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APPLIED GEOGRAPHIC INFORMATION SYSTEM (GIS) AND REMOTE SENSING: FLOOD HAZARD RISK ASSESSMENT IN THE CITY OF BULAWAYO

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Abstract

The study assessed flood hazard risk for the city of Bulawayo to determine its resilience to flood hazard events. Remote sensing data and GIS tools were used in the assessment of the flood hazard risk. Flood hazard mapping was done by testing the probability of the occurrence of flooding with the height above the nearest channel base in ILWIS Academic (ITC, 2003). Logistic regression was employed to predict the occurrence of flooding with height above the channel base. The study used the logistic regression equation which was derived for the Musengezi basin for predicting the probability of flooding. Results indicated that the probability of flooding in the city of Bulawayo could be predicted reliably using the nearest channel base. The study also established that the people and infrastructure in residential areas such as Makokoba, Parklands, Richmond and Northend were not vulnerable to the risk of flooding since they were located in flood safe areas. People in areas such as Matsheumhlope, Riverside and Mahatshula were in the high flood hazardous zones and were therefore vulnerable to the risk of flooding. The research findings imply that the city planners of Bulawayo need to take note of the following critical recommendations in order to improve the city `s resilience to flood hazards events: There is need to establish early warning systems in high flood hazard risk zones such as Matsheumhlope, Riverside and Mahatshula. It is also crucial to put in place emergency shelter and evacuation routes to improve urban sustainability or the ability of the city to cope with flooding events in the future. The emergency shelters should be established in flood safe areas such as Makokoba, Parklands, Richmond and Northend. The information on the spatial

distribution of flood hazard should also be used by planners in siting and designing of infrastructure in flood prone areas.

Key words: GIS, Remote sensing, flood hazard

Introduction

The increase in the rate of urbanization is one of the critical issues currently facing many countries in the developing world (Cohen, 2006). As cities grow, they begin to experience shocks and stresses. The nature of shocks varies from socio economic to natural hazards related challenges such as flooding (Cohen, 2006). Copying with the challenges of urbanization requires urban systems that are resilient. The concept of urban resilience has become popular in referring to the essential attributes of the city that enable them to deal with disasters and other threats which they have little control over (Seeliger 2013). The ability of the city to cope with hazardous occurrences and adapt to unfavorable conditions is crucial to their prospects of sustained growth and development (Seeliger, 2013). Currently the critical question for urban planners is: Is building urban resilience really possible? According to Matsumoto et al (2013), it is possible to build the resilience of the city to any form of shocks and stresses that the city might be exposed to. This can be achieved by carrying out urban hazard risk assessments to shocks such as flooding.

Flood risk assessment is still at its infancy in Zimbabwe. This is because the country was considered a flood safe zone until the cyclone Elline induced floods of 2000-2001(Pawaringira, 2008). Some of the few researchers who modeled flood hazard include Murwira and Murwira (2005), Madamombe (2006) and Rurinda (2006). However, all the studies were conducted outside the urban areas, implying that flood hazard mapping remains largely unexplored in the urban areas of Zimbabwe. This is despite the fact that there is a potential threat to some communities who reside in flood prone areas in the cities due to lack of flood hazard mapping studies. In Bulawayo, prolonged heavy rains usually results in flooding of some houses in the high, medium and low density suburbs. To the best of my knowledge, studies based on flood hazard risk assessment in the city of Bulawayo have received little attention in previous studies. Such knowledge is critical as assists urban planners and policy makers to reduce vulnerability to flood hazard (Pawaringira, 2008). Flood hazard maps also supports risk reduction measures, thereby improving urban resilience and sustainability.

Objectives

- To identify high flood hazard zones within the city of Bulawayo
- To determine flood safe areas in the city of Bulawayo
- To determine the vulnerability of infrastructure and people located in proximity to flood hazard zones

Definition of terms

Flood hazard mapping- determining the probability or likelihood of a flood to occur at a particular place

Resilience to flooding- the ability of the city to copy and adapt to flood risks

Risk of flooding- susceptibility of the city to flooding

Delimitation of the study

The study was conducted in the city of Bulawayo which is located at latitude 20^0 18'07S and longitude 28^0 22'10E (figure1). The study assessed the resilience of the city to flooding. This was achieved by conducting a flood hazard risk assessment exercise to determine flood safe areas and those areas which are at risk of flooding. The residential areas shown on the map are not the only ones in Bulawayo. However, they were just chosen among all the suburbs in the area of Bulawayo for the purpose of this study.

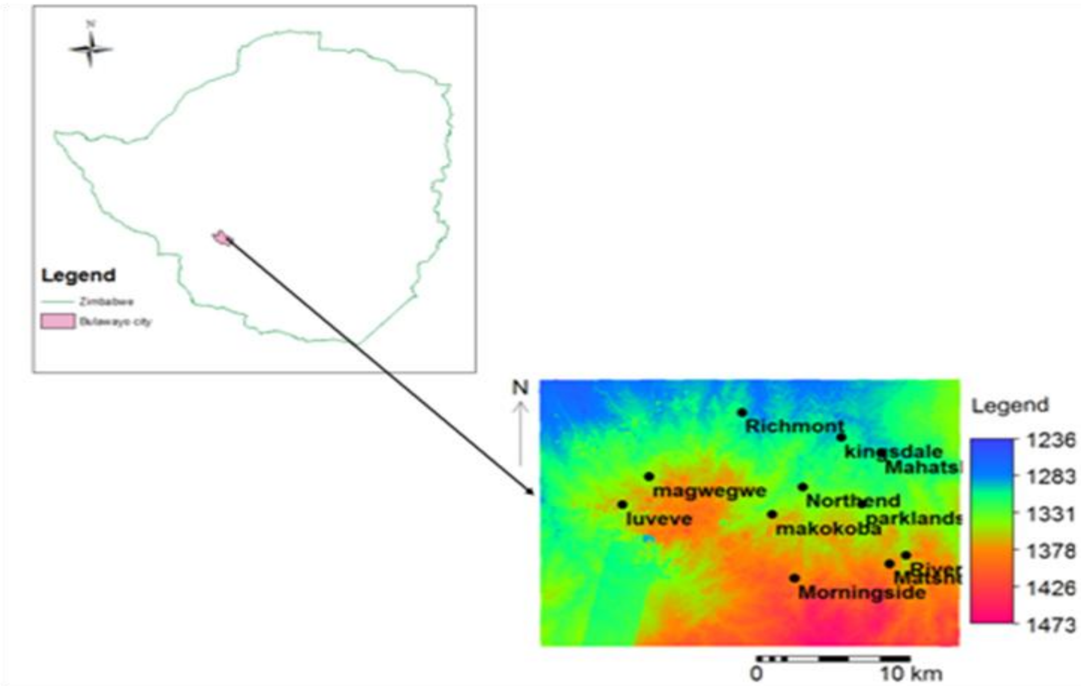

Figure 1 Location of the study area in Bulawayo, Zimbabwe

Theoretical framework

As illustrated in figure 2, the theoretical framework guiding this study is the three key elements of risk assessment which include hazard, exposure and vulnerability.

Risk	=	Hazard	×	Exposure	×	Vulnerability

Figure 2 Key elements of risk assessment

Source: Cardona et al (2012)

The rationale for selection of this theoretical framework is that risk is determined by exposure and vulnerability to the hazard event (Cardona et al, 2012).

Risk assessment

According to Jha et al (2012) risk assessment is a technical tool for quantifying the possible impacts of disaster in terms of change and loss and the probability or likelihood of the event occurring. Risk assessment combines hazard, exposure and vulnerability analysis (Jha et al, 2012). The process of risk assessment provides a spatial assessment of risk based on hazards, vulnerable populations and the ability of the community to copy with disasters.

Hazard identification

In urban resilience terms hazards are defined as disturbances to urban areas that threaten human life and habitation (Jha et al, 2012). Disturbances refer to natural disasters like floods. This component of risk assessment includes the collection and analysis of underlying hazard data to produce a probabilistic event set.

Exposure analysis

Exposure analysis involves connecting the identified hazards with the elements at risk such as human populations and infrastructure that is in proximity to the hazard. GIS helps in exposure analysis by identifying the location of critical infrastructure such as roads, power stations and residential areas (Matsumoto et al, 2013).

Vulnerability analysis

Vulnerability analysis involves assessing the susceptibility of exposed populations to different levels of hazard. Chellen et al, (2012) suggests that vulnerability to risk is influenced by the copying and adaptive capacity of people and infrastructure to hazard.

Research design and methodology

Quantitative research design

This research employed the quantitative design. Creswell (2008) defines research design as a plan and procedure for research. The quantitative design involves testing of theories by examining the relationships among variables. The choice of the quantitative design was prompted by the problem under study. There was need to test the probability of flooding and height above the nearest in order to establish flood safe areas and areas that are vulnerable to flooding in the city of Bulawayo. Figure 3 depicts the relationship between research paradigm, methodology and methods in a quantitative research design employed for this study.

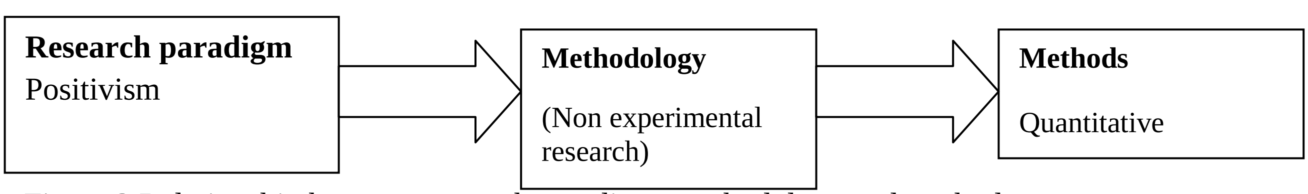

Figure 3 Relationship between research paradigm, methodology and methods

Source: Crotty (1998)

Positivist research paradigm

Research paradigm is a perspective about research held by a community of researchers that is based on a set of shared assumptions, concepts, values and practices (Barks, 1995). Research paradigm forms the philosophical dimensions of research. The positivist research paradigm advocates the use of a scientific approach by developing numerical measures to generate knowledge (Wahyuni, 2012). The rationale for selecting the positivist paradigm was that the research adopted scientific methods in data collection and analysis.

Quantitative research methodology

The type of quantitative research methodology employed for this study is the non experimental research. According to Bell (2008), non experimental research refers to any quantitative study without manipulation of treatments or random assignment. Non experimental designs are used in situations where data collection through true experimental designs is impossible. Rationale for selecting the non experimental quantitative research methodology is that the variables used for the study are inherently not manipulated. For instance, it is impossible to manipulate the probability of flooding or the height above the nearest channel.

Quantitative Research methods

According to Creswell (2008), research methods are procedures data collection, analysis and interpretation that researchers propose for their studies. The research methods which were adopted for this study are quantitative, meaning that the data collection, analysis, presentation and interpretation are quantitative. The following quantitative techniques were employed to assess the risk of the city of Bulawayo to flooding.

Data collection

Digital elevation model (DEM) data for Bulawayo

The DEM data was obtained from remotely sensed images. Figure 4 shows the Digital Elevation Model (DEM) for the area of Bulawayo. The DEM shows the variations in altitude across the city of Bulawayo (figure 4).

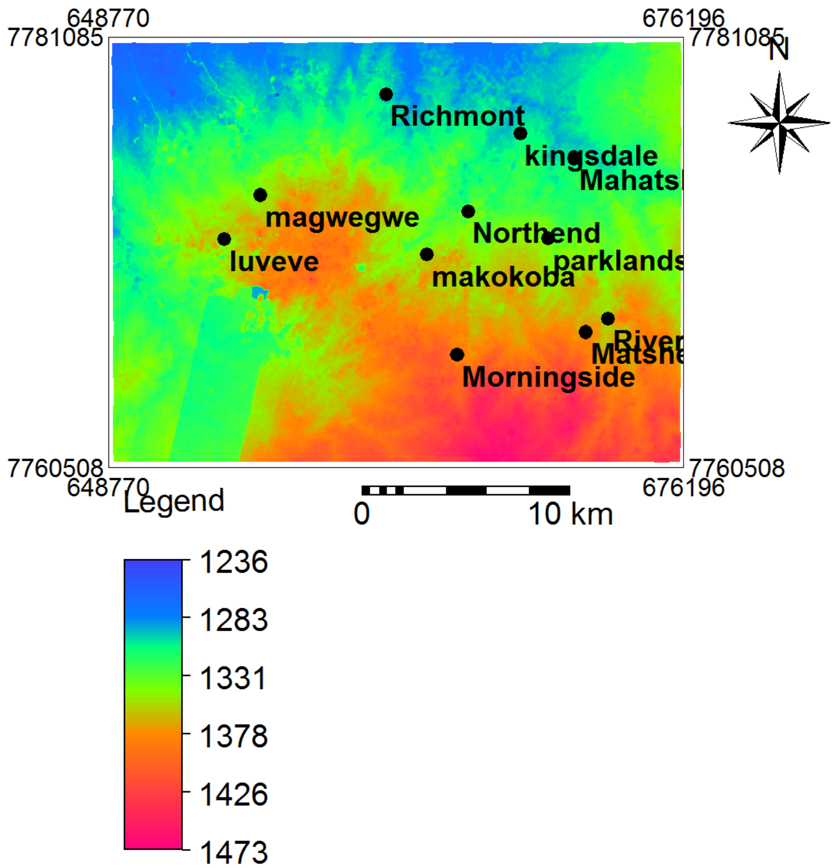

Figure 4 Variations in altitude for the areas in Bulawayo

Coordinates are in UTM 35 South

Calculating stream network in ILWIS GIS

The stream network data was extracted from the DEM of Bulawayo. The DEM was first filled to remove the sink holes. Flow direction and flow accumulation were calculated from the DEM. Finally, the stream network was calculated by typing the following equation on the main command window in ILWIS: streamnetwork=flowaccumulationmap>1000. Figure 5 depicts the stream network in the city of Bulawayo. The data shows the location of the stream channels in the city of Bulawayo.

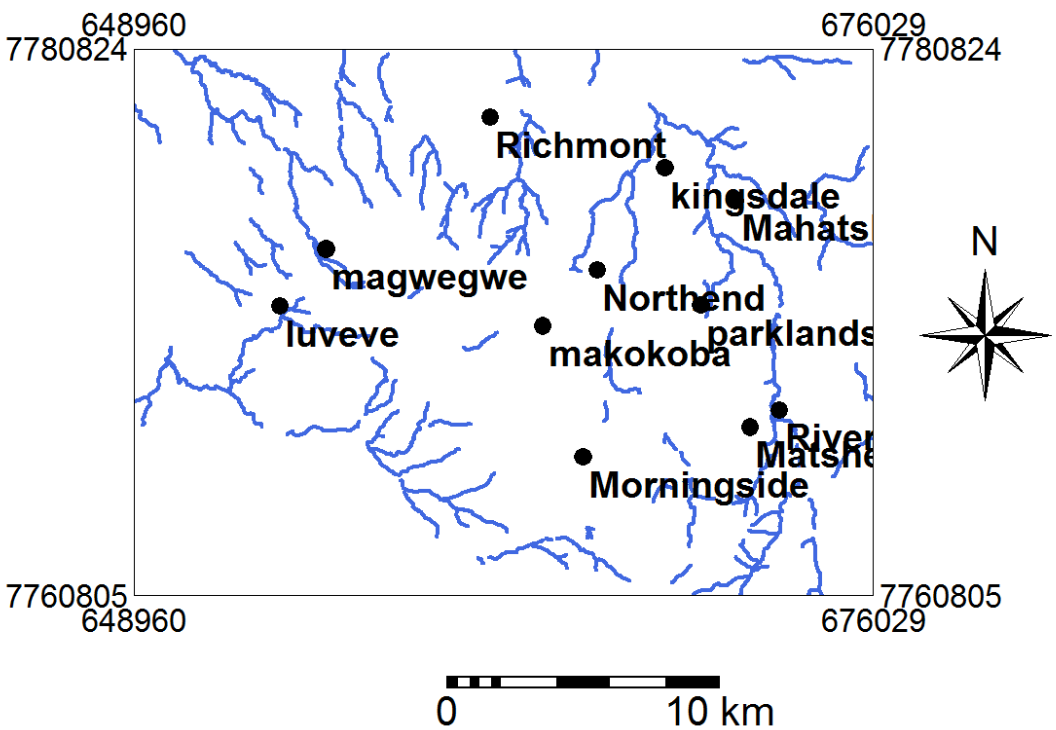

Figure 5 River and stream network in Bulawayo

Coordinates are in UTM 35 South

Derivation of the elevation of river channels data

The elevation of rivers in the area of Bulawayo was obtained from the river network in the study area. The calculation of the elevation of the river channels was done in Arc GIS using the spatial analyst tools. The elevation data from Arc GIS was imported and converted into a point map in ILWIS GIS. The point map was then converted to a raster map through a map Inverse Distance Weighted (IDW) interpolation. Figure 6 illustrates the elevation of the river channels in the area of Bulawayo.

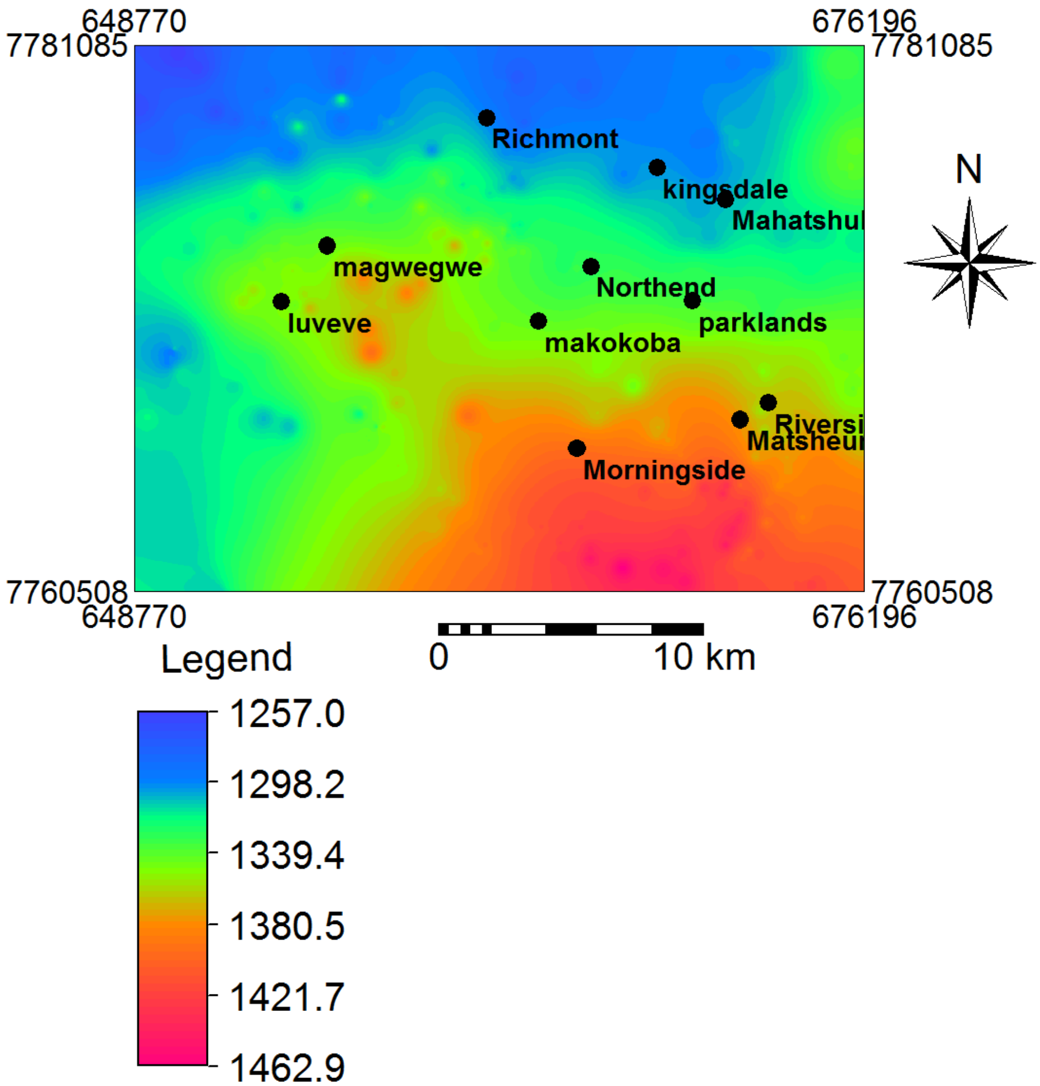

Figure 6 Elevation of the river channels in the area of Bulawayo

Coordinates are in UTM 35 South

Derivation of height above the nearest channel base

The elevation or height above the nearest channel of all the places in Bulawayo was calculated by subtracting the elevation of the river channels from the DEM of Bulawayo area. The following equation was typed in the ILWIS GIS command window: heightabovechannel=bulawayodem-elevationrivers. The resultant map (figure 7) shows the elevation or height above the nearest channel for the places in the Bulawayo city. The height above the channel base is the covariate of the probability of flooding. This implies that the probability of flooding is significantly related with height above the channel base.

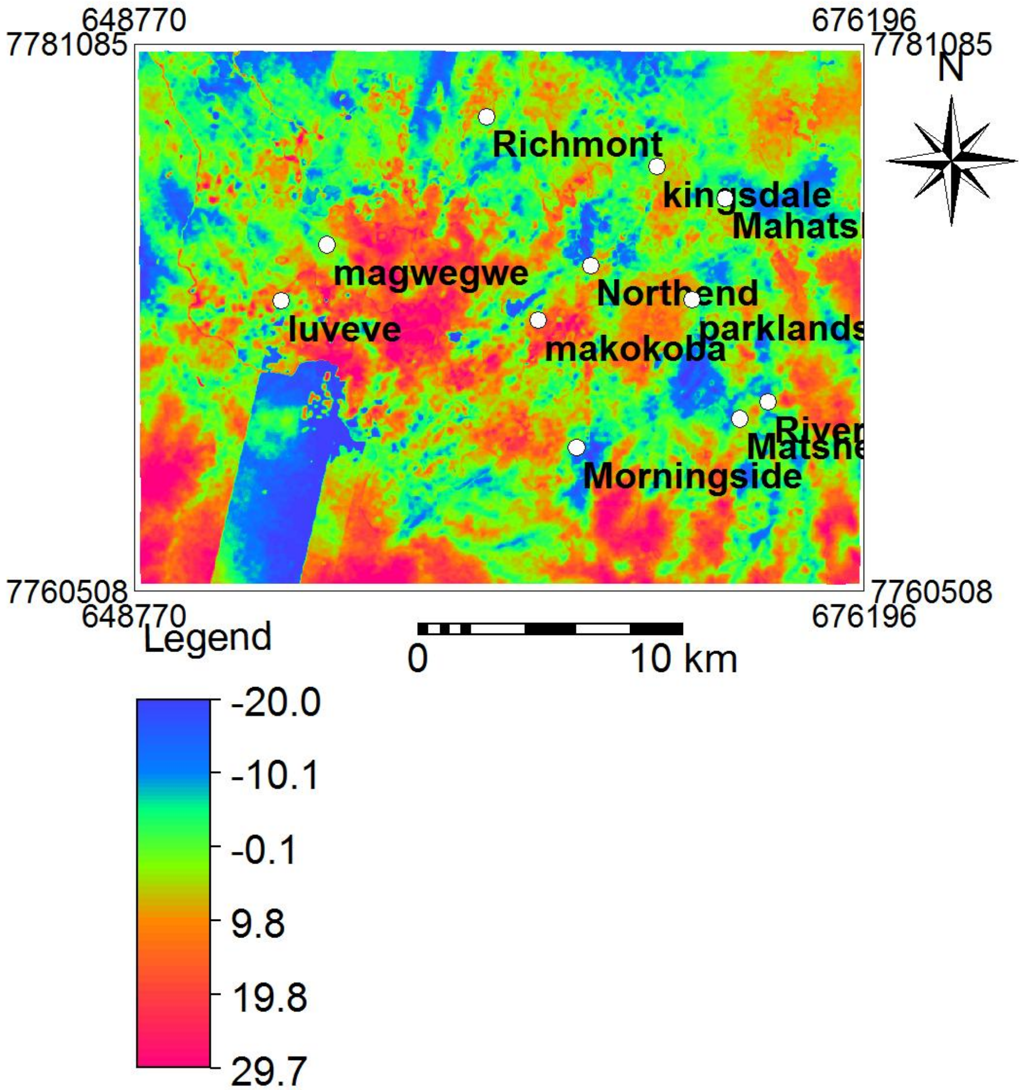

Figure 7 Variation of height above the nearest channel base in Bulawayo

Coordinates are in UTM 35 South

Derivation of flood condition data

The study used the following logistic regression equation which was derived for the Musengezi basin for predicting the probability of flooding:((x*-0.95)+2.764)/(1+exp((x*+2.274)) (Murwira and Murwira, 2005).

Data collection for infrastructure (roads, built up areas)

Figure 8 depicts the built up area data which was obtained from remotely sensed image of the area of Bulawayo. This data was used to assess the bulit up areas which are at risk of flooding in the city of Bulawayo.

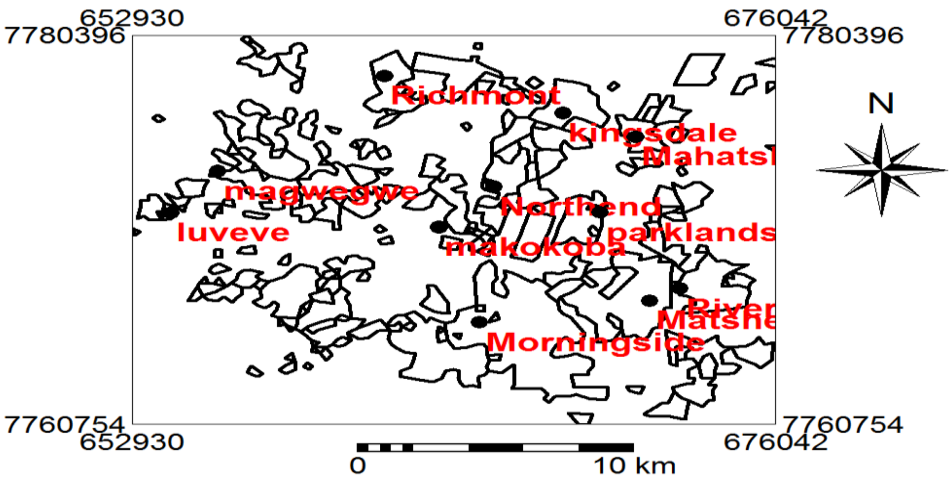

Figure 8 Distribution of built up areas in the city of Bulawayo

Coordinates are in UTM 35 South

Figure 9 depicts the roads network data in the city of Bulawayo. The data was employed to identify the roads which are at risk of flooding in the city of Bulawayo.

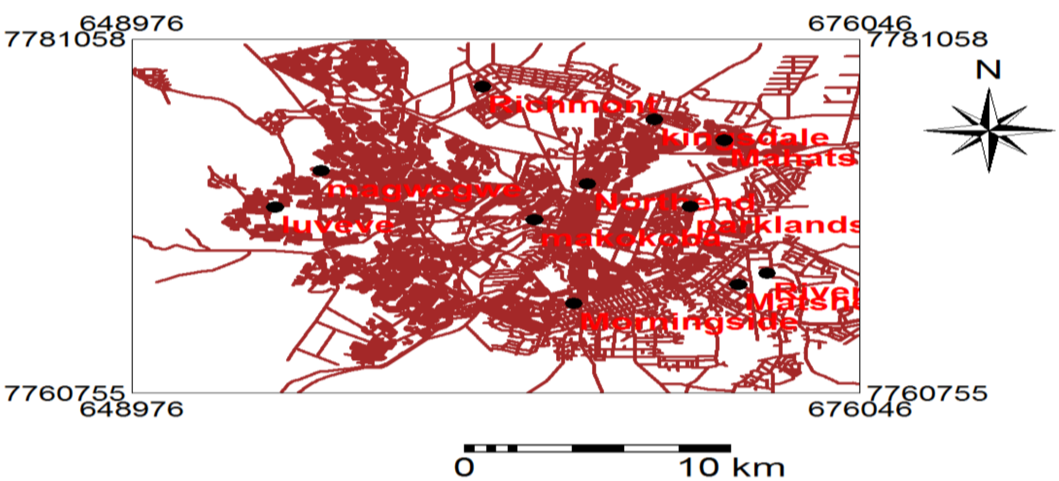

Figure 9 Distribution of road networks in the city of Bulawayo

Coordinates are in UTM 35 South

Data analysis

Geographic Information System (GIS) software tools were used for data analysis. The rationale for using GIS is that it has capabilities of creating and analyzing geospatial data such as hazard and exposure maps as part of risk assessment (Jha et al, 2012). The spatial tools of GIS also allow urban planners to have an understanding of the spatial distribution of risks in the urban area. The flood probability and flood hazard maps were processed in ILWIS 3.3 Academic (ITC, 2003).

Calculating flood hazard

Logistic regression was employed to predict the occurrence of flooding with height above the channel base. The study used the following logistic regression equation which was derived for the Musengezi basin for predicting the probability of flooding: ((x*-0.95)+2.764)/(1+exp((x*+2.274)) . X is the height above the nearest channel. (Murwira and Murwira, 2005). The equation was typed in the main ILWIS command window. The resultant map shows the spatial distribution of the probability of the occurrence of flooding in the city of Bulawayo (figure 10).

Results

Spatial distribution of the probability of flooding in different areas in the city of Bulawayo

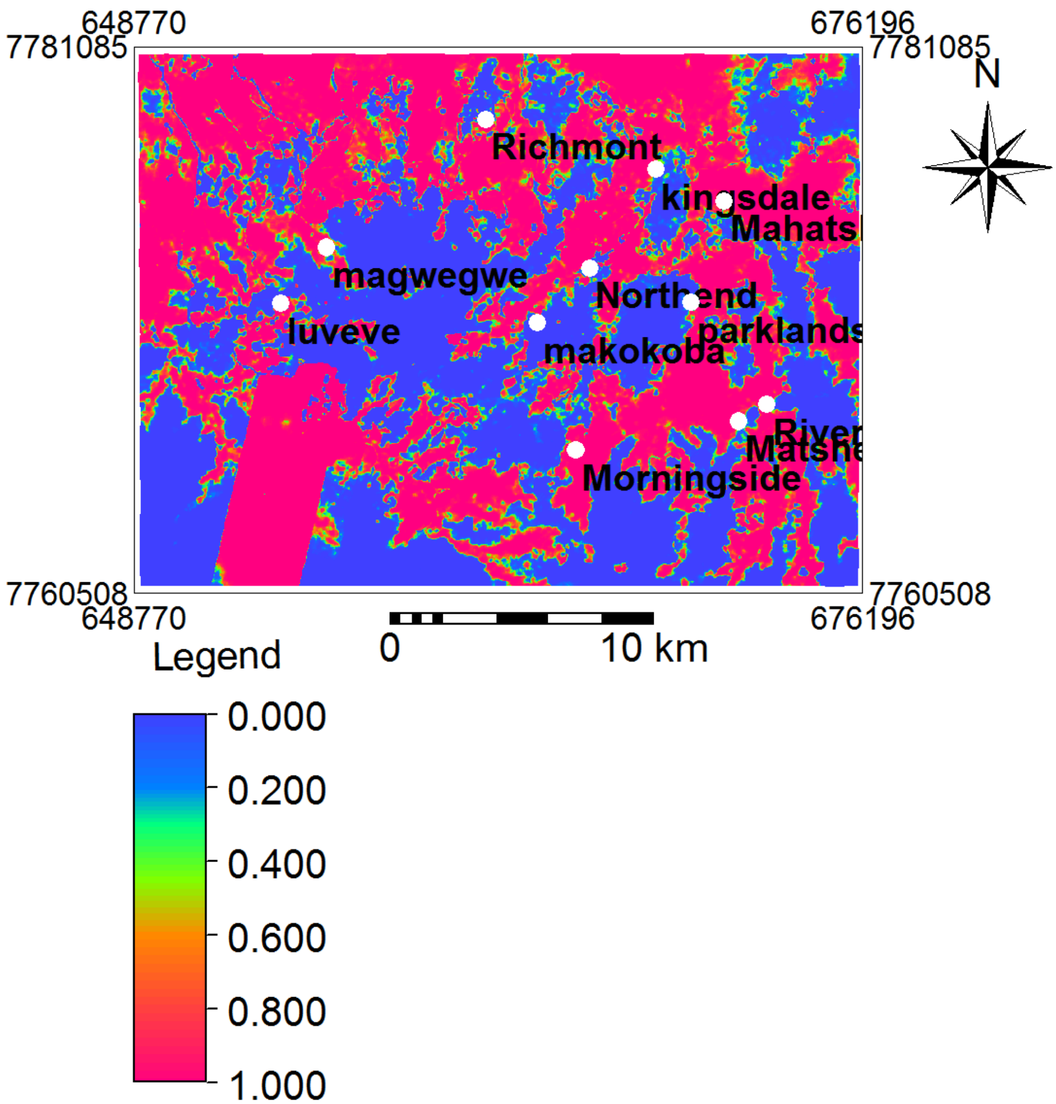

Figure 10 Probability of the occurrence of flooding in areas in Bulawayo

Coordinates are in UTM 35 South

Figure 10 shows the probability of the occurrence of flooding in different areas in the city of Bulawayo. Results (figure 10 indicate that Riverside, Mahatshula and Matsheumhlope are among the suburbs which have the highest probabilities (0.6 -1) of flooding in the city of Bulawayo. Figure 10 also shows that residential areas such as Makokoba, Northend and Parklands are among some of the areas which have low probabilities (0-0.2) of flooding in the city of Bulawayo.

Spatial distribution of flood hazard classes in the city of Bulawayo

The flood hazard map was classified into different hazard classes as follows :<0.25 (low hazard), 0.25-0.50 (moderate hazard), 0.50-0.75 (High hazard),0.75-1 (very high hazard). The classification was adopted from Murwira (2012). This was done in order to identify safe areas and high hazard areas in terms of flooding in the city of Bulawayo. Figure 11 depicts the distribution of flood hazard areas in the city of Bulawayo.

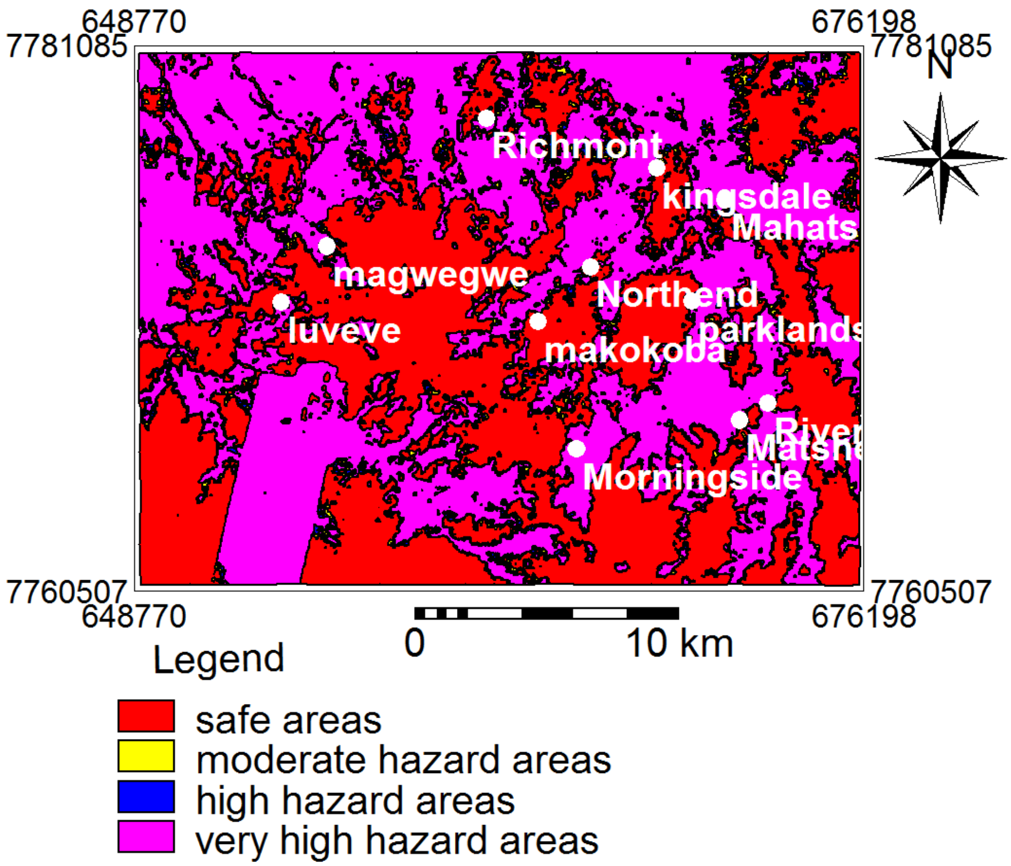

Figure 11 Classified flood hazard map as a function of height above channel in Bulawayo

Coordinates are in UTM 35 South

As shown in figure 11, residential areas such as Makokoba, Parklands, Richmond and Northend are among the flood safe areas in the city of Bulawayo. It can be observed from figure 11 that Matsheumhlope, Riverside and Mahatshula are highly hazardous zones when it comes to flooding.

Figure 12 depicts the location of built up areas in relation to different flood hazard classes.

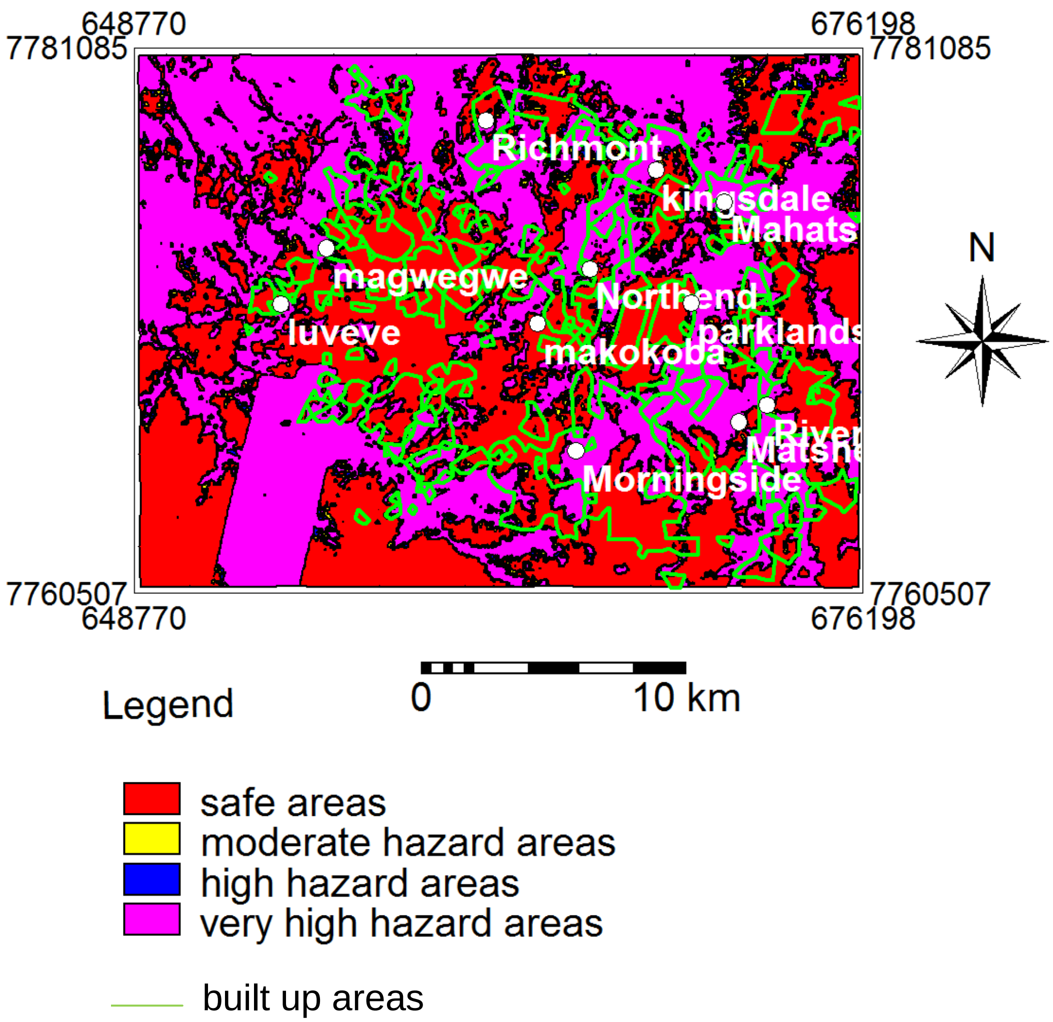

Figure 12 Location of built up areas in relation to flood hazard in the city of Bulawayo

Coordinates are in UTM 35 South

As shown in figure 12, the buildings located in the flood safe areas are at low risk when it comes to flooding. Figure 12 also indicate that the buildings located in high flood hazard zones are at higher risk of flooding. This implies that the buildings located in the residential areas such as Makokoba, Parklands, Richmond and Northend are not at risk of flooding since they are located in flood safe areas. Buildings located in high flood hazardous zones such as Matsheumhlope, Riverside and Mahatshula are at risk when it comes to flooding.

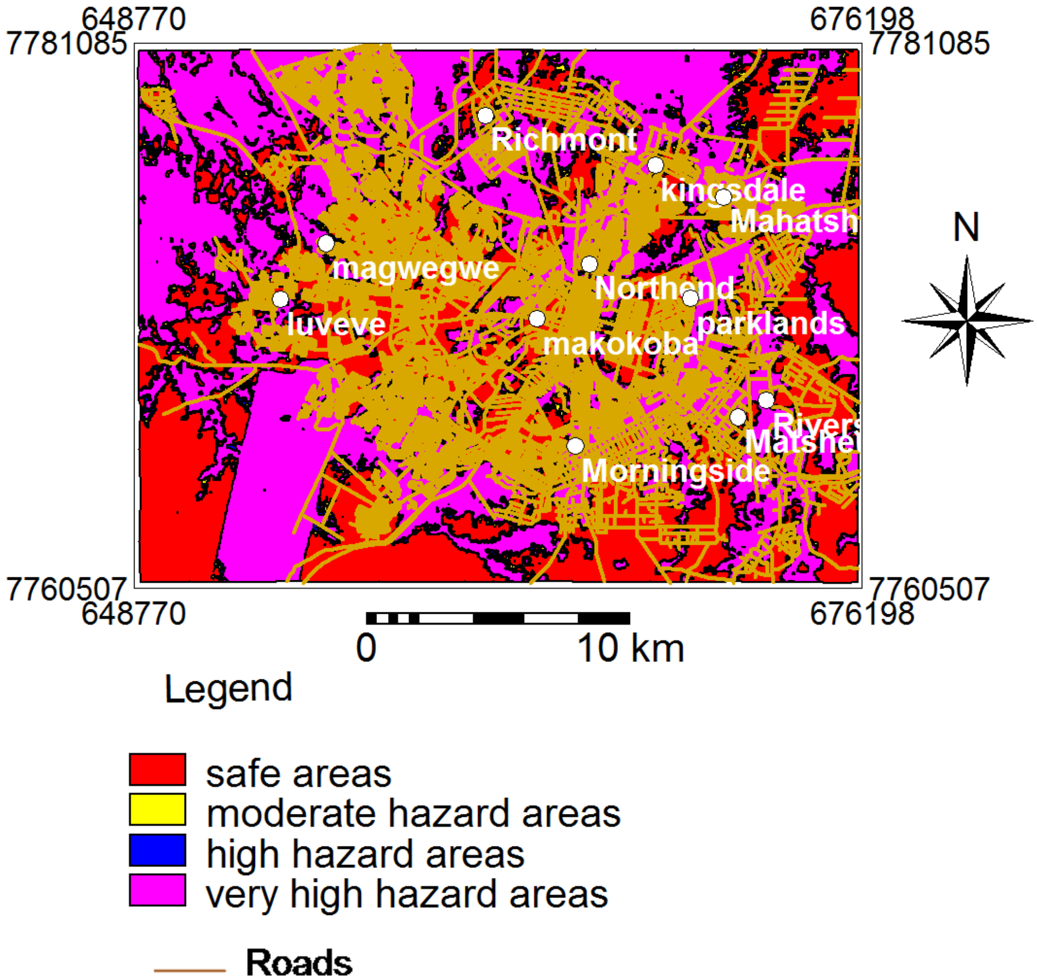

Figure 13 Location of roads in relation to flood hazard in the city of Bulawayo

Coordinates are in UTM 35 South

As shown in figure 13, the roads located in the flood safe areas are at low risk when it comes to flooding. Figure 13 also indicate that the roads located in high flood hazard zones are at higher risk of flooding. This implies that the roads located in the residential areas such as Makokoba, Parklands, Richmond and Northend are not at risk of flooding since they are located in flood safe areas. Roads located in high flood hazardous zones such as Matsheumhlope, Riverside and Mahatshula are at risk of flooding.

Discussion

Results of this study indicated that people and infrastructure in residential areas such as Makokoba, Parklands, Richmond and Northend are not vulnerable to the risk of flooding since they are located in flood safe areas. However, the results showed that infrastructure and people in high flood hazardous zones such as Matsheumhlope, Riverside and Mahatshula are vulnerable to the risk of flooding. So far there is no study that assessed the resilience of the city of Bulawayo to flooding. Hence this has been the first time that flood hazard mapping has been conducted in Bulawayo. Most studies on the assessment of the city`s resilience to flooding has been done in the Pacific countries. This is because the geography and geology of these countries expose to hydro meteorological events such as floods and cyclones. Many countries in the Pacific are located in the tropical cyclone belt (Matsumoto, 2013).

In Zimbabwe, flood hazard risk assessment researches remain largely unexplored as the area was generally perceived to be a safe area in terms of flooding until the cyclone Elline induced floods in 2000-2001 (Pawaringira, 2008). However, most studies on flooding in Zimbabwe were not carried out in the context of urban areas. For instance Murwira and Murwira (2005) developed a flood hazard model for Musengezi basin in Muzarabani. Madamombe (2004) conducted a flood risk assessment in the flood prone areas of Zambezi valley. Rurinda (2006) mapped flood hazard in Chikwarakwara. However, these previous findings were not carried out in the context of urban areas and therefore cannot assist much in understanding the resilience of urban areas to flooding. Therefore, the uniqueness of this research is that it has been the first study to conduct flood risk assessment with the intention of assessing the resilience of the city to flooding.

Conclusions

The general conclusion that can be drawn from this study is that the people and infrastructure in residential areas such as Makokoba, Parklands, Richmond and Northend are not vulnerable to the risk of flooding since they are located in flood safe areas. It can also be conclude that the infrastructure and people in high flood hazardous zones such as Matsheumhlope, Riverside and Mahatshula are vulnerable to the risk of flooding.

Recommendations

This study recommends that there is need to further this study by embarking on a full vulnerability assessment study which should be based upon assessing the ability of the people and infrastructure in proximity to the flood prone areas to copy with the risk. This might involve establishing the level of awareness about flooding as well as the availability of flood warning systems and evacuation measures in all areas which are prone to flooding.

For the city planners in Bulawayo, the following recommendations are critical to improve urban resilience to flood hazards events in the future: There is need to establish early warning systems in high flood hazard risk zones such as Matsheumhlope, Riverside and Mahatshula. It is also crucial to put in place emergency shelter and evacuation routes to improve urban sustainability or the ability of the city to cope with flooding events in the future. The emergency shelters should be established in flood safe areas such as Makokoba, Parklands, Richmond and Northend. The information on the spatial distribution of flood hazard should also be used by planners in siting and designing of infrastructure. For individuals who wish to buy a stand for business or residential purposes, information on the spatial distribution of flood hazard areas in the city is critical as it informs their decisions based on the safe areas and high flood hazard risk areas.

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