

Flood Disaster Risk Assessment Based on Fuzzy Information Optimization Method in Limbe Town, Cameroon

Tchoudjin Tchagna Abdou Franklin

College of Economics And Management, Taiyuan University of Technology, china.

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Abstract— Cameroon like many other countries is a victim of the negative externalities of flood disaster. The alarming record register by the report of the international Emergency disaster database discloses the undesirable consequences of natural disaster on the economy of the country. Flood risk has escalated in Limbe Town as a result of the rising, industrial development, and urbanization. Although there has been a substantial rise in flood risk assessment studies in Limbe, there still exist problem as to what concern flood risk assessment in the city of Limbe. Due to these issues, we gathered and analyzed flood damage data from the Limbe urban council disaster database from 1990 to 2018 to determine the flood risk in different Limbe neighborhoods. To evaluate disaster data, the study proposes a new method called fuzzy information optimization. Our results demonstrate that Down Beach, Church Street, and Mile two localities located at the south of Limbe are the most vulnerable areas, with the highest risk of flood, followed by New town, Clerk's quarter, Njengelle Quarters, and Gardenswhile limbe camp, Bota, and mile one have the lowest flood risk. The fuzzy information optimization approach makes risk information available to decision-makers and planners, allowing them to identify areas as high-risk flood, moderate-risk flood, or low-risk flood, and implement flood risk management at the national and local levels. The first tool used to assess flood disaster risk in Limbe was fuzzy information optimization, which can also be used to assess flood disaster risk in other countries and regions.

I. INTRODUCTION

The earth's surface is referred to as a planet of life due to its infinite flora and fauna, the latter is also seen as a fertile environment of natural calamity, broadly known as natural disaster and natural hazard. According to (Petrucci, 2012) There is a difference between a natural hazard and a natural disaster. Meanwhile the former can be due to a geographical, atmospheric, and hydrological occasion, which can take the form of a tsunami, landslide, windstorm, earthquake, flood, or drought, which have the possibility of causing injuries or damages. The latter is the occurrence of a catastrophic incident that has a detrimental effect on society, causing destruction, chaos, and casualties, and has

the potential to place the affected zone in a dire situation, forcing her to rely on external assistance to work properly. Also, from the aforementioned mentioned forms of natural disaster, (Chen, Zhou, Zhang, Du, & Zhou, 2015) consider flooding as the most dangerous due to its capacity of causing great loss in terms of human life and properties leading to a drastic effect on the economy. Following the finding of the author, According to the International Emergency Disaster Database, there were nearly 12547 natural disasters worldwide between 1900 and 2017, resulting in 22,989,400 deaths. Couple with an economic loss estimated at 290.28 billions Dollar. Likewise, among these disasters, flood disasters rank top, leading to

numerous deaths and loss of properties in the society, as an illustration, in 2001, due to heavy rainfall. The City of Limbe in Cameroon led to a combination of flood and landslide causing more than 32 landslides scar, several tensional cracks, 154 houses were destroyed rendering nearly 233 people homeless, 93 people dead and About 197 people registered related to post-illness and wound at the Limbe District Hospital alone (Ndille & Belle, 2014). Likewise Flooding is caused by groundwater levels, hill slide runoff from sudden storms, and river flooding. (Saral, Özcan, & Musaoglu, 2010). Extreme rainfall events combined with rising sea levels, as a result of climate change, are likely to increase the frequency and intensity of flood disaster damage. Furthermore, global flood exposure is expected to triple by 2050, owing to rising population and economic assets in flood-prone zones, which are typically seen as economically desirable areas due to their developed nature.(Jongman, Ward, & Aerts, 2012). Regardless of the huge investment in the riverine and coastal areas, faced with flood disasters, this seems very inadequate(Bubeck, Botzen, Kreibich, Aerts, & Sciences, 2012). no matter the spatial policies planning set to mitigate flood risk, this situation is also worsened by the settlement of people near flood-prone areas like low-lying areas and coastal areas(Aerts, Barnard, et al., 2018).Flood risk assessment is the calculation of the overall adverse effects of flooding for a specific region, according to (Tingsanchai and Karim, 2015). It is affected by a variety of factors, including the depth of flooding, the length of flooding, the velocity of flood waves, and the rate at which water levels rise. Many African countries are prone to natural hazards, Cameroon as well is not an exception to this, worsened by the vulnerability of its rising population, resulting in the regular disaster which has a severe incidence on the economic aspect of the country. yet, Cameroon face great constraint in the implementation of the Kyoto 2005-2015 framework and that of the current Sendai framework recommendation of 2015-2030, which has as aims to mutilate natural and manmade disaster(Bang, Miles, & Gordon, 2019).

As mentioned by(Saleth & Dinar, 2004), we can underline that countries that are bounded by water bodies are fertile lands for flood disaster risk, and Cameroon is not an exception. Flood disaster risk is determined by a combination of two factors: danger and vulnerability.The

land and its uses are determined by flood hazards expressed as vulnerability. As a result, in less populated urban areas, the effects of this phenomenon can cause less damage.In urban areas, flood risks are evaluated more than in rural areas. As in urban areas, flood hazards lead to the destruction of buildings, equipment, roads, houses, and track. In Cameroon, the flood hazard record dated in 1980, and since then the country has witnessed a drastic series of flood hazards(Tchindjang, Amougou, Abossolo, Bessoh Bell, & Africa, 2012).

Limbe Town is located on Cameroon's coast, in the fako division, specifically in the country's southwest region. She has an estimated population of 120,000 people within a total surface area of 545km². The city's previous characteristics explain why it has one of Cameroon's highest population densities of 220 people per square kilometer.This important number of people can be justified mainly by socio-economic reasons such as the presence of the CDC plantation which offers jobs to the population and the presence of beaches couple with a botanic garden in Limbe. Likewise, the city of Limbe renders her a fruitful zone of flood disaster risk. The city is dominated by a low-lying coastal plain that rises to a chain of horseshoe-shaped hills with varying degrees of steepness toward the northeast and east, the highest point reaching 362 meters above sea level (Njabe and Fobang 2006). In addition to this, Limbe is 10 miles away from Debundscha, where the latter is considered to be the second the wettest place after Cherrapunji in India. This explains why the city experiences constant heavy torrential rainfall in the rainy season which runs from the month of October, and it equally witnesses the highest average monthly precipitation in the month of June, July, and August in Cameroon of about 700mm (Ndille & Belle, 2014). Couple with this, the city is also blessed with small streams that flow into larger drainage beds, and the latter flows into main rivers and eventually ends their course into the Atlantic Ocean. During these heavy rainfalls, it is important to underline that these rivers overflow their banks due to the severity of the precipitation in the rainy season and causes flooding. This situation is also favor mainly due to the absence of proper conceived drainage channels throughout the city. This exposes the Settlement that is located along the coast of Limbe.

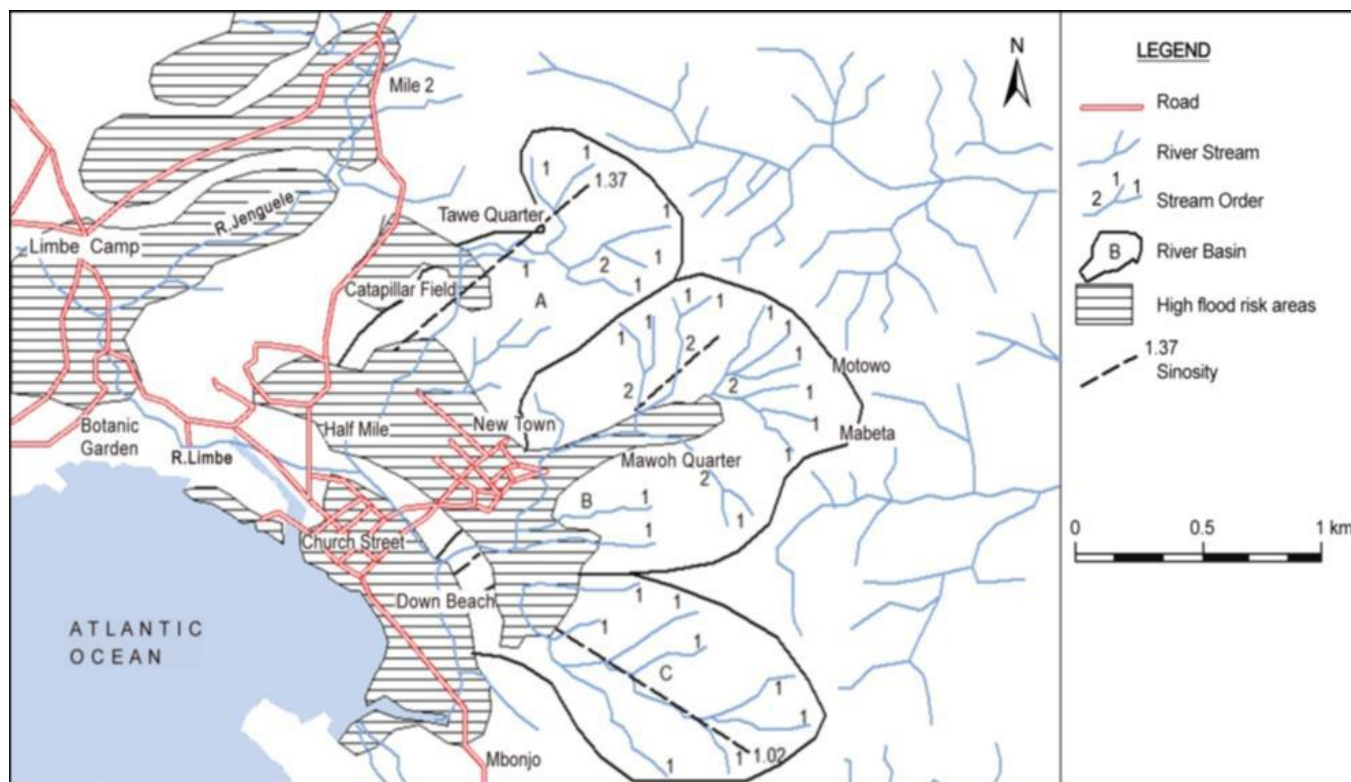


Fig.1 Geographical location of Limbe

II. LITERATURE REVIEW

Following the increasing occurrence of flood disasters worldwide, the literature has outlined a panoply of methods aimed at assessing the later flood. According to the literature and thanks to the work of (Ali, Bajracharya, Koirala, & Biotechnology, 2016) flood disaster risk can be assessed following either a hydrological, meteorological, or socioeconomic perspective. Base on the GIS and the risk assessment theory (Wu et al., 2015) developed a model to assess flood risk disaster. They designed an index system based on natural disaster risk and economic society vulnerability. Furthermore, they add two indices, reservoir storage modulus, and flood retention basin modulus, to aid in the analysis of human interaction power in flood hazard indexes. In addition, (Shi, Zhai et al. 2019) used the FDRA index to assess the probability and effects of flood disasters in Xiamen, which is one of the cities in China with the most severe flood disasters. They based their studies on the risk theory, and their findings show that Xiamen's flooding and drainage control capacities are insufficient, resulting in high flood risk. Apart from socioeconomic negatives externalities of flood to an area, (Garrote, Diez-Herrero, Escudero, & García, 2020) emphasize the negatives impacts which flood has on the cultural aspect of Castile and Legion regions in Spain, which is composed of 2155 cultural heritages. Likewise, (Aerts, Botzen, et al., 2018) carried out a study which was

aimed at disclosing the role of human behavior of flood in their environment and how the latter can also be used in assessing flood. One of the most difficult issues for researchers in quantitative risk assessment is determining how to resolve the position of individual expectations of risk-reducing activity and how these factors affect agent decisions to take flood-prevention steps (Kleindorfer, Kunreuther et al. 1993). Also, to reinforce the accuracy of forecast data related to flood disaster risk, (Escuder-Bueno et al., 2012) base on the SUFRI project which analyses flood risk in two dimensions. The first dimension raises awareness for pluvial and river flooding risk assessments in urban areas to educate and inform policymakers, while the second dimension investigates human risk perception by disseminating information with a social context and analyzing trends in how people perceive floods. The study reveals that the application of these two dimensions or methodologies appears to be a key tool for the decision-maker in their role of assessing flood disaster risk. Still in the same vein, (Pistrika, Tsakiris, & Nalbantis, 2014) established a methodology to assist water managers and authorities in developing rational flood-prevention plans. This is possible following a three steps assessment approach to assess flood disaster risk, where the first step involves analyzing hazard which incorporate both probabilities occurrence couple with anticipating potential damages; The second step is to assess flood vulnerability

in flood-prone areas, and the third and final step is to assess flood risk.

Equally, to assess physical and socioeconomic vulnerability, where the former comprise of susceptibility and exposure whilst the latter is based on quantitative and qualitative indicators, (Cutter, 1996) developed an index that assesses flood risk into four dimensions which are high, moderate, moderately low and low. This index mention can categorize flood risk in four dimensions and it acts as a key tool to handle flood disaster risk. (Bang et al., 2019), faced with the alarming nature of natural and manmade disaster risk in Cameroon. despite the various engagement of the country to an international framework such as the Sendai frameworks and recommendations with the aim at promoting RRD in developing countries, Due to resistance in communication, coordination of DRR operations, availability of services, foreign assistance, formulation of DRR plans and policies, and integration into sustainable development plans, the country still faces some significant constraints. Equally, (MOFFO, TONYE, & Maurice, 2013), alert the devastating nature of flood in the city of Douala partly due to the heavy average rainfall of 4000mm per year during these two past decades, carry on a study based on the methodology of (Beven & Wood, 1983) which delineated wetlands and extract flood zones. Also, the literature focuses on the case of African countries which are also fertile zones for flood disaster risk but the inadequate database related to past flooding observation and insufficient studies on the issue in Africa expose the latter to high risk of flood disaster, which has heavy negatives consequences as point out by (Conway, 2009). This situation can justify the occurrence of flood disasters and the inefficiency of African authorities in their strategies of flood disaster risk reduction.

Nevertheless, (Talha, Maanan, Atika, Rhinane, & Sciences, 2019) faced with an alarming number of flood disaster records in Africa and in the Western part of Morocco couple with huge direct and indirect damage in terms of properties and human life which has a great incidence on the economy.

III. METHODOLOGY

To assess flood risk in Limbe, this study uses a fuzzy information optimization approach making use of data from the national archives in Limbe. Weights for flood damage attributes are generated using the AHP. After that, the weighting result is combined with the fuzzy information optimization method to rate the flood risk of different Limbe neighborhoods.

3.1 Data used

The researcher obtained flood damage data from the National Archives in Buea (NAB), the National Archives in Yaounde (NAY), the Ministry of Territorial Administration and Decentralization (MINATD), and the Limbe district, which is located in the Limbe province of Cameroon (former urban council). The Limbe Urban Council data consist of different flood and storm events of four different years. The database contains a large set of direct flood data in ten categories; Maximum annual precipitation, Drainage density, Nature of topography, Soil texture, Population in the unit area, Reported health cases, Building destroy, Roads and bridge damage, Electricity/water installation damage, Gross domestic product (USD). These 10 categories are quantified.

3.2 Data processing

The data has been compiled at the Limbe urban council from different localities that are: Lumpsum, Mile Two, Church Street, New Town, Lower Cassava, Clerk's Quarter, Down Beach, and Manga William's, Motowoh Quarters, Dockyard, Mawoh Quarters, Bimbila, Limbe1, Etome, and Mokunda. The flood damage data used for analysis are data from different localities in the Limbe town for four different years respectively (1990, 2000, 2001, and 2007). with ten variables of Maximum annual precipitation, Drainage density, Nature of topography, Soil texture, Population in the unit area, Reported health cases, Building destroys, Road and bridge damage, Electricity/water installation damage, Gross domestic product (USD). Each year an observation is carried out for each of these locality making a total of 1400 observations.

3.3 Flood risk assessment using the Fuzzy Information Optimization Method

The Fuzzy Information Optimization Method (FOP) was used in this study to assess flood disaster risk. This approach employs fuzzy mathematical theory to create an overall assessment of complex problems that are influenced by several factors. This approach is used to determine flood risk to remove any ambiguity or confusion that might occur during the assessment process. Furthermore, using fuzzy set theory and fuzzy logic, fop converts qualitative evaluation into quantitative evaluation results. Fuzzification, fuzzy inference, and defuzzification are the three steps in a fuzzy scheme or solution.. Fuzzification is the means of transforming qualitative to quantitative values in a proposal using the membership function. The membership function and control rules are combined to produce variables or indexes in the fuzzy inference process. Defuzzification is the process of combining the outcomes of each rule to generate the final result. In this study, the three processes above Fuzzy

classification, membership features, and comprehensive evaluation all correspond to each other.

3.3.1 Fuzzy Classification

When FOP was used to determine flood risk, it was divided into five categories: very low, low, moderate, high, and very high, respectively. standard deviation statistics and the value of each raster layer were used to determine

the level interval. The interval grade value (Δ) of the raster data fuzzy subset is determined by the lower value of the standard deviation difference. Each raster data set is graded on the same interval value. There are five interval points in each.

D1, D2, D3, D4, D5 (Table 1).

EACH FACTOR'S INTERVAL VALUE

TABLE 1

Kind of index	Δ	D ₁	D ₂	D ₃	D ₄	D ₅
Maximum annual Precipitation (m/m ²)	70	150	220	290	360	430
Drainage density (m/m ²)	0.0010	0.006	0.0016	0.0026	0.0036	0.0046
Nature of topography	0.34	1.20	1.54	1.88	2.22	2.56
Soil texture	5	8	13	18	23	28
Population per unit area /10 ⁵ m ²)	2.65	1.20	3.85	6.15	9.15	11.80
Reported health cases	19	20	39	58	77	96
Building destroyed	16	83	99	115	131	147
Roads and bridge damage	7	5	12	19	26	33
Electricity/water installation damage	15	8	23	38	53	68
Gross domestic product (USD)	2218	1120	3338	5556	7774	9992

3.3.2 Membership function

The fuzzy set is used to quantize fuzziness through membership functions (MFs), it helps to eliminate the uncertainty while obtaining a fuzzy evaluation matrix. That is the determination of suitable membership function can be critical for risk assessment results. Many types of

membership functions exist such as Waveforms such as Gaussian, bell-shaped, sigmoidal, triangular, trapezoidal, and so on. Since floods are short-duration events, the trapezoidal and triangle waveforms must be chosen to describe the piecewise functions.

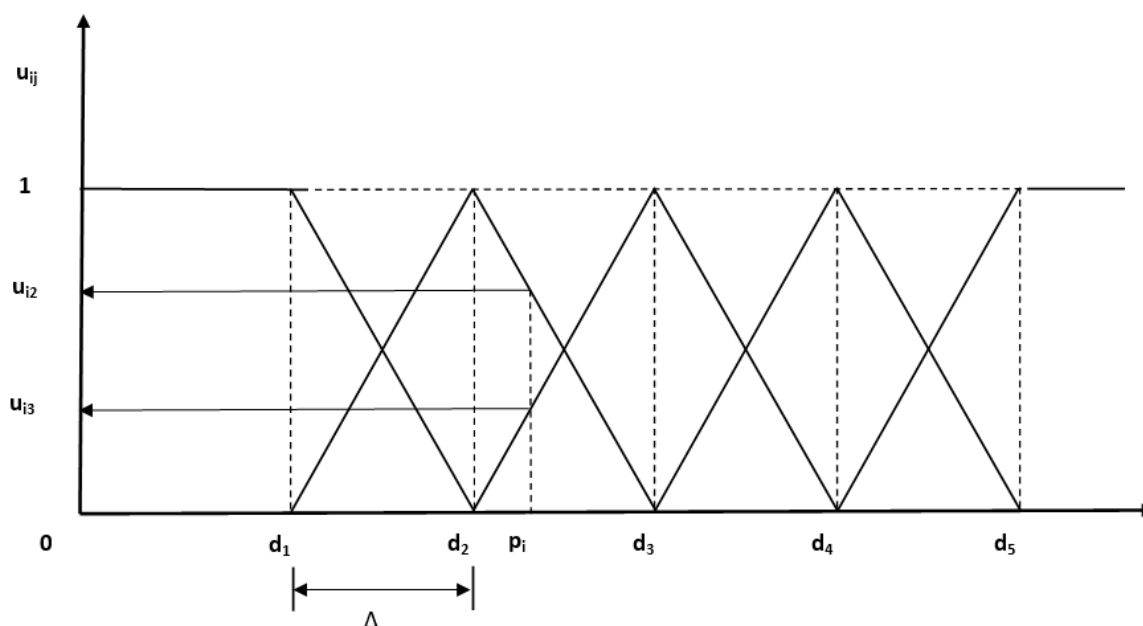


Fig.2: Fuzzy set of membership functions

$i = 1, 2, \dots, 10$; $j = 1, 2, 3, 4, 5$. P_i represents the raster data of index i . In Fig 2, P_i has two levels of membership that is U_{i2} and U_{i3} .

Sets of formulas (Equation (1)- (5)) can be used to obtain the fuzzy membership function value of each factor related to the five evaluation levels.

$$u_{i1}(p_i) = \begin{cases} 1 & 0 \leq x \leq D_1 \\ \frac{D_2 - p_i}{D_2 - D_1} & D_1 < x < D_2 \\ 0 & x \geq D_2 \end{cases} \quad (1)$$

$$u_{i2}(p_i) = \begin{cases} 0 & p_i \leq D_1 \text{ or } p_i \geq D_3 \\ \frac{p_i - D_1}{D_2 - D_1} & D_1 < p_i < D_2 \\ 1 & p_i = D_2 \\ \frac{D_3 - p_i}{D_3 - D_2} & D_2 < p_i < D_3 \end{cases} \quad (2)$$

$$u_{i3}(p_i) = \begin{cases} 0 & p_i \leq D_2 \text{ or } p_i \geq D_4 \\ \frac{p_i - D_2}{D_3 - D_2} & D_2 < p_i < D_3 \\ 1 & p_i = D_3 \\ \frac{D_4 - p_i}{D_4 - D_3} & D_3 < p_i < D_4 \end{cases} \quad (3)$$

$$u_{i4}(p_i) = \begin{cases} 0 & p_i \leq D_3 \text{ or } p_i \geq D_5 \\ \frac{p_i - D_3}{D_4 - D_3} & D_3 < p_i < D_4 \\ 1 & p_i = D_4 \\ \frac{D_5 - p_i}{D_5 - D_4} & D_4 < p_i < D_5 \end{cases} \quad (4)$$

$$u_{i5}(p_i) = \begin{cases} 0 & p_i \leq D_4 \\ \frac{p_i - D_4}{D_5 - D_4} & D_4 < p_i < D_5 \\ 1 & p_i \geq D_5 \end{cases} \quad (5)$$

3.3.3 Comprehensive Evaluation

The membership values establish the evaluation matrix T .

additionally, the associated flood disaster risk indicators

$$T = \begin{bmatrix} t_{11} & t_{12} & \dots & t_{15} \\ t_{21} & t_{22} & \dots & t_{25} \\ \vdots & \vdots & \ddots & \vdots \\ t_{i1} & t_{i2} & \dots & t_{i5} \end{bmatrix} \quad (6)$$

$$t_{ij} = u_j(p_i), i = 1, 2, \dots, 10, j = 1, 2, \dots, 5.$$

Given the difficulty of assessing flood disaster risk, this paper employs raster data layers as a flood disaster risk index, resulting in the establishment of a hierarchical structure of flood disaster risk assessment indexes based on an analytic hierarchy process (AHP). The weight of ten

variables was taken into account, which are as follows: 0.3295, 0.1793, 0.0456, 0.1601, 0.0852, 0.0425, 0.0212, 0.0631, 0.0140, and 0.0072.

IV. RESULTS AND DISCUSSIONS

The flood disaster risk map was obtained for the various localities in Limbe. High-risk, medium-risk, and low-risk zones are represented on the diagram. zones of high areas are Cassava farms, Clerks Quarters, Down Beach, Lumpsum, Church Street, Mawoh Quarters, Motowoh Quarters, and Dockyard. The reason for the high-risk zone

of these areas is simply because of its location at the coastal area or areas along rivers. whereas the medium risk zones include Bimbila, Limbe1, most especially Moviokulu, Batoke, and Limbe III particularly Camps Three. Etome, Mokunda, and Limbe II Mokundange are low-risk zones. The low-risk zone is because of High Mountain and low population.

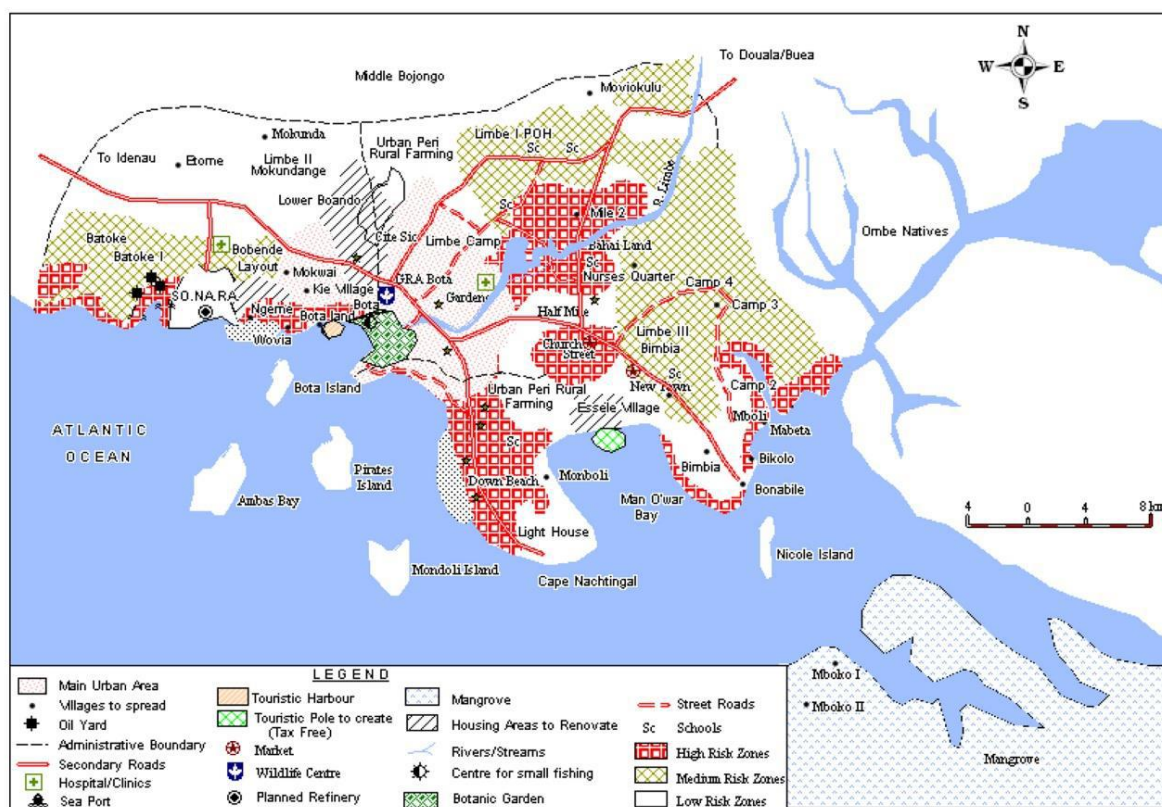


Fig. 2. Map showing the flood-affected areas in Limbe

Source: Adapted from the map of Limbe, NIC (2016)

4.1 Risks validation

Flood risk validation is the process of determining the accuracy of a risk assessment by comparing it to other data to confirm the vulnerability of

high-risk areas. Flooded areas are well considered to be high-risk areas. Based on the information and findings of this paper, we can outline the areas of high-risk and low-risk zones and their justification.

Table.2 Vulnerable Limbe Zones to flood risk

Categories of flood risk vulnerabilities	Limbe towns which are prone to flood disaster risk	Justification
Very high probability	Down Beach church street, mile two	These towns are characterized by functional plains When there is a storm, water must flow or be collected. In general, these lands are subjected to a 1 in 20 (5%) or greater annual risk of flooding or are planned to flood in a (0.1 percent) flood. Also, these towns witness permanent flooding during the peak rainy season month.
High probability vulnerability	New town, Clerk's quarter, Njengelle	These towns have a 1 in 100 or higher annual probability of river flooding (greater than 0.1 percent) or a 1 in 200 or higher annual

	Quarters, Gardens	probability of sea flooding (greater than 0.5 percent) in a given year. Similarly, these towns observed floods weekly during the last days, and floodwaters ubiquitous.
Moderate probability vulnerability	Lumpsum, cassava farm, Poto-Poto Quarter, Mahow, Mabeta new layout	These towns are characterized with 1 in 100 and 1 in 1000 probability of (1% to 0.1%) in a year of river flooding and a 0.5 percent annual risk of sea flooding (between 1 in 200 and 1 in 1000)Likewise, these towns witness monthly flooding
Low probability vulnerability	Limbe Camp, Bota, and Mile one	These towns have an annual likelihood of river or sea flooding of less than 1 in 1000 (0.1 percent), and floods occur only when storms are particularly severe.

Source: (Nguh and Anumveh, 2018)

Based on the table above Down Beach, Church Street, and mile two localities in Limbe town, flood disaster risk assessment accuracy is invalidated. When a fuzzy information optimization approach is used to evaluate risk, it can reduce a variety of uncertainties by quantifying risks arising from human experience. The FOP approach is focused on fuzzy set and fuzzy logic theories, which transform uncertainty into certainty in risk assessment. In the fuzzy information optimization approach, the outcome of flood risk is determined by the grade interval of various indicators as well as the waveform of the membership function. In addition, the grade interval is divided based on the properties of each indicator's value as well as the current state of the study location.

However, it should be noted that in this paper, we used the risk conceptual structure suggested by the United Nations when conducting flood risk assessment research using the fuzzy information optimization approach. This approach aims to choose a more accurate and acceptable risk indicator while also acknowledging the effect of natural and socioeconomic factors on flood risk without affecting the final risk area result.

4.2. Flood Risk Reduction

The aim of a flood risk assessment is to recognize areas that are at risk of flooding and to develop flood management strategies to reduce flood damage.. We suggest implementing a series of flood control and mitigation steps in high-risk areas of Limbe town based on the FOP's risk-zoning map and field investigation. These activities include engineering and non-engineering measures

4.2.1 Engineering Measures

Engineering steps apply to any location or structure that is used to avoid, divert, store, or drain floodwater. After conducting a field survey in the various Limbe Town neighborhoods, engineering measures were requested.

(1) Upgrading flood protection structures: Because of the flat terrain and low drainage, flood control or an artificial levee, as well as the building of a hydrological system network, has been established along the riverine. Moreover, Limbe camp, Bota, and Mile one have comparatively low fortification criteria since they are located in mountainous areas in Limbe, can withstand floods for a longer period. This can therefore be prevented by removing dangerous water dam projects.

(2) Dredging of the channel in highly aggressive areas, sedimentary section: The hydrodynamic environment weakens as rivers flow out of the mountains and into the plains due to the widening of the river's channel. Because of sediment aggregation, the riverbed rises, increasing the likelihood of flooding. As a result, routine strategic dredging is essential to restore the natural state of aggradation.

4.2.2 Non-Engineering Measures

There are a variety of regulations, rules, administrative management, and technological options for reducing flood disaster losses in floodplains. In this study, various measures are proposed with the actual situation of our study area.

(1) Rules regarding land use planning: The land use in the study area, as well as the flood plain management strategy, must be carefully designed. Zones with a high chance of being identified as high-risk zones should be designated for low occupancy. Additionally, industrial and residential land should be designed to be used in high-altitude areas, with urban development ensuring that the river channels are preserved at a reasonable area.

(2) Putting in place flood risk insurance: Flood insurance is an effective tool for flood risk management in floodplains. Insurance, on the other hand, is a social-economic aid for flood-related property loss. As a result, we propose that the government establish a flood insurance program for residents in high-risk areas.

(3) Flood resistance capacity building construction of flood resistance capability necessitates real-time and reliable hydrological tracking, forecasting, and early warning systems. Furthermore, the community can practice evacuation exercises regularly to boost flood awareness and disaster preparedness. Each of these measures will help minimize the likelihood of flooding, as well as the number of people who die and the amount of money lost.

V. CONCLUSION

Over the last few decades, climate change and rapid urbanization have increased the risk of flooding in metropolitan areas. Flood risk assessment is important because it aids in the identification of high-risk areas for potential management.

In this study, a fuzzy information optimization approach based on the weight of selected variables was proposed and applied to risk assessment in Limbe's various quarters. Due to the existence of several rivers, medium, high, and very high-risk zones were primarily found along the coast, while low and very low-risk zones were found in the Limbe town's plateau and mountainous regions, according to research. The Limbe municipalities, on the other hand, proposed mitigation strategies for high and very high-risk areas, considering the field investigations as well. This is important because it aids in the reduction of urban disasters, reducing fatalities and economic losses.

The fuzzy information optimization approach is based on fuzzy set and fuzzy logic theory, which helps risk management procedures minimize or remove fuzziness and ambiguity. The waveform of the membership function, which is calculated by the value of each indicator and flood event characteristics, determines the performance of risk. When using the fuzzy information optimization approach in conjunction with a particular collection of risk indicators, a risk zoning map is created, which can be regarded as the risk map of any study area. The collection and accuracy of data indicators will need to be refined in future studies or analyses.

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