Chapter

Flood Risk Analysis for Critical Infrastructure Protection: Issues and Opportunities in Less Developed Societies

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Abstract

This chapter presents all-important discussions relating to flood risk analysis which arguably is a subject of overwhelming significance within the context of less developed societies, for example Nigeria. Whilst a possible means of eradicating flooding from human environment is inconceivable, debates for more effective flood risk reduction methodologies for critical infrastructure protection must continue. Increased population and urbanisation scenarios drive worsened flood risk which trigger increased efforts for corporate adaptability to flooding. To ensure that social systems can cope with floods, it is important to investigate why best practices in flood risk reduction are not fully applicable. This chapter explores these issues drawing from extant dialogues on flood risk management (FRM). Arguably, the current flood modelling techniques and assessment of vulnerability operations largely do not support a realistic analysis of flood risk. Funnelled through an interpretative research paradigm, the chapter conceives that these limitations fall under five cardinal issues – (1) data, (2) theories and concepts, (3) existing flood risk analyses methods, (4) legislation and policy, and (5) sustainable development. It argues that the realisation of a more effective flood risk reduction for the poorer and less developed societies will depend on effective tackling of these issues which creates opportunities for flood risk analyses through simplified approaches, and use of free and open geospatial data infrastructure.

Keywords: flooding, flood risk analyses, less developed societies, urbanisation, flood risk management, flood modelling, vulnerability assessment

1. Introduction

The widespread flooding in recent times, the reduction of its impacts on human populations, properties and economic activities and the impracticability of its eradication from natural environment are factors of global concerns [1–4]. In the developing countries (DCs) such as Nigeria, there is evidence to suggest that the thought of the next flooding event appears to apprehend many local communities, urban residents and authorities' hierarchy [5]. Arguably, this reality suggests among other interesting discourse, that the recognition of flooding impacts and the curiosity they drive in human populations are fundamental towards finding realistic solutions to the hazard. Worthy of note within this context is the damage

potential of flooding which is debatably unprecedented when compared to other known environmental hazards occurring within natural human environment in recent times [6, 7]. Whilst the failure and/or limitation of efforts to tackle flooding are issues in the DCs that clearly require urgent attention [8, 9], the need for sustainable development which underpins adaptability and collective resilience of the general public to flooding cannot be disregarded [10, 11].

The interplay between causes, impacts and remedies of flooding phenomenon highlights the situation in the less developed societies in respect of flooding and the risk it poses. This chapter focuses on the Lagos metropolis of Nigeria in West Africa. Under the quandary of rapid population increase and urbanization, it appears the conurbation has been subject to critical and disturbing scenarios. The idea that population growth will compel worsened future flood risk highlights the need to engage with more proactive measures of tackling flooding and more importantly more effective means of building the capacities of human population to cope with floods [11, 12]. However, present efforts at addressing the challenges of flooding in the Lagos area are flawed [13, 14]. Whilst the area signifies the economic and industrial hub of Nigeria and attracts tourists from within the country and abroad, responses to security challenges, poor corporate adaptation and resilience to flooding among other besetting environmental hazards is inadequate [15, 16]. Existing knowledge regarding particularly to the state of affairs of flooding in Lagos is unsatisfactory and falls short of solutions to the impacts of the hazard on human populations and has been unable to support sustainable development within the region [14, 17].

Within these contexts, it is imperative that the critical factors which undermine efforts at tackling flooding in Lagos as well as gaps in knowledge among other considerations which can be associated with increasing flood risk generally are identified. Thus, the need to support present efforts at tackling flooding in the Lagos region and to advance existing knowledge relating to flood risk reduction in the area motivate the debates in this chapter which considers a triplet of objectives: firstly, to summarise the widespread flooding in the Lagos metropolis of Nigeria, secondly, to summarise the current efforts towards tackling the hazard in Lagos and to identify key limitations and gaps in knowledge and practice, and finally, whilst the author argues that inadequate flood modelling in the area and limited application and scope of assessment of vulnerability to flooding undermine the success of current efforts to tackling flooding, why more of such investigations are needed is presented along with the possible challenges facing their applications in Lagos, Nigeria. It equally presents the prospects for flood risk analyses through simplified approaches and open geospatial data.

2. Widespread flooding in Lagos Nigeria

Past and present flooding in Lagos Nigeria, highlight the influence of climate change, rapid population growth and urbanization on the local hydrology of the region [18–20]. First and foremost, the Lagos metropolis consists of 16 local government areas (LGAs) of varying spatial enumeration units (the largest being about 194 km^2) (see **Table 1** and **Figure 1**). The total land mass of the conurbation exceeds 1100 km^2. Based on the state government's statistics [22], up to 21 million people reside in the area and this creates a yawning dimension of adverse social and environmental condition mostly overcrowding and slum development. The lack of space for a myriad of anthropogenic activities forces development of flood prone areas thus instigating a severe vulnerability to flooding for those inhabitants who lack social capacities to cope with the hazard. The abundance of impervious surfaces

S/no.	LGAs	Land area (km^2)
1	Agege	11.263
2	Ajeromi-Ifeledun	12.395
3	Alimosho	186.195
4	Amuwo-Odofin	135.240
5	Apapa	26.798
6	Eti-osa	193.460
7	Ifako-Ijaiye	26.769
8	Ikeja	46.427
9	Kosofe	81.889
10	Logos-island	8.707
11	Lagos-mainland	19.572
12	Mushin	17.576
13	Ojo	158.884
14	Oshodi-Isolo	44.999
15	Shomolu	11.615
16	Surulere	23.122

Table 1.
16 local government areas and their spatial units in the Lagos metropolis of Nigeria. Source: Adapted from [21].

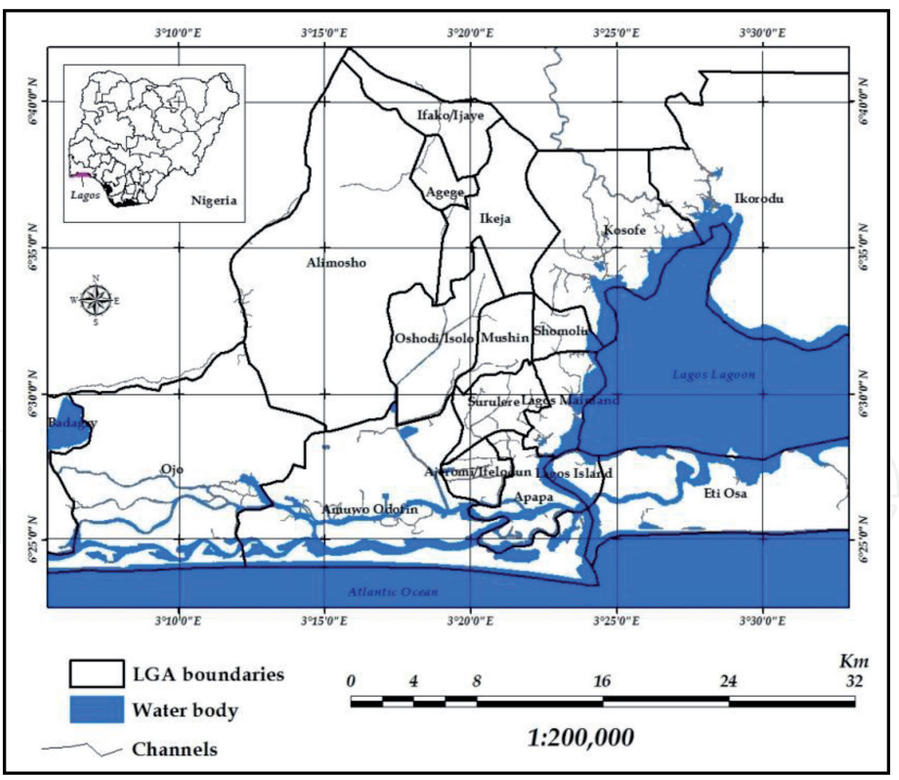

Figure 1.
The Lagos metropolis of Nigeria. Inset showing the location of Lagos State in Nigeria. Source: Drafted by authors.

in the area which generally causes increased surface water runoff and reduced soil infiltration highlights the impediments of poor urban drainage system [23].

Following the overview of Lagos metropolis presented in the preceding paragraph, a clearer picture of the devastating effects of flooding in the area can be

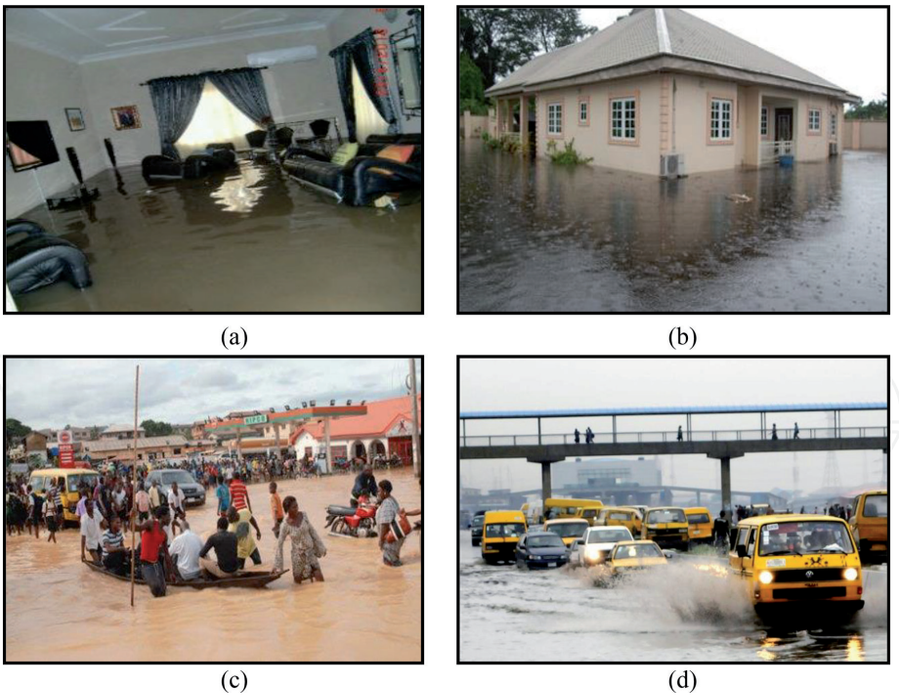

Figure 2.
Examples of flooding scenes in the Lagos metropolis of Nigeria: (a) living room submerged by flood water, (b) residential building submerged, (c) local community affected by flood waters, and (d) expressway overwhelmed by flood water. Source: Online images of flooding in Lagos, Nigeria.

appreciated. Typically, the hazard which has been generally attributed to climate change and poor urban planning affects hundreds of thousands of people (mostly through homelessness, physical injuries, mortality, spread of diseases and emotional trauma), destroys chains of urban infrastructure and disrupts economic activities [14, 24]. Fiscal losses caused by the hazard in the area amount to millions of US dollars [25]. Although fluvial and coastal flooding occurred in the early days of flooding – i.e. in the early 1960s – pluvial floods resulting from prolonged rainfall which overwhelms urban drainage facilities and soil infiltration capacity are now more widespread. Such floods usually recur annually between the months of March and October (but usually more severe in July) with considerable environmental and socio-economic impacts [26]. These floods which have triggered concerns for environmental mismanagement, urgent humanitarian needs and services, primary health delivery, solid waste management, urban development and governance, and the resilience of the general public within the area are claimed to be more severe for Lagos Island, Apapa, Ikeja, Mushin, Surulere and parts of Ikorodu [16, 26–29]. The magnitude of flooding experience in the Lagos region of Nigeria is highlighted in **Figure 2(a-d)** below. A typical example of flooding event in Lagos is the July 2011 flooding, caused by a heavy rainfall that lasted 17 hours. The flood affected more than 10 thousand people with deaths exceeding 100 and a range of damage including public infrastructure such as roads, bridges and schools. Houses were submerged by flood water while lots of properties including vehicles were destroyed due to the intensity of the flood. An estimated economic loss of about 50 billion Naira ($US 320 million) was incurred [30].

3. Summary of current efforts towards tackling flooding in Lagos

For appraisal of current approaches to flood risk management in Lagos city by public and private sectors and the implications of such approaches within the

context of global flood risk management practices, refer to Adelekan [31]. Flooding and the means of tackling its risk in the Lagos metropolis of Nigeria have received considerable attention in the literature since the last two decades, and this arguably demonstrates commitment on the part of the Lagos state government and various stake holders. Some of the ongoing practices as argued by Oshodi [32] include: expansion of drainage infrastructure within the city heartland, annual debris removal from principal drainage facilities within the city heartland, recommendation and resettlement of the dwellers of flood plains and wetlands and the residents of Ogun river catchment areas, demolition of homes in the flood prone areas. Several flood preventive and curative initiatives ranging from community self-assistance actions to World Bank assisted programmes were identified in Odunuga [26]. Recently, key initiatives which include the Drain Dock and The Emergency Flood Abatement Gang (EFAG) were launched by the government of Lagos state to improve current efforts towards addressing the challenges of flooding. Action by the ministries of Environment, Works and Health as well as the Lagos Metropolitan Development and Governance Project (LMDGP) towards controlling flood hazard in the area including waste management programme, shoreline protection, low carbon emission, school advocacy programme and climate change club are acknowledged [14].

It can be shown that how to promote sustainable drainage infrastructure and sustainable access to basic urban services for urban residents and the general public are a top priority. Lagos state emerged as the first in Nigeria to carry out a detailed topographic mapping of the area with LiDAR (Light detection and ranging) data acquisition and GIS based analysis aimed at addressing the challenges of flooding. Although it is claimed that these measures have been preventive in context, they are unprecedented in Nigeria and clearly demonstrate practical commitment to fighting flooding [33, 34]. However, in the light of 'best practices' in flood risk reduction and 'lessons learned' from other countries' experiences of flooding, it can be argued that such measures are at best limited. Although the lack of data, lack of funds and improved technology as well as poor political will have been implicated [23, 35], flood modelling which is needed to systematically tackle flooding within the context of flood risk/hazard mapping and provision of flood data for improving the perception of flooding among the general public and to support other non-structural approaches to flood risk reduction seems to have been ignored.

4. Flood modelling and assessment of vulnerability to flooding for the Lagos metropolis of Nigeria

Flood risk reduction is fundamentally a knowledge-driven ideology that shapes the pathway towards living with floods. Key knowledge that drives this idea is often based on flood risk/hazard maps, public opinions and specialist judgement on flooding. Within this perspective, flood modelling which predicts flood data (mainly flood water depth, duration and extent, as well as depth-averaged velocities) essentially needed for flood risk/hazard analyses, mapping and assessment plays significant roles [36, 37]. Conceptually, flood modelling may be perceived as a scientific technique that numerically or analytically solves relevant governing mathematical equations and generates computer algorithms and codes for fast, continuous and routine simulation of flood data [9]. Quick, continuous and routine provisions of flood data appear to undermine ground survey methods and remote sensing technologies, thus most evidently highlighting the relevance of flood modelling.

For the Lagos area, besides the importance of quick, continuous and routine provision of flood data, it is pertinent to realize the specific roles which flood modelling can play towards flood risk reduction and these includes: (1) to align the goals of flood risk management in the Lagos areas with the objectives of such roles in other places such as the United States, United Kingdom and the Netherlands, (2) to pave the way for overcoming the various hassles associated with flood modelling generally such as computation complexity and model instability/conditional stability, (3) to strengthen the means of improving flood awareness among urban residents and other stake holders through flood risk/hazard mapping, and (4) to combine with vulnerability assessment in order to build the capacity of a wider population to cope with floods.

Vulnerability is clearly a relevant concept in disaster/risk management and it suggests the propensity to which a system, subsystem or systems component can be adversely affected by a stressor [38]. System, subsystem or systems component refer to human populations and/or critical infrastructure that appear to be in harm's way during flood hazard occurrence which is the reason why exposure, sensitivity and adaptive capacity are often considered in the course of analysing vulnerability [38, 39]. In the Lagos metropolis of Nigeria, the issue of vulnerability to flooding is critical given that urbanization and rapid population growth which both trigger and increase slum development and development on flood prone areas [40]. However, this odd scenario has not been sufficiently tackled with adequate knowledge of vulnerabilities of social systems to flooding and the factors that influence such vulnerabilities. Few studies that considered vulnerability to flooding in Lagos are limited in scope, constrained by paucity of quality data and narrowed discussions down to small areas [15, 16, 41, 42]. It can be shown that results obtained from analysing vulnerability to flooding at such small scales cannot be generalized for the Lagos area [43].

5. The challenges of flood modelling and vulnerability assessment in the Lagos metropolis of Nigeria

Given the general merits of flood modelling and assessment of vulnerability to flooding and the specific roles they can play towards flood risk reduction in the Lagos metropolis of Nigeria (refer to [42]), it is important to identify the factors that potentially constrain their application. In view of this, the author conceived and discuss the following issues:

5.1 Issues on data

The fact that flood modelling and assessment of vulnerability to flooding require sufficient and accurate data to implement suggests paucity of data as mostly constraining such operations. For the Lagos area, it can be argued that issues relating to relevant data can be likened to a total mirage ranging from abject paucity, inaccuracy and limited access. A typical example is demography for which two key sources (2006 National Population Census and Lagos State Digest of Statistics) quoted different figures representing the Lagos region. Equally complicating is media reporting which has been inconsistent in many instances [44]. Although high resolution LiDAR data is now available for the area, access to the dataset for flood modelling and assessment of vulnerability is been constrained by cost.

5.2 Issues on theories and concepts

Flood risk reduction is a key concern for major environmental research themes (for example Climate Change Adaptation (CCA) and Disaster Risk Reduction (DRA)) which promote the development of integrated methodologies subject to living with floods rather than fighting them [45, 46]. Invariably, such methodologies seem to require in-depth understanding of the drivers of flood risk while their practicability appears to suit ideal situation favoured by easy access to relevant datasets and technical requirements. However, these methodologies often lack sufficient flexibilities for application to external case studies such as the DCs. To circumvent such methodology inflexibility, it is imperative that new methodologies are developed. For the Lagos area, it can be argued that the development of new methodologies with sufficient capacity to support assessment of vulnerability to flooding and flood modelling can be easily undermined by the underlying concepts and theories which are generally inductive based on ontological perspective.

5.3 Issues on existing methodologies

Expectations are increasing for more efficient methodologies with regards to tackling flooding and the risks it poses [47]. Based on this, improving on the functionality of existing methodology has become a popular hypothesis recently. Whilst this assumption has been affirmed in many cases, intuitively, an important concept such as flood modelling underlines the need to understand the basic components that limits existing methodologies [48, 49]. Within the context of flood modelling, existing methodologies (especially for the physically based numerical flood models) lead to models that are computationally expensive, often unstable/conditionally stable requiring a certain CFL condition (Courant-Freidrichs-Lewy condition), which prescribes small time steps leading to high computation burden. Besides, some of these models lack extensive calibration due to insensitivity to certain parameterisation. For the Lagos metropolis of Nigeria, it is argued that the means to overcome these challenges present a critical consideration which undermines flood modelling in the area, although the Lack of funds to acquire commercial codes along with their technical assistance can also have a resistive impact on flood modelling [9].

5.4 Issues on legislation and policy

Flood risk reduction within the context of living with floods is strengthened by robust legislation towards environmental management, intensive research and adaptation of human population to the hazard. Nigeria among many DCs is characterized by weak legislation towards hazard management [50]. This arguably impacts negatively on the inclusion of more robust approaches such as flood modelling and assessment of vulnerability to tackling flooding and the challenges it poses. As argued by Oshodi [32], due to the weak legislation and poorly implemented policies regarding hazard risk and environmental sustainability in the Lagos area, full preparedness to deal with the challenges of flooding is uncertain.

5.5 Issues on sustainable development

Flood modelling and assessment of vulnerability to flooding required to effectively tackle flooding underpin sustainable development [11]. Within the context of sustainable development, every society aspires towards meeting human development goals while sustaining the ability of natural systems to continue to provide

the natural resources and ecosystem services upon which the economy and society depend [51, 52]. Despite much attention which it has received, sustainable development in the DCs remains uncertain and almost unrealistic due to a number of factors for examples: gender inequality, poverty, weak legislative impetus, governance and political will, sluggish judicial administration and access to justice, corruption, asymmetric corporate social irresponsibility and poor access to information, and technical knowledge [53, 54]. For the Lagos area of Nigeria, poor public participation in planning, capacity building, and integration of information technology into planning practice are key factors that constrain sustainable development [55]. Poor public participation can be revealed mainly in the poor awareness of flooding among the wider public, and lack of compliance to environmental laws. To investigate the vulnerability to flooding of social systems for example, relevant information is often derived from public survey and responses to questionnaire. Arguably, inaccurate or uncorrelated responses from questionnaires which jeopardize the outcomes of such investigations can result from poor awareness of flooding.

6. Opportunities for flood risk analyses through simplified approaches and free and open geospatial data in the less developed societies

Kovacs *et al.* [56] compiled a French technical report of several simplified approaches to flood risk analyses in the developing countries. These techniques are simplified in theory and often require utilise freely available datasets for flood risk analyses and protection of critical infrastructure in the less developed societies. Several other attempts have been made in the literature. The prospects within these simple techniques to enable stakeholders lessen the threats of flooding on critical infrastructure and sustainable development are significant. Hammond *et al.* [57] developed a modified Drivers-Pressures-State-Impact-Response (DPSIR) framework which enables policy makers to evaluate strategies for improving flood resilience in cities. Nkwunonwo *et al.* [49] proposed the new scheme, *GFSP-1,* to model urban flooding using a minimum of data. The model which was implemented in a MATLAB environment was tested using the flooding event of year 2000 in Portsmouth, UK, and later used to simulated the historic flooding of year 2011 in the Lagos area of Nigeria. See *et al.* [58] utilised an open data approach which includes open street map and field paper to map urban drainage infrastructure in the Philippines. Results emerging from these simplified approaches correlate positively with real life data, and have been effective in assessing flood risk and vulnerabilities, and providing realistic feedbacks to stake holders.

The major weakness in these simplified approaches is the lead time in moving towards an integrated flood risk management. This is because of many assumptions made to actualise data fitting in the simple methods, and the inability of the simple techniques to capture all the physical parameters and nexus around the variables that motivate flooding within catchment area. This increases epistemic and aleatory uncertainty, and makes it hard to generalise the methods towards a more effective stimulus in flood risk management. Flood risk is an aggregate of multiple factors – hazard, exposure and vulnerability – drawing from Crichton's risk triangle [59]. Land use analyses and flood modelling are able to evaluate the magnitude of exposure and flood hazard (depth and extent along with velocity of flood water) [9, 60, 61]. Vulnerability is a bit more practical because of its conceptualization and theories that underpin its analyses. In the current literature, flood vulnerability is a measure of elements at risk of flooding because they lack coping capacity or any form of adaptive mechanism. It is an ideal science culture to includes community participation in analysing flood vulnerability. This is

standard technique in the developed societies, and few authors have discussed its application in the Lagos area of Nigeria. Although, data paucity and challenges adapting existing methodologies to new case studies often stand in the way of an ideal vulnerability analyses, participatory approaches for collecting informal knowledge on exposed elements and vulnerabilities from the population and local actors is invaluable towards assessment of vulnerability to flooding. Douglas *et al.* [19] Adelekan [13, 15], and Salami *et al.* [62] used this approach in the Lagos area of Nigeria, and the result have been fundamental to decision support in flood risk management within the area.

One clear insight into stare-of art methodologies for vulnerability assessment is the importance of indicators as proxies to vulnerability variables. Several studies have applied this method for examples Müller *et al.* [63] and Tapia *et al.* [64] and the outcomes demonstrate how the various types of vulnerability – physical, economic and social – not only relate to various dimensions of the society, but also varies according to the complexity and main determinants of sustainable development. This understanding plays important roles in protecting critical infrastructure from flooding, bearing in mind the question of what makes a critical infrastructure vulnerable? For example, social vulnerability is based on social factor such as age, gender, socio-economic status [65], an idea which Nkwunonwo [41] applied, using demographic distribution from Nigeria's 2006 census to assess the social vulnerability of Lagos to urban flooding. Indicator-based vulnerability analyses is often complicated by the lack of method to measure a particular indicator. In such a situation, expert elicitation based on observed vulnerabilities and impacts following a previous catastrophic event can been used for vulnerability assessment and modelling. This is a simple approach that serves the purpose and addresses the gap in flood risk assessment in developing societies.

7. Conclusion

Flooding experiences in the Lagos metropolis of Nigeria are overwhelming and has remained an issue of incessant debate. Although there are present efforts at tackling the hazard, success so far has arguably been limited and ample discussion regarding this condition are critical. Whilst flooding is generally accepted as an inevitable phenomenon in present day environment, reducing its impacts on people and the environment is a significant priority for many regional and international flood management initiatives and directives [3, 66]. To achieve the sole aim of flood risk reduction which is "living with floods rather than fighting them", flood modelling and assessment of vulnerability to flooding are fundamental operations and have been applied in many developed countries such as the United States, United Kingdom and Netherlands [67]. However, for the Lagos metropolis of Nigeria, flood modelling and assessment of vulnerability to flooding have been skimped.

As a critical focus, this chapter makes attempts to bridge the gaps in knowledge and practice of flood risk reduction in the Lagos area and investigates the key reason why these approaches were skimped in the Lagos area. It is argued that unless these critical issues such as limitation in data, legislation and policy and mismatch in sustainable development, the application of flood modelling and assessment of vulnerability to flooding in the Lagos metropolis of Nigeria will remain unrealistic. Moreover, simplified approaches and freely available and open source datasets create opportunities to undertake flood risk assessment despite the issues that cause severe limitations. Research is needed to provide bespoke methodologies that will take advantage of these resources to provide workable feedbacks to stake holders and flood risk management policy males.

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