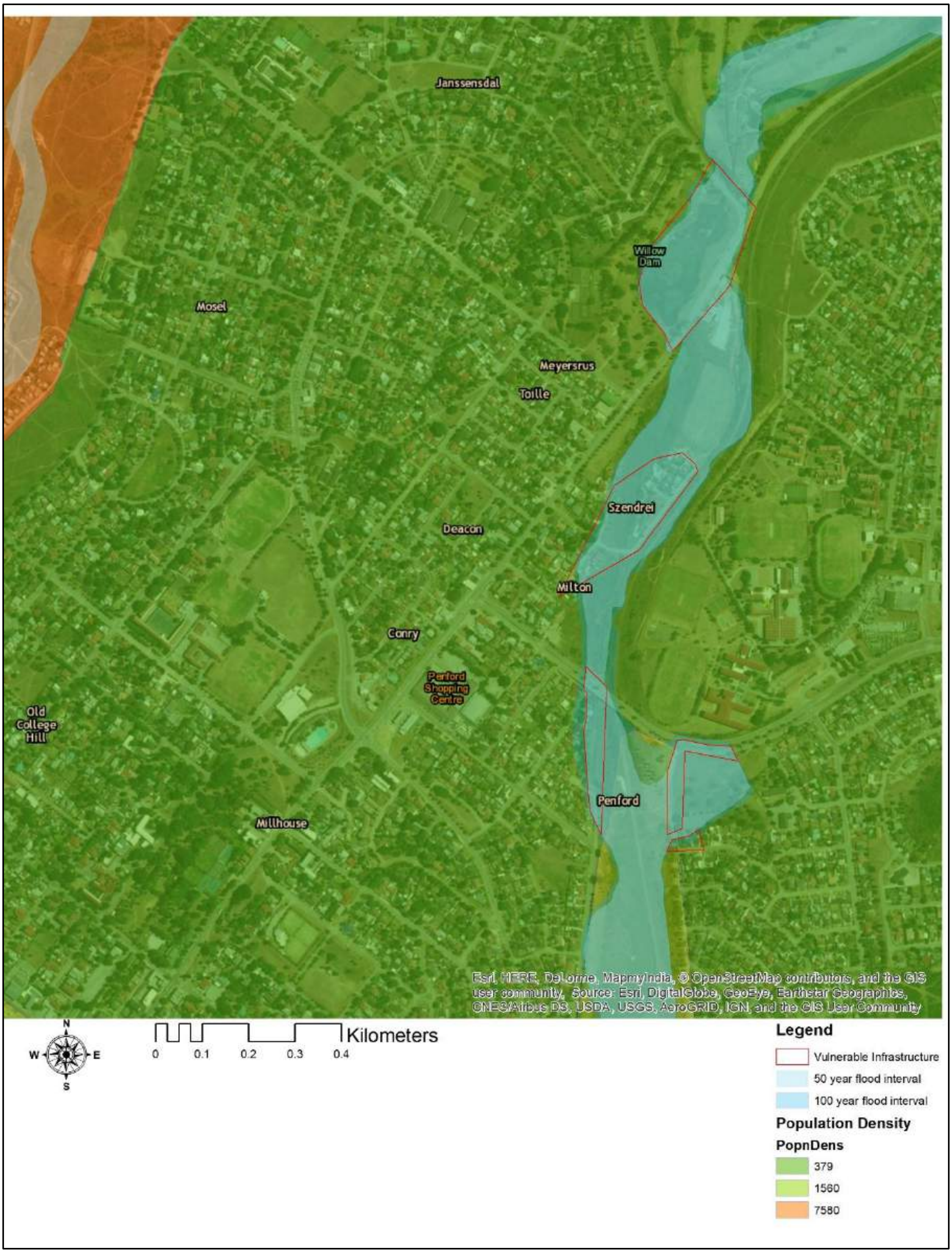

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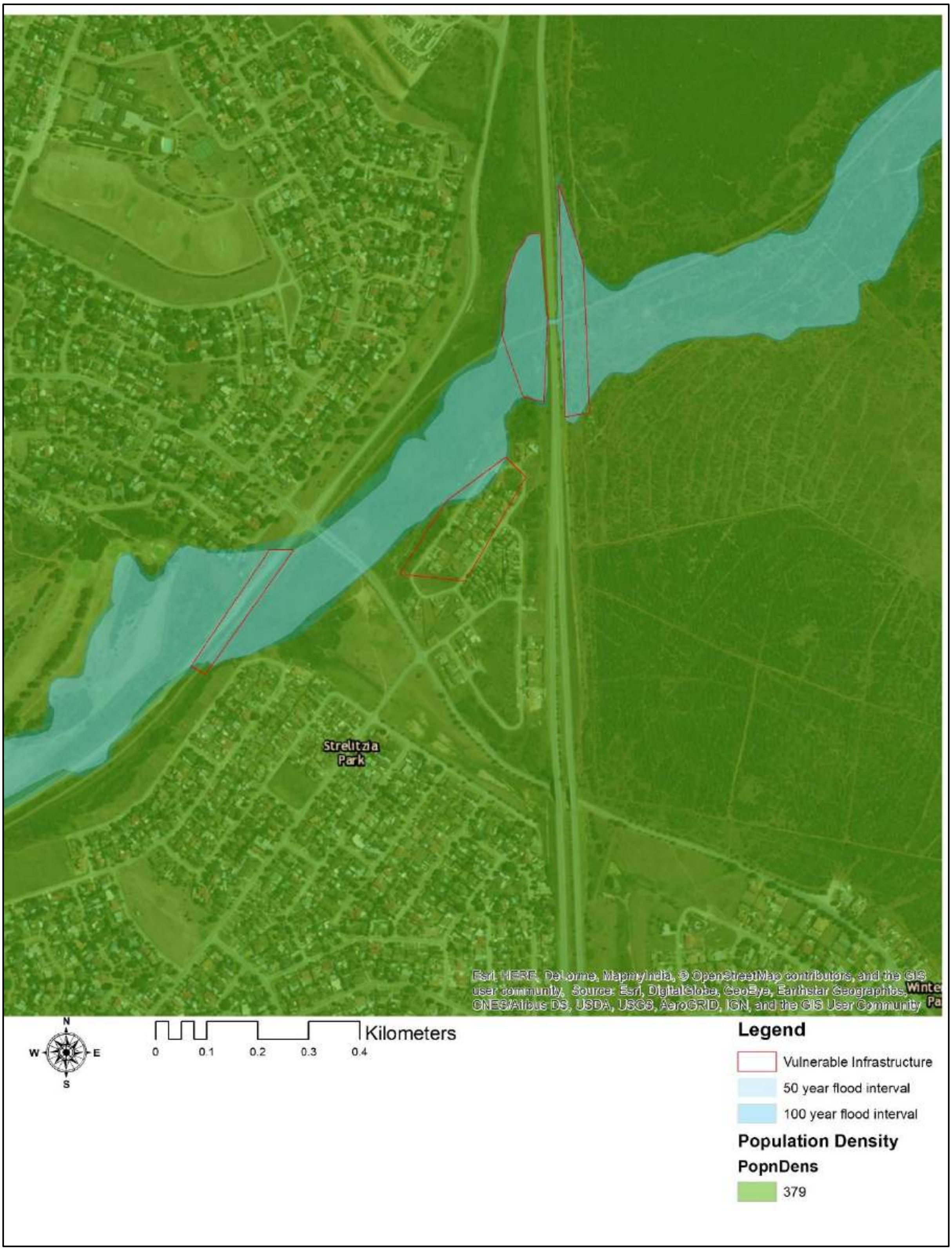

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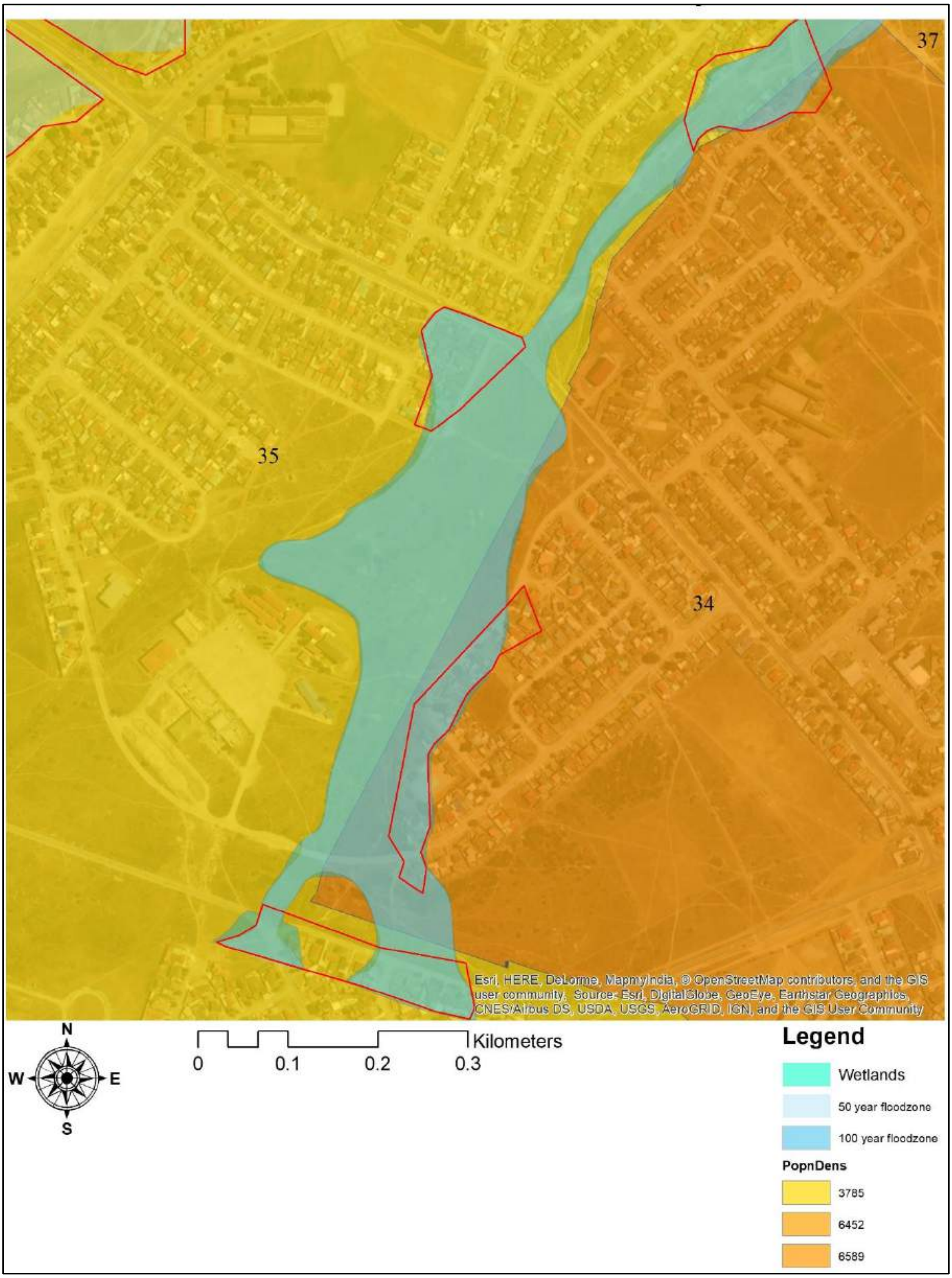

Map 31: Vulnerable dwellings and roads at William Slammert

Appendix B- Current flood mitigation strategies implemented in the NMBM

Improved storm water and roads infrastructure

Climate change indicates that increased incidences of flooding and warmer temperatures are expected. By adjusting specification levels for roads and storm water management infrastructure the NMBM can experience less damage to infrastructure during extreme events. This will lead to better management of future run-off volumes and availability of road infrastructure during flooding.
Estimated budget: R7.4million.

Target: Chatty River flood risk improvements (NMBM Stormwater Master Plan, 2011)

Green Buildings and Infrastructure

The application of sustainable standards for all components of built environment can make structures perform better in increasing adverse climatic conditions. Intervention can be applied in the entire built environment (low cost housing to large buildings).
Estimated budget: R20million. Procurement standards revision: Revision of specifications for building development and maintenance. Retrofitting of public buildings and facilities.

Target: Adopt revised procurement specifications for the built environment that comply with the worst case flooding projections. Adopt revised (green) procurement specifications for the built environment that support GHG mitigation targets and local socio-economic targets. A case can be made for sandbag building. All scheduled retrofits/ refurbishments of council buildings to address climate change projections and GHG mitigation targets. Green star rating (High Level Housing Strategy, 2012).

Urban and open space management

Provision of open space plays an important role in improving the quality of human life through the direct benefits of recreational space and beautifying the city. Indirect benefits involve microclimatic amelioration, wind and dust suppression, groundwater recharge, flood mitigation, storm water conduit and other benefits for plants and animals.

Budget: R90million over 10 years.

Target: Incorporating Metropolitan Open Space System in Structural Development Framework and Integrated Development Plan. Formal protected status to protected areas; improved access to facilities and infrastructure; Maintenance of open space areas.

Coastal Management

Coastal management programme aims to manage the coastal zone in a manner that builds resilience to sea level and potential of greater intensity of storm surges.

Targets: Implementation of Integrated Coastal Management Plan (ICMP). Coastal setback line; Coastal Ecosystem Management (sediment management, beach nourishment, erosion protection, dune management.); Defence works at vulnerable locations.

Budget: R7million per year.

Catchment Restoration

Krom and Kouga catchments both lie outside the NMBM boundary, but the catchments have natural assets providing high value ecosystem services. The assets are impacted by excessive consumption of ecosystem goods and neglect which leads to regional flood damage and water shortages. These are worsened by climate change (flooding). Large catchment programme required which includes alien plant clearing, restoration of degraded areas and fire management. Catchment management can generate additional 37million m3 per annum in base flows, with a 200 000m3 reduction in sediment deposition in dams, and large scale carbon sequestration. It will increase catchment storage in the system by slowing run-off and increasing infiltration, thereby elevating soil water storage and increasing dry season flows. The reduced run-off will reduce sediment yields and increase the life span of water storage infrastructure. The elevated infiltration will reduce storm flow and thereby reduce impacts of climate induced flooding events, whilst the catchment restoration will also reduce the severity of more frequent fires (likely to result from climate change).

Budget: R252million over 30 years.
Target: Alien plant clearing in riparian areas and across the landscape, with subsequent follow up clearing. Restoration of indigenous vegetation in degraded localities. Management of restored and cleared areas.

Short term (2015/2016): Continue with EPWP works in Krom and Kouga catchments.
Medium term (2016/2017): Krom – 418ha cleared alien plants per year and 580ha restored per year. Kouga – 1514ha cleared of alien plants per year and 1014ha restored per year.
Long term (2021/2022): Cleared and restored areas are managed with 3000ha added to management process every year for 30 years. Thereafter catchment will be at low level and will have benefits for water supply and tourism.

Relocation in infrastructure and communities

The ICMP contains recommendations with regards to relocation and or demolition of municipal infrastructure that is highly vulnerable to the impacts of sea level rise and the probability of greater intensity storm surges. This is due to their current location on the seaward side of the coastal management/setback line. Several communities (mostly informal) are highly vulnerable to the impacts of flooding due to their locations within flood lines. NMBM has an informal settlement upgrade and relocation plan Key adaptation measure in terms of diverting risk away from vulnerable communities.

Budget: R50million over 10 years.

Target: Relocate/ demolish inappropriately placed infrastructure.

Short term (2015/2016): First stage is to identify risk areas and vulnerable infrastructure. Second stage is to incorporate the information into planning maps.
Medium term (2016/2017): Approval for relocation projects. Complete relocation projects.
Long term (2021/2022): Complete relocation plan. Look at Informal Settlements Upgrading Plan (2008). There is a need for more flexible tenure schemes to facilitate socio-economic migration.

Disaster Risk Management

Full range of disaster planning response actions including flooding and damage to infrastructure. Proactive planning for climate change disasters that are exacerbated by climate change. Up to date information on risk profiles of municipality and communities. Awareness and preparedness training. Communication. Disaster mitigation strategies such as disaster relief, recovery and rehabilitation.

Budget: R30million per annum.
Target: DRM office; Disaster Management forum; Forecasting and Early warning system linking to all sectors (labour, health etc.)

Data was compiled according to the NMBM Climate Change and Economic Development plan in 2016.