

Chapter 22

A Geospatial Analysis of Flood Risks and Vulnerability in Ogun-Osun River Basin, Nigeria

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Abstract The frequency and intensity of flood disasters have become serious issues in the development process as flood disasters have caused serious environmental damage, loss of human lives and wanton destruction of economic assets globally. Loss of human lives and development assets, rising costs of reconstruction efforts and associated hardship are putting the issue of disaster reduction and risk management higher on the policy agenda of affected governments, multilateral agencies and NGOs. The starting point of concrete flood disaster mitigation efforts is to identify the areas with higher risk levels and fashion out appropriate preventive and response mechanisms.

This paper proposes a GIS-based model for identifying flood-prone areas for the purpose of planning for disaster mitigation and preparedness, using a river basin as a unit of analysis. This model uses a number of physical, demographic and landuse data to identify areas and settlements that are vulnerable to flooding. Based on this multi-criteria model, areas, settlements and populations with varying degrees of vulnerability to flooding were identified and mapped. The model results showed that over 1,200 settlements harbouring over 13 million people are at grave risk of flooding. These vulnerable settlements and populations are mostly located within

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the coastal stretch, river valleys and urbanized parts of the study area. While the model proves to be usable for planning purposes, inclusion of population data at a finer level (Enumeration Areas) would improve the performance of this model by providing a near accurate estimation of population at risk as well as their spatial spread.

Keywords Flood • Multi-criteria • Risk • River basin • Vulnerability

22.1 Introduction

Increased fluxes in the global climatic regime have led to a concomitant increase in the frequency and severity of hydro-climatic events, of which flood accounts for more than a half. The rising frequency and severity of flood events and related disasters which are linked to hydro-meteorological changes on one hand and the consequences of human activities on the other hand have put man and the current civilization on the brink. Although, flooding has occurred throughout human history, available statistics shows that the frequency, severity, spatial coverage and level of destruction remain staggering and are on the increase. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) predicts that 'heavy precipitation events, which are very likely to increase in frequency, will augment flood risk' which will affect life and livelihoods in human settlements in all areas, especially in coastal zones, river deltas and mountains (Nicholls et al. 2007).

In spite of the increase in activities targeted at natural disaster reduction in the past decade, losses in assets and human lives resulting from flooding have been on the increase in tandem with increased incidence of flooding. Between 1901 and 2012, a total of 806 major flood events was recorded in Africa with fatality in 24,393 settlements while 56,840,203 people were affected (EM-DAT). These figures exclude a large number of unreported events mostly in remote areas of the continent which were no less devastating as many people were rendered homeless, infrastructure damaged and farmland washed away by floods caused by excessive rainfall and associated dam breaks. Nigeria has had more than her fair share of losses in material and human lives as flooding has become a single most recurrent disaster in the country. In 2012, pervasive flooding of major rivers stemming from concentrated rainfall and persistent release of water from dams claimed over 150 lives, destroyed property worth billions of Naira, disrupted inter- and intra-regional movements, and caused disruptions in the lives of tens of millions of people. The prevalence of poverty and illiteracy and lack of institutional framework have combined to weaken the capacity of people in Sub-Saharan Africa to respond and cope with flood disasters.

The devastation that attends flood events has remained a serious concern to policy makers and the academia alike. Research efforts focusing on different aspects of flood disaster are quite enormous, with many digging into the root, the

impact and various ways of mitigating the occurrence and severity of damage that result from such disasters (Ojo 1991; Ologunorisa 2006). In Nigeria, much research energy has been dissipated on the study of causes and effects of floods within the context of cities (Olaniran 1983; Gobo 1988), since in the view of the researchers, the impact of flooding together with its associated damage is felt more in the urban areas being centres of population and human civilization (Adelekan 2009). However, flood disaster impact is even more severe in the countryside and vulnerabilities are higher among the rural dwellers than their urban counterparts. A dissection of flood related literature in Nigeria shows that majority of the works treated specific flood events (Babatolu 1996; Abams 1995; Ojo 1991; Omuta 1988), their nature and perception (Okechukwu 1983); while others focused on the causal factors such as rainfall fluctuation (Olaniran 1983; Ojo 1991; Ologunorisa 2000), climate change (Adefolalu 2000) as well as risk and vulnerability assessment of different spatial units (Adelekan 2009; Ologunorisa 2006). Despite the copious coverage of the range of issues addressed in these studies and the diverse methodologies applied, there exists a clear lacuna in the methodologies and focus as many of the previous works adopted purely descriptive risk perception techniques often combined with rainfall data to identify places at risk and vulnerable populations. Few (if any) of these studies have tapped into the geospatial capabilities of modern GIS to carry out multi-criteria flood risk and vulnerability assessment.

A number of methods ranging from descriptive to quantitative exist for assessing the level of risk exposure of population to a specific disaster. Previous studies have focused on flooding and its impact on urban dwellers (Adelekan 2009; Maantay and Maroko 2009; Orok 2011). Studies adopting regional approach to flood risk modelling using a GIS-based multi-criteria analysis are scant. Ologunorisa (Ologunorisa 2006) attempted a flood risk assessment using a hydro-climatic method in parts of Niger Delta region of Nigeria. In a similar study, Adelekan (Adelekan 2009) examined the vulnerabilities of urban poor to flood disaster in the coastal city of Lagos employing the integrated assessment framework that includes both natural and human sub-systems interactions. A recent perception study of flood incidence in Lagos using questionnaire survey methods (Aderogba 2012) reported a progressive increase in volume and areas of coverage. (Kolawole et al. 2011) have examined various options available for flood risk mitigation in Ilorin, Nigeria, concluding that assessment of the risk impact of flood will facilitate countries to plan adaptation measures and adapt effectively to flood events. None of these studies employed GIS methods in their estimation of the vulnerability and risk assessments. This study is designed to plug these identified lacunae by attempting a multi-criteria analysis of flood risk and vulnerability, using river basin as a unit of analysis.

The current effort is aimed at bringing conceptual as well as methodological improvement on the existing body of knowledge in the area by expanding the variable that form input to the flood risk model within a regional framework.

22.2 Flood Risk and Vulnerability: Some Conceptual Clarifications

A major challenge in the analysis of risk and vulnerability to disasters is the clarification of concepts which are often used by a wide range of academics, professionals and practitioners. The concepts of hazard, risk exposure and vulnerability are critical to the understanding of regional pattern of vulnerability to flooding in Nigeria and globally.

The concept of hazard in disaster management is used to describe an extreme event with potentially damaging effects if and while it occurs. In other words, hazard can be seen as stressors or perturbations (Turner et al. 2003; Maantay and Maroko 2009). In this wise, a higher than normal rainfall, proximity to a river channel may constitute a flood hazard. According to Jeb and Aggarwal (2008), "Flooding is a general temporary condition of partial or complete inundation of normally dry areas from overflow of inland or tidal waters or from unusual and rapid accumulation or runoff". Natural hazards may produce significantly different impacts on people and places, often depending not only on the severity of the hazards, but also on their biophysical attributes and the socioeconomic characteristics of a locale (Huang et al. 2011).

Vulnerability is conceived as a measure of the degree to which an entity (a population, city, ecosystem etc.) can anticipate, cope with, resist, and recover from the impact of a natural hazard (Maantay and Maroko 2009; Blaikie et al. 1994), or a social response to a biophysical danger within a specific geographic domain (Huang et al. 2011), or within the context of specific human groupings or animal kingdom. But since the geographical domain is made up of both biotic and abiotic components, it may well be apt to focus on the spatial unit in the analysis of risk and vulnerability to flooding which itself is a geographic phenomenon. A regional view of vulnerability therefore focuses not only on the people but also on other elements of the environment such as critical infrastructure, plant and animal species and other elements of the bio-physical environment. Vulnerability is a function of a wide range of factors paramount among which are the frequency and intensity of the stressor (hazard), physical, structural and socio-economic capacity of the people to resist and or cope with the resultant devastation. Of course, the level of vulnerability will vary from one individual or group to another due to variations in the socio-spatial characteristics and the available institutional support system.

Risk is a concept usually defined in relation to disaster to describe future or potential condition which is a function of exposure to natural hazard and the vulnerability of exposed entities in a particular location. It is often interpreted in terms of the total loss and damage in terms of lives, injuries and property incurred in the event of a disaster occurring at any given place and time period (Dolan and Walker 2004). It is important to note the spatio-temporal component of the risk definition. Also, risk perception on the part of individual and communities varies based on their locations and socio-economic conditions and circumstances.

Flood risk assessment is usually carried out by considering the nature, extent and the probability of occurrence of hazard together with factors that predispose a particular individual or community to the hazard. In the context of flood hazard, hazard factors are conceived in terms of the physical characteristics of the stressor (flood) like flood depth, frequency, duration damage, and velocity (Ologunorisa 2006) and vulnerability factors like socioeconomic variables (income, level of education), land use type, proximity to hazard source, building type and material quality, and adequacy of flood damage. Often times, risk perception of the exposed population may form part of the input into risk assessment and analysis. However, risk perception is usually fraught with value judgment and may not reflect actual levels of exposure. Flood risk assessment incorporates meteorological parameters (spatio-temporal distribution of rainfall) that regulate water supply to the earth's surface, hydrological parameters that directly cause inundation and cultural parameters that capture the effect of human activities.

22.3 Material and Methods

This section highlights the type of data used in this study and their sources. It also discusses the various methods employed in data processing and analysis.

22.3.1 Data Types and Processing

The study relies on spatial data obtained from different sources. Elevation data for the region was derived from the STRM data which was downloaded from their website. Digitized drainage, and administrative boundary maps, land use maps alongside the Digital Elevation Model form input into the flood risk analysis. These data are complemented by attribute data like rainfall and population data, obtained mostly from archival sources. Figure 22.1 presents the cartographic model of the data input, analysis and output of the flood risk analysis.

Spatial data from satellite images were georeferenced and existing digital data transformed to the WGS_1984 Projection System. This was done to allow for consistency and avoid representation errors that may arise from differing spatial extent of these data. The attribute were joined to spatial data based on common fields to further improve the usefulness of the spatial data. Specifically, the population and rainfall data which came as tabular data were joined to the administrative boundary data.

The SRTM Digital Elevation Model (DEM) for the study area was downloaded from SRTM website. Rainfall data were obtained for selected stations within the study area and used to produce precipitation map of the study area. The rainfall data were obtained from Nigerian Meteorological Agency. Drainage map of the area was produced from vectorization of the scanned topographical maps of the area and

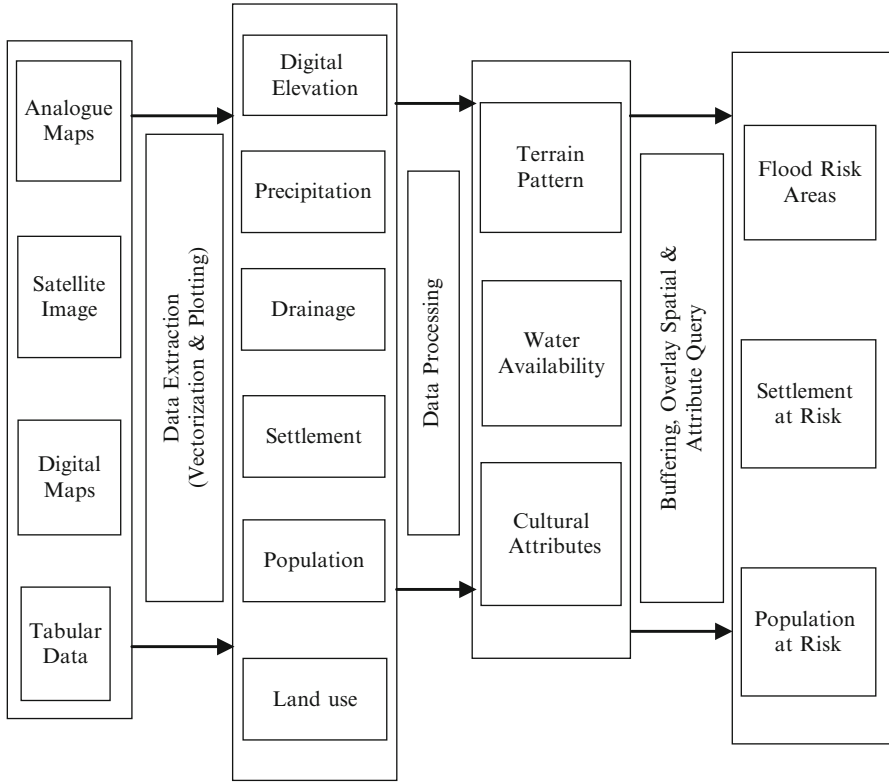


Fig. 22.1 Cartographic model of flood risk analysis

re-projecting the data to WGS_1984. Settlement data were obtained from the Settlement delineation study conducted by the Nigeria Communications Commission conducted in 2005 which remains the most comprehensive settlement data in the country till date. Absence of population figures on a locality basis presented a problem. However, GRUMP population figures raster data were downloaded and used in the study to estimate population under varying degrees of flood risk. Population data were downloaded from Global Rural-Urban Mapping Project, Version 1 (GRUMPv1) (Center for International Earth Science Information Network (CIESIN) 2012). The population raster data have a resolution of 4 km (each cell is a $4 \times 4 \text{ km}^2$). Since this size in the most urbanized area is bigger than the size of an Enumeration Area (EA) in Census data, the accuracy of this data may be slightly lower than what could obtain if EA were used as spatial units for population sampling. Land use data were obtained from digital vector data from FORMECU, a Federal Government Department in charge of forest management. Due to the numerous land uses types used in the original data, the land use types were reclassified into three major types for the purpose of flood risk analysis. These three major classes are urban, agriculture and undisturbed forest.

Table 22.1 Decision variables for flood risk analysis

Variables	High risk	Score	Medium risk	Score	Low risk	Score	Total score
Relief (meters)	≤50	3	50.1–400	2	>400	1	6
Drainage (buffer in meters)	≤100	3	101–1,000	2	>1,000	1	6
Land use types	Urban	3	Agriculture	2	Undisturbed forest	1	6

22.3.2 Data Analysis

The data analysis for this study was essentially carried out within GIS framework, using ESRI's ArcGIS 10.0™. Three major variables were used to determine the risk exposure to flooding in the areas. From literature, it is apparent that relief, hydrology and human activities are risk factors in flooding (Ologunorisa 2006). Each of the three variables was categorized into three major categories—high, medium and low risk factors.

The study area is for the most part a lowland area made up of coastal and flood plain of major rivers. This informed the choice of the decision variables for delineating the area into high-, medium- and low- flood risk areas (Table 22.1). Since the rainfall regime is essentially the same for most parts of the study area, it was excluded from the decision variables. Generally, areas with height less than 50 m were designated as high risk areas; areas with height between 50.1 and 400 m were described as medium risk areas while areas above 400 m are designated as low risk areas. Proximity to river channels is an important variable in this analysis. Distance from rivers and their tributaries were reckoned at 100, 1,000 and 2,000 m, with areas within 100 m of river channels were categorized as high risk areas; areas within 101–1,000 m as medium risk areas and areas located at over 1,000 m to the river channels were described as low risk areas. Based on land use, urbanized areas were designated as high risk land use; cultivated land as medium risk and forested areas as low risk area.

22.3.3 The Study Area: The Ogun-Osun River Basin

The Ogun-Osun River Basin is one of the twelve river basin authorities created as part of the Nigeria's Third National Development Plan in 1977 (Federal Government of Nigeria (FGN) 1975). Located between longitudes 2° 38' and 7° 32' E and latitudes 6° 14' and 9° 25' N, the Ogun-Osun River Basin has an area of 49,580 km² (Fig. 22.2). The area is bounded in the north, east, south and west by Niger River Basin, Benin-Owena River Basin, the Atlantic Ocean and Benin Republic respectively. The drainage is characterized by rivers and streams that mostly flow in a north-south direction, taking their sources from the Western Uplands in the North

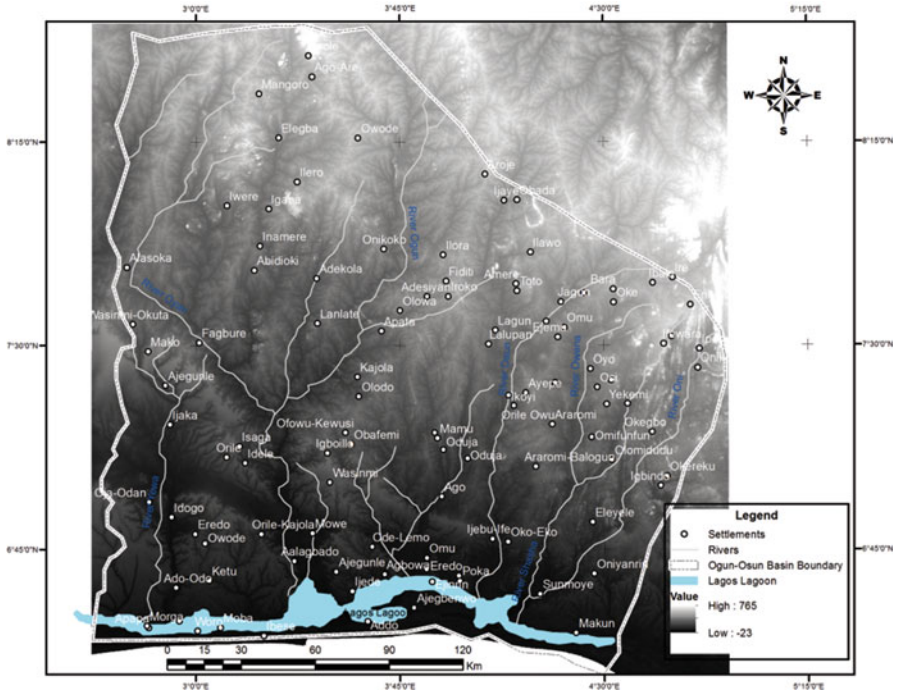


Fig. 22.2 The physiography of Ogun-Osun river basin

and emptying their waters into the Gulf of Guinea in the south via Lagos lagoon. Important rivers include Osun, Ogun, Shasha and Yewa. The climate is wet equatorial climate with annual rainfall ranging between 1,016 mm in the northern part and 2,540 mm per annum in the southern coastal fringe. The concentration of rainfall, mostly from cyclonic sources is responsible for constant inundations of the entire areas during heavy rainfall. This is not helped by the generally low relief which is less than 500 m above the mean sea level. The coastal plain is particularly low in relief with some parts less than 10 m above the mean seal level.

This region has a population of over 20 million people, concentrated in about 26 urban centres and over 9,000 appendage semi-urban and rural enclaves. Invariably, the region is the most urbanized area in Nigeria, with Lagos (largest city) having more than 10 million inhabitants. The significance of the region is also underscored by the concentration of economic activities and infrastructures. The Western Industrial Complex that extends from the coastal areas of Lagos and Ogun to Ibadan accounts for more the 70 % of Nigeria’s industrial output. The region also houses the busiest air and sea ports in the West Africa sub-region. In the hinterland, various agricultural activities ranging from plantation agriculture to arable farming are carried on. In fact, the region is the heart of cocoa and kola nut production in the country. Pastoral nomadism and poultry farming are also part of important

agricultural activities in the region. The region is well served by road and rail transportation.

The presence of thick population, concentration of important national infrastructure and the climatic, topographic and drainage systems that predispose the entire region to flood hazard accord the region a high point on the vulnerability index. Previous flooding events in the area had resulted in significant loss in human lives, extensive damage to national infrastructure and private property while crops and livestock were washed away. Hitherto, there has not been any systematic assessment of the pattern of risk exposure of settlements and populations in this region to the flood hazard.

22.4 Results and Discussions

The purpose of the flood risk analysis conducted was to among other things categorize the areas flood risk into different risk zones and produce classified risk maps based on some selected predefined criteria. Based on this, areas, settlements and population were classified as high risk, medium risk and low risk, depending on their risk ratings. A number of spatial queries were used to generate the areas, settlements and population at varying levels of risk of flood in the study area.

Categorization of areas was achieved by combining all the three parameters used in this study namely height (above mean seal level), proximity to drainage channel and land use type to generate a risk variability surface. Each of these areas were ranked on scale of 1–3 as shown in Table 22.1. The highest score (3) denotes high risk and the lowest (1) indicates low risk. These scores were added together and areas that scored more than 10 on the scale were designated as high risk zones while areas that scored between 8 and 10 were categorized as medium risk area. Any area with less than 8 as the score was categorized as low risk area. Following this procedure, the settlement and population at varying level of flood risk were delineated. The summary of result of land area, settlement and population at risk are shown in Table 22.2.

It is apparent from Table 22.2 that 50,126 km² (79.3 %) of land area is moderately at risk of flooding while a considerable 12,574 km² or 19.9 % of the land area is at high risk of flooding. Only 548 km² of land has a low risk of flooding. Figure 22.3 shows that the areas at high risk of flooding are mostly located in the vast lowland area bordering the Atlantic Ocean. These areas are also the most densely populated areas of the Ogun-Osun River Basin. Areas with medium

Table 22.2 Risk properties of selected phenomena

Parameters at risk	High risk (%)	Medium risk (%)	Lower risk (%)	Total (%)
Land area (km ²)	12,574 (19.8)	50,126 (79.3)	548 (0.9)	63,248 (100)
Settlements	1,256 (12.3)	8,449 (82.6)	518 (5.1)	10,223 (100)
Population	13,233,010 (55.1)	10,773,693 (44.8)	13,219 (0.1)	24,019,922 (100%)

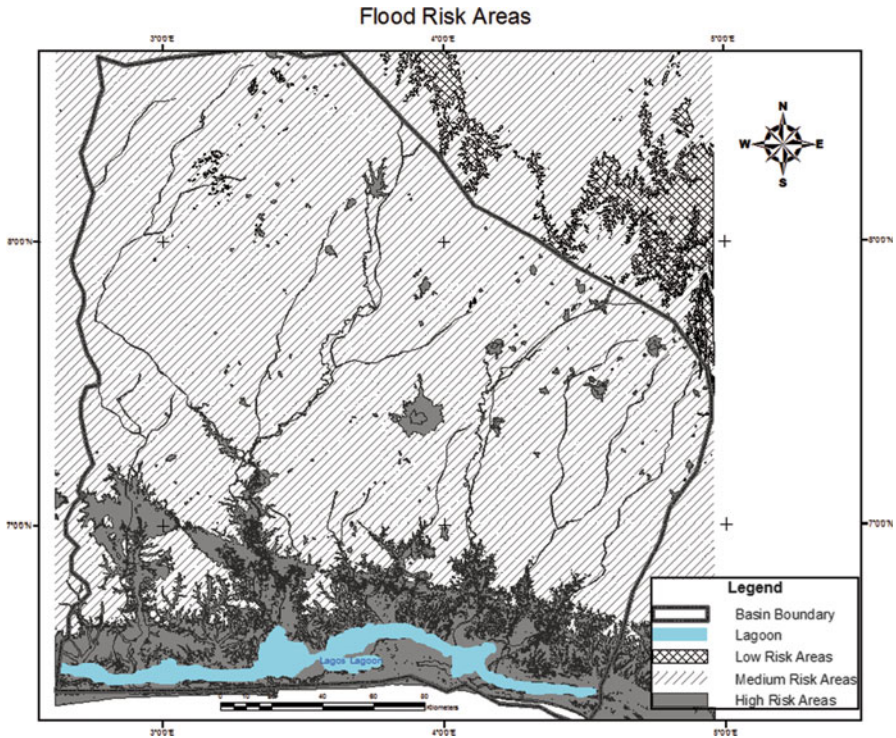


Fig. 22.3 Areas at varying risk of flooding

likelihood of flooding are located in the moderately high ground of the interior. The proportion of settlements at high risk of flooding (1,256 or 12.3 %) is also relatively high compared with 8,449 or 82.6 % of the 10, 223 settlements in the entire area. However, the distribution of land areas and settlements at risk of flooding contrasts with the population. It is evident from the table that the largest proportion of the population in the study area (55.1 %) is located in areas that are considered high risk areas, while 44.8 % is in medium risk zone. Only 13,219 people representing a paltry 0.1 % of the total population are located at the low risk zone.

Figures 22.3, 22.4, and 22.5 show areas, settlements and population at varying levels of risk of flooding respectively. The entire area has a moderate to low relief but the southern part being close to the ocean has lower relief than the northern part. Also, the digital terrain model depicts a wide, gently sloping river valley in the southern end of the basin area [Fig. 22.2] while urban land use is also more widespread and intense along the coastline. These factors combined with high annual rainfall predispose the entire basin area to flood disaster. However, the level of exposure to flood risk is highest along the coastal and flood plains in the extreme southern part with the upper part of the basin having moderate exposure. The coastal plain is exposed to flash flooding due to its low relief, river flooding as a

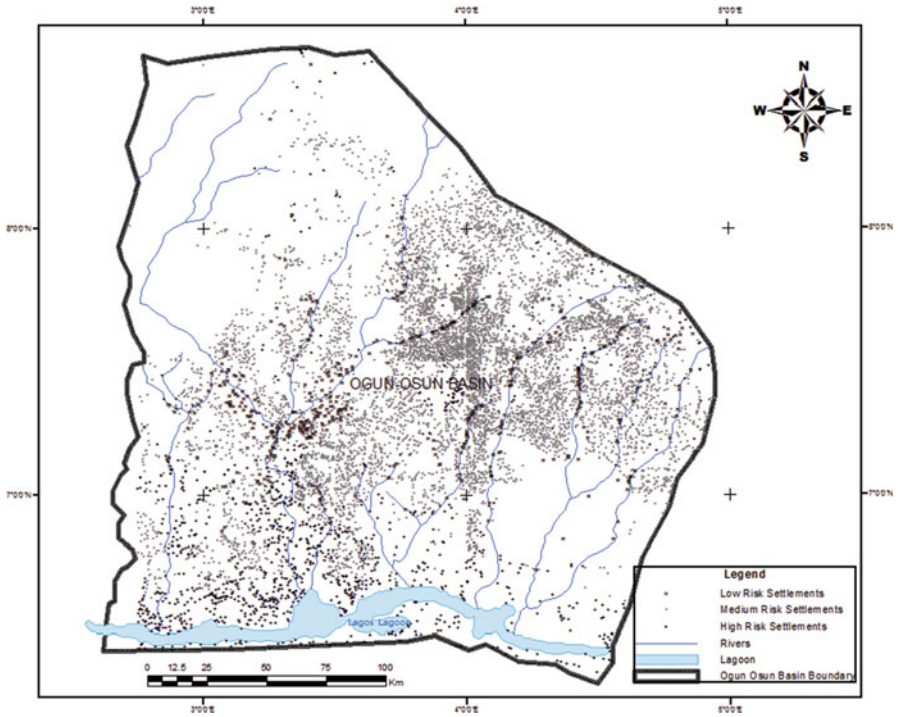


Fig. 22.4 Settlements at risk of flooding

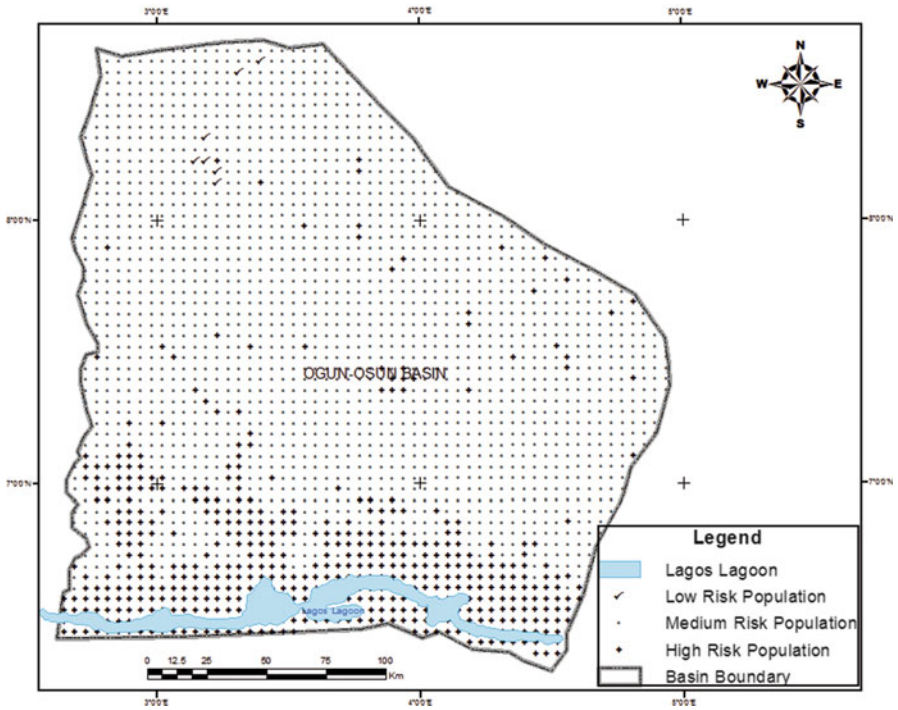


Fig. 22.5 Population at risk of flooding

result of several rivers entering their flood plains and ocean surge from occasional rise in the volume of ocean water. The relief in this upper part is fairly high with narrow river valleys and large expanse of undisturbed forest and cultivated land. As evident in Fig. 22.3, only some small patches of urban land use exhibit a high risk to flood hazard in the study area. Except for some isolated high grounds in the northwestern part of the study area, no part of the study area has a low exposure to the risk of flooding.

The situation is almost the same with settlements at risk of flooding. Most settlements in the basin area have moderate exposure to flood risk. Figure 22.4 shows clearly that virtually all of these settlements are located outside of the coastal area where diverse forces of consistently heavy precipitation and intense human activities combine to increase risk of flooding. In terms of population, the population with high risk of exposure to flooding is more than half of the population. Out of over 24 million inhabitants, over 13 million inhabitants face a high risk of flooding (Table 22.2). These populations are located in the low-lying coastal areas (see Fig. 22.4). The effect of the mega city of Lagos with a population of over ten million people is apparent in this case. Even when the land area and settlement numbers in the high risk zones are smaller than what obtains in the medium risk zones, the population with high risk of flooding is far more than in the medium risk zone. This indeed underscores the need for urgent flood mitigation efforts in the high risk zones since the area is home to some 15 million people, and several billion dollars of critical infrastructure and personal property.

22.5 Conclusion

This study has attempted an assessment of flood risk in Ogun Osun River Basin, which unarguably is the economic nerve centre of the country. The study reveals that low-lying coastal areas are in grave danger of perennial flooding due to its hydro-climatic as well as topographic configurations and human interference. The study estimates that over 1,200 settlements harbouring over 13 million people, mostly in coastal areas, are at grave risk of flooding. Incidentally, this high risk coastal stretch is the most urbanised in the basin area and is home to about two thirds of the population and more than 80 % of the economic wealth. It is therefore imperative that policies aimed at mitigating the effect of flooding be strictly implemented in order to forestall losses in human lives and material possession.

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