ISSN No:-2456-2165

Climate Variability and Populations Vulnerability to Floods in Urban Spaces of Southern Countries: An Analysis of Determinants, Threats and Adaptation Strategies in the City of Yaoundé in Cameroon

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Abstract:- Contemporary climate variability is having a disproportionate impact on societies, especially in developing countries where adaptive capacity remains low. It is characterized by floods that threaten people's lives and property in southern countries towns. This study is aimed at analysing the factors of vulnerability to flood risk in the town of Yaoundé within the context of climate variability. The methodology is based on a literature review, inter-annual analysis of average rainfall between 2005-2020 and average deviations, direct field observations and interviews. It shows that the vulnerability of Yaoundé inhabitants to flood risks has increased over the past fifteen years with climate variability, due to rainfall surpluses and deficit. This climate variability manifests in untimely and heavy downpours and significant rainfall surpluses. Moreover, the topography of the city, demographic pressure and anarchic urbanization and the environmental incivility of the populations are all factors that regularly expose the city to floods despite the efforts made by the Government with the support of donors and development associations to combat this phenomenon. Environmental sensitization and education and the mastery of urbanization are all the challenges that the government should face in order to ensure the well-being of people.

Keywords:- *Climate Variability, Vulnerability, Floods, Adaptation, Yaoundé.*

I. INTRODUCTION

Extreme weather events (droughts, heat wave, floods, hurricanes, etc.) are increasingly threatening humanity and sustainable development. According to the IPCC report [2007], these events could multiply with current global warming. Regarding floods, developing countries are most affected by urban poverty and low adaptive capacity. Thus, for several decades, floods have become a fatality for the inhabitants of the city of Yaoundé in Cameroon. This disastrous phenomenon has increased over the years due to climate variability. For several decades, the Yaoundé station has experienced various climatic disturbances marked by near-dry months and others with precipitation well above normal [ABOSSOLO & *al*. 2006]. These rainy months are mostlycharacterized by heavy and sporadic torrential rains that engulf certain areas of the city. Thus, not a single year goes by without the people of the capital city being hit by the spectacular floods, sometimes leaving dozens or even hundreds of families affected. These floods are all the more serious a threat, as they often leave behind dead or homeless families not counting numerous significant property damage that disrupts and paralyzes human activities and worsens people's living conditions. To cope with this phenomenon, the populations of the city at their level try to provide ad hoc solutions that sometimes prove ineffective and unsustainable. On the other hand, (before using on the other hand, make sure you have used on the one hand to make your ideas coherent and keep parallel sentence struture) governments and local authorities are struggling to make up for this by combating anarchic urbanization through, not only eviction operations of populations from risky areas, but also through the development of some of the remediation works in the capital. However, these government measures, though for prevention and protection purposes, are not always appreciated by the occupants of high-risk areas who are very often in distress as a result of these out-of-home operations.

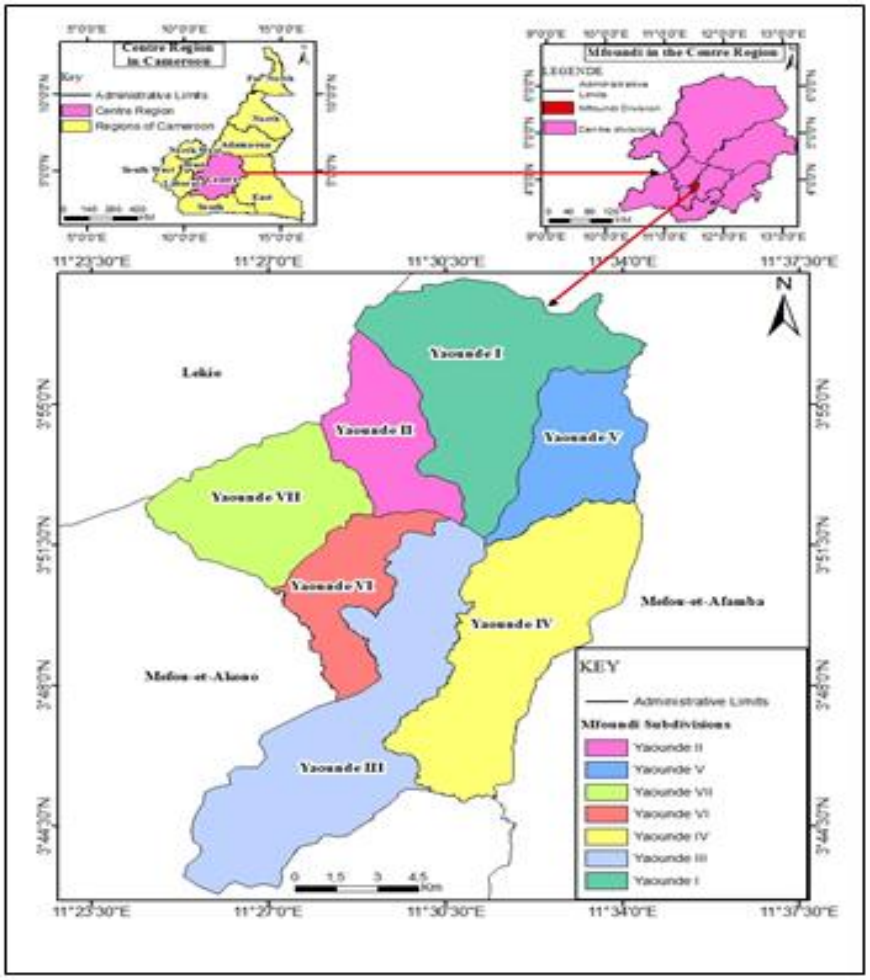
II. MATERIALS AND METHODS

2.1. Description of the city of Yaoundé

Yaoundé is the political capital of Cameroon, situated in Centre region of Camerooon, and covers the Mfoundi Division. It extends between 3°44’30’’ and 3°55’00’’ N and 11°23’30’’ and 11°37’30’’E. It is located on the South Cameroonian plateau and has an average altitude of about 750 m. Yaoundé commonly known as the "town of seven hills", consists of a ? of hills (called *Nkol* in *ewondo* language) separated by a maze of valleys relatively large and deep, sometimes expanded into swampy basins that are very often affected by floods (*Etetak, Elobi*) and where poor people live in sometimes appalling living conditions. The most striking reliefs are to the west of the town they dominate and have an average altitude of 1000m (Mbam Minkom: 1295m, Nkolondom: 1221m, Eloumnden: 1169m) [SANCTOIR, 1993]. Yaoundé is influenced by a transitional equatorial climate characterized by average rainfall of about 1654mm. The umbrothermal diagrams highlight the bimodal pace of precipitation characterized by two rainy seasons, the first (March-June) which is longer and less powerful and the second (September-November) which is highly concentrated

ISSN No:-2456-2165

on the October month and two dry seasons or more accurately less rainy. During the short "dry season" of (July-August), Yaoundé receives 149mm of rain. The "long dry season" from December to February takes off in intensity and duration [SUCHEL and TSALEFAC, 1993]. The average annual temperature in the town is estimated at 23.5oC and the annual thermal amplitude at 2.4oC. The geographical situation of the town of Yaoundé in Cameroon is presented as follows (Fig.1).



Source: PDU of Yaoundé, 2018

Fig.1. Geographical situation of Yaoundé in Cameroon

2.2.Methodology

This study is the result of a combination of documentary, rainfall, mapping, observation and survey data. Through documentary research, data on the manifestations and consequences of climate variability as well as the recurrence of floods and collateral damage in the city of Yaoundé have been collected. The rainfall data used in this study are derived from satellites and cover a 15-year period (2005-2020). The use of precipitation data from satellites is related to insufficient data at the Yaoundé weather station over this period. The analysis of inter-annual average precipitations was conducted to assess the inter-annual variability of precipitation from 2005-2020. The inter-annual average rainfall was calculated to show the differences with annual rainfalls using the following formula:

PIA*=∑ *Pa/16 *[E2]* with: PIA : Inter-annual average precipitation; Pa: annual rainfall.

This made it possible to assess the years of excess and deficit rainfall. The R^2 determination coefficient obtained through the analysis of rainfall data in the Excel spreadsheet was used to study the dispersion of precipitation around the linear right. The analysis of the monthly distribution of precipitation per year permitted to compare the fluctuations in monthly precipitation during each year over the period concerned, in order to detect the rainfall anomalies that caused the phenomenon of floods. Field observations in some areas exposed to floods risk have resulted in photographs that illustrate the phenomenon in the capital as well as the constructions made by governments or populations to prevent floods. Mapping the risky areas in the Mfoundi river drainage basin, using Google Earth images and developing the digital field model, enabled us to analyse the level of vulnerability of populations and the spatial distribution of flood risk in the town. Interviews were also carried out with some inhabitants and municipal authorities to complete the data set. They provided information on their perception of flood risk and measures to prevent and protect populations from flood.

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III. RESULTS AND DISCUSSIONS

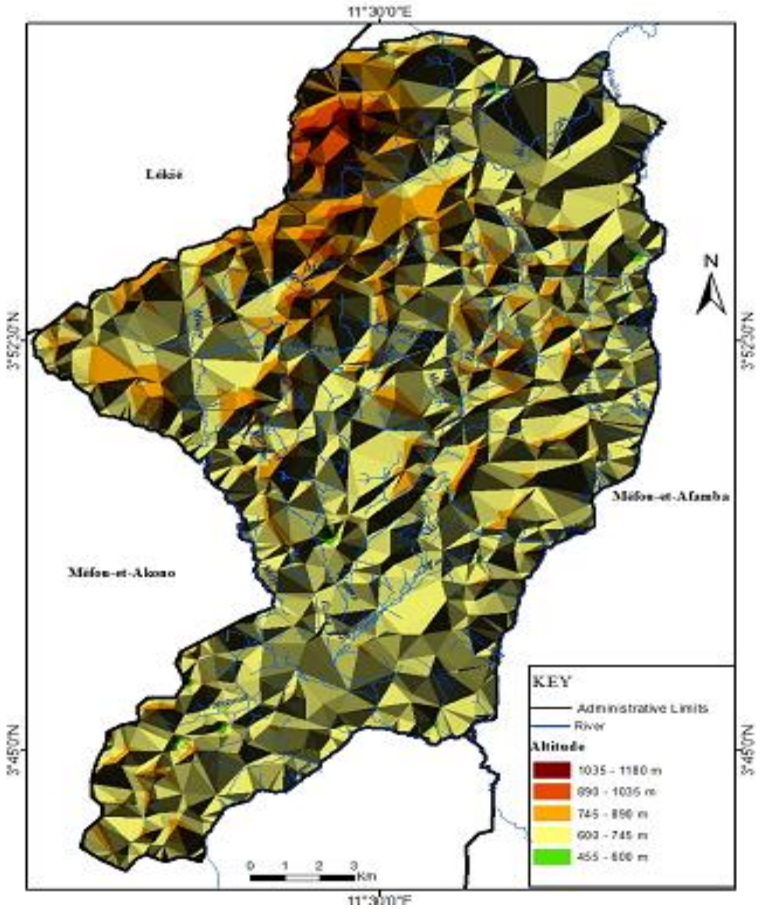
3.1. Floods risk determinants in Yaoundé

3.1.1. A phenomenon linked to the morpho-hydrological configuration of the city

The geographical configuration of the city of Yaoundé, consisting of a set of hills separated by swampy valleys, naturally predisposes it to floods. Yaoundé is located on the Mfoundi watershed, the main river that runs through the town around which other small tributaries form a dendritic network. The presence of a series of hills that prevail in the town has promoted a centripetal flow on the slopes that converges towards the marshy shallows to reach the various rivers and streams that cross the town before flowing into the Mfoundi River. The speed of runoff flowing down the steep slopes of the town's hills to the valleys, very often causes a rapid upsurge of floodwaters that are the cause of the floods generally observed in the swampy slums.

Moreover, these hills constitute a barrier to the urbanization front in areas where the vigour of the slope is quite strong, with the consequent increase in pressure on easily urbanized spaces.

The relief of Yaoundé town is very hilly and its hydrological network is dense (Fig.2)



Source: Digital Elevation Model, 2018

Fig.2. The morpho-hydrological feature of Yaoundé

3.1.2. Climate fluctuations with rainfall surpluses and deficits

Yaoundé experiences very high rainfall variability characterized by fluctuating precipitation at the inter-annual and annual scale in relation to global climate variability. Thus, the analysis of inter-annual rainfall evolution shows that the years 2007, 2010, 2015, 2016 and 2018 were particularly rainy with rain, that is, 1476 mm, 1536 mm, 1480mm, 1554 mm and 1553 mm respectively. On the other hand, the years 2008, 2009, 2011, 2012 and 2017 were less rainy. The annual rainfall recorded during these years was of about, 1262mm, 1142 mm, 1183 mm, 1209 mm, 1219mm and 1271 mm. (Fig. 3). Statistical analysis of precipitation distribution through the determination coefficient (R^2-0.0089) that mean a strong dispersion of rainfall from de linear regression line. Nevetheless, the analysis of the general tendency of rainfall evolution shows that, rainfall has increased between 2005 and 2020 (Fig.3).

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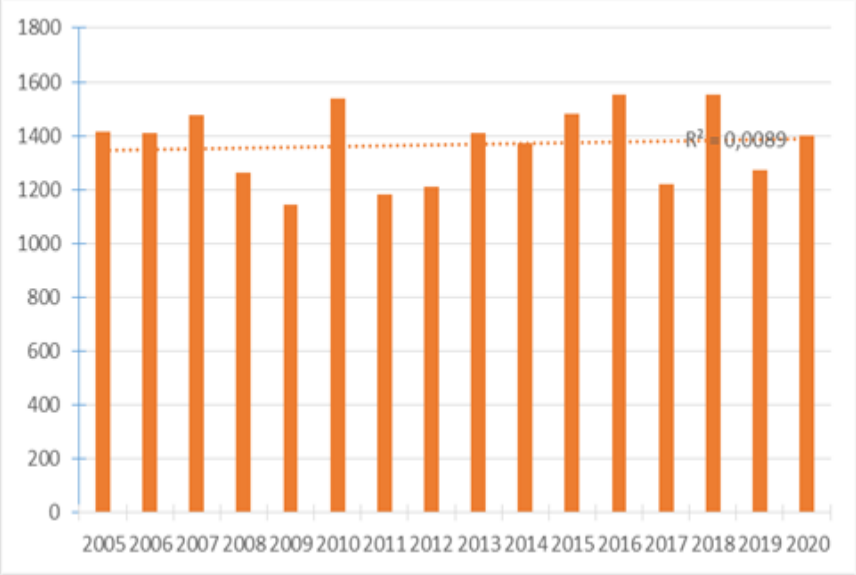
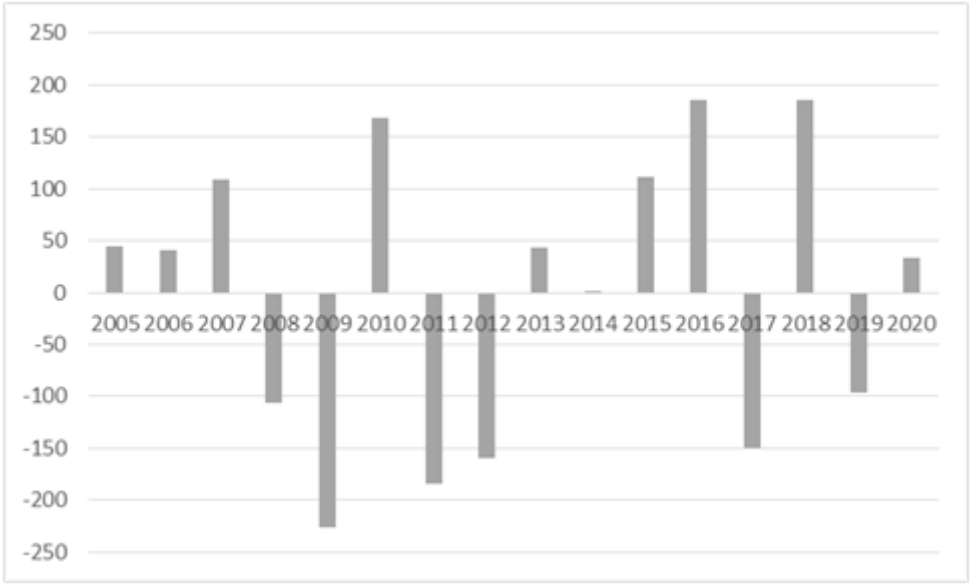


Source: Yaoundé weather station, 2020

Fig.3. Inter-annual changes in precipitation in Yaoundé between 2005 and 2020

The analysis carried out using the reduced centred variable made it possible to characterise the variability of rainfall and to identify surplus and deficit years. Thus, the years 2005, 2006, 2007, 2010, 2013, 2014, 2015, 2016, 2018, 2020 recorded a rainfall surplus compared to the average for the period (2005-2020), with a maximum of + 185 mm in 2016 and 2018 respectively; while the minimum of + 1.28 mm is observed in 2014. On the other hand, the deficit years are 2008, 2009, 2011, 2012, 2017 and 2019. Whilethe deficit is most pronounced in 2009 (-226mm), it is least pronounced in 2019 (-96mm) (Fig.4).



Source: Yaoundé weather station, 2020

Fig. 4. Distribution of rainfall surpluses and deficits in Yaoundé between 2005 and 2020

The analysis that can reasonably be drawn from figures 3 and 4 is that the 2005-2020 period experienced high inter-annual variability in precipitation in relation to climate variability, exposing the city of Yaoundé to floods. These irregularities in the seasonal rhythm, characterized by the early arrival of sporadic and intense rains as well as heavy rains during the rainy seasons, are the cause of most of the devastating floods observed in the town of Yaoundé. In general, the intensity of the rains, exceeding the capacity of water infiltration into the soil leads to the surface runoff and rising floodwaters in the Mfoundi, causing the spectacular regular flooding at the central post and Kennedy Avenue (**Plate 1**).

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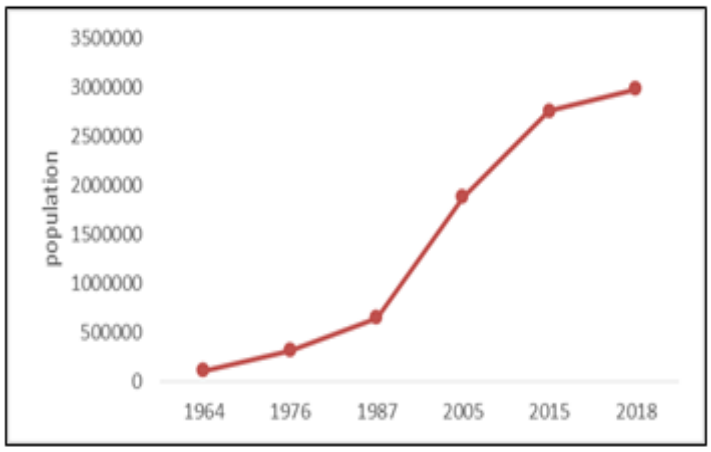
Picture: Kengmoé, 2018

Plate 1. Heavy floods in commercial centre in Yaoundé

The above pictures show the spectacular floods at Kennedy Avenue in Yaoundé in May 2018. On the left are roads and vehicles flooded and on the right, some closed shops due to rising flood waters.

3.1.3. The Role of urban growth and anarchic urbanization

The rampant urban growth related to natural growth and rural exodus cause a spatial extension of the town and land speculation over the years. The surface of the city increased from 1740ha in 1956 to 15900 ha in 2002 [MINDUH & CUY, 2008]. Its population today has almost been multiplied by thirty compared to the 1964 data. It increased from 109,200 inhabitants in 1964 to about 3 million inhabitants in 2018 with the significant pressure on marginal spaces (Fig.5).



Source: BUCREP et INS, 2018

Fig. 5. Population evolution of the town of Yaoundé between 1964 and 2018

The poor people of the town and the newcomers in search of living space occupy the slopes by destroying the vegetation cover or settle in swampy areas where land is generally less expensive and consequently easy to acquire. This anarchic occupation of space is increasing because of administrative tolerance or rampant corruption in land services and even in councils from which people fraudulently obtain land titles and illegal building permits in areas declared *non aedificandi* and not subject to private appropriation. Law No. 2004/003 of 21 April 2004 organising urban planning in Cameroon, which stipulates in its article 9 paragraph 1 that "land exposed to natural risk (flooding, erosion, landslide, earthquake, etc.) is unbuildable, except for special requirements); parts of the public domain classified as such and ecologically protected areas as defined by environmental management legislation." At the same time, ordinance No 74/2 of 6 July 1974 setting out the state regime specifies in Article 3 that wetlands are part of the river public domain and are therefore insusceptible to private ownership (Article 2). It is therefore clear that in the face of non-compliance with legal and regulatory measures, the anarchic occupation of forbidden areas due to the impunity of the municipal authorities is growing in the town of Yaoundé.

The marshy valleys that make up the major riverbed are invaded by buildings, causing floods that pose an environmental and health hazard to people. In addition, the anthropization of slopes and periurbanization contribute to the destruction of vegetation cover and the waterproofing; which favours water runoff instead of their infiltration into the soil.

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3.1.4. Poor solid waste management

Environmental incivility caused by the proliferation of solid waste leads to a clutter of the riverbed during heavy rains, causing the overflow of water from their beds. Thus, during heavy rains, runoff carries garbage, including polyethylene bottles (PET) to the gutters and streams where they transit and form piles of garbage that obstruct the passage way for water flow. The overflow of water that flood the roads and entire quarters endangering people's lives, property and activities are caused by the the obstruction of the river water flow channel and undersized gutters in some cases as well as the obstruction of the draining sewers from runoff by waste (**Plate 2**).

Picture: Kengmoé, 2018

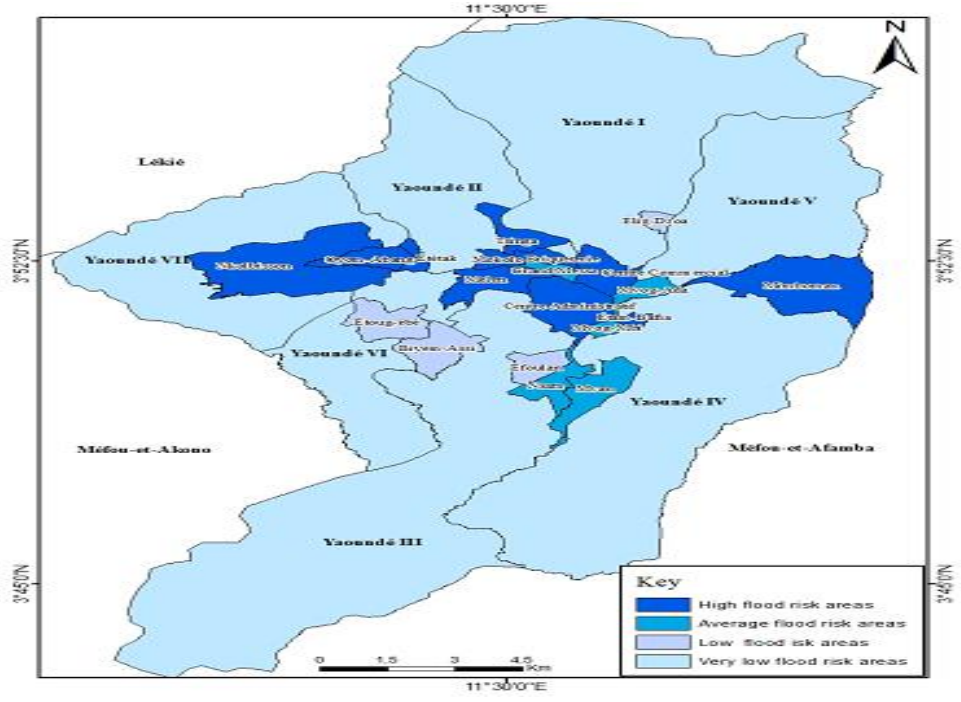
Plate 2. Impact of poor waste management on river flow

Poor management of urban solid waste is causing riverbed congestion and obstruction of drainage systems that are partly responsible for flooding in the capital. On the left is a bridge whose base is completely obstructed by the rubbish and on the right is a river in which is a cluster of PET bottles.

3.2. The increased risk of floods in the town of Yaoundé and its consequences

The recurrence of flooding after heavy downpours in thecity normally and abnormally is a real fact observed with climate variability. As a result, floods are becoming more frequent in such a way that there are years where several spectacular cases can be recorded. The capital's hotspots such as the Central Post Office and Kennedy Avenue? in the commercial centre, as well as parts of the unstructured populated quarters such as *Nkolbisson, Etam-bafia, Elig-effa, Mimboman, Mvan, Briqueterie, Tsinga Elobi, Mokolo Elobi, Messa* etc. close to rivers are frequently experiencing these floods.

The spatial vulnerability of populations of the city to floods is not the same over time. It depends on the level of planning of the quarter, the density of settlement and the relief. So, there are high floods risk areas, average flood risk areas, low flood risk areas and very low flood risk areas (Fig. 6)



Source: Administratif map of Yaoundé, Google earth and field work, 2020

Fig. 6. Spatial vulnerability to floods in Yaoundé

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Natural hazard surveys carried out by Cameroon's Civil Protection Direction in 2002 classified the town of Yaoundé as a severely exposed area to floods risk. Throughout the 1980s, 1990s and 2000s, more than fifty more or less dramatic and spectacular floods were recorded. In addition, ZOGNING [2005] in his work counted sixty-one (61) floods from 2000 to 2005 period of time that killed 12 people including two babies. The vulnerability of the inhabitants of Yaoundé to floods and especially those lving in precarious quarters near rivers in the various drainage basins, increases over the years in view of the regularity of this phenomenon. Several more or less dangerous spectacular cases were summarized from 1983 to 2018 (table 1).

Table 1. Summary of some major floods in the city of Yaoundé between 1983 and 2018

Date	Place	Outcome
May 15, 1983	Downtown	Damage estimated at 5 million CFA francs
August 26, 1986	City council highway	One (01) bridge washed away after 87mm torrential rain
September 27, 1990	-	Huge damage and eight (08) people dead
September 12, 1997	Central Post office	Town cut and traffic blocked by the Mfoundi River with more than one (01) meter in height
February 8, 2000	Central Post office	Town cut in half and traffic blocked by the Mfoundi River with more than one (01) meter in height
February 26, 2003	Shell Obili Valley	Five (05) people who died
May 29, 2007	Central Post office and Kennedy Avenue	-Town cut off and traffic blocked by Mfoundi floodwaters -Stopped activities, closed stores, damaged goods, out-of-service offices -Damage estimated at several millions CFA francs according to the owners of the affected stores
April 04 and 26, 2008	Nkolbisson	-Three (03) peoples dead, 500 people left homeless - Damage estimated at several million -Evictions
May and June 2013	Tsinga Elobi	-Three (03) children died by drowning -Many property damage
February 27, 2018	Central Post office and Kennedy Avenue	-Traffic interrupted -Significant property damage
May 29, 2018	Central Post office and Kennedy Avenue	-Traffic interrupted -Significant property damage

Source: Direction of Civil Protection, PANGIRE [2009] and field observations.

3.3. Actors and adaptation strategies to the floods in the town of Yaoundé

To adapt to floods in Yaoundé, the government and municipal authorities, donors, civil society and the inhabitants themselves are working and adopting preventive or spontaneous measures.

3.3.1. Preventive adaptations

Floods prevention in the Town of Yaoundé began over a decade with a series of eviction operations organized in some of the town's high-risk quarters by the Yaoundé city council, especially in the Ntaba-Nlongkak quarter in 2008, Elig-Effa quarter in 2009, Mokolo Elobi, Tsinga Elobi and Nkolbisson quarters in 2015. Unfortunately, these life-saving operations often leave many families in distress. They are not aware of the risk of flooding around them and the merits of these operations, which for them are measures which are aimed at harming them and therefore resist to it. The Yaoundé city council has also undertaken a project to plant 1000ha of urban forests by the reforestation and restoration of highlands and marshy lowlands such as the sections MEEC crossroad - Oyomabang; Messa crossroad - Bastos new road and the slopes of Mount Messa.

Several quarters in the town of Yaoundé have been benefiting from urban sanitation since 2009 through the World Bank-funded urban sectors development and water supply project called “PDUE”, including the development of drains to ensure the flow of storm water. In the same vein as regards floods reduction, the first phase of the Yaoundé sanitation project known as “PADY” enabled the construction of 3.5 km of the River Mfoundi canal to the tune of 22.3 billion CFA francs by the African Development Bank. Now in its second phase, the government has obtained a funding of about 52.5 billion from the French Development Agency for the construction of an additional 14 km drains on the Mfoundi River. This project included a component on environmental sensitization and education of populations on the adoption of responsible behaviours in the management of solid household waste.

3.3.2. Spontaneous adaptations

To combat floods, civil society organizations and the development committees of the different quarters spontaneously organize general interest works which consists in cleaning gutters to facilitate the drainage of water storm (**Photo**.1).

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Picture : Kengmoé, 2020

Photo 1: People cleaning out drains to facilitate the evacuation of rainwater

Furthermore, some inhabitants living in marshy areas usually raise the foundations of homes, they also construct walls with vehicle tires and fill it with soil or they stack sandbags onto the streams banks or the edges of drainage channels in order to better canalize the water and avoid overflowing. Other people build drains around homes, build walls in cinder blocks in front of their houses or build houses on stilts to prevent water from flooding them.

3.4.Discussions

The rugged topography of the city of Yaoundé consists of a succession of hills with more or less steep slopes, interspersed by marshy valleys drained by a large river system, naturally favourable to floods, as the results of ABOSSOLO & al. [2015] shows. Public policies to combat these floods in the town should be re-examined. The government, with the support of donors, initiated, as part of the Yaoundé sanitation project called "PADY", to develop the Mfoundi river channel to the tuneof billions of CFA francs in order to increase the drainage capacity of the river and its tributaries, but the town continues to experience floods after heavy rains. The need for efficient management of the solid waste that abounds in the town should be sufficiently taken into account in the context of control policies. For example, only one out of the four holes put into place for the evacuation of water from the Mfoundi river at the entrance to the tunnel at the central post office functions optimally; the other three are clogged in part by solid objects and sand, causing regular floods that inundate the central post office considered to be the receptacle of runoff from both sides of the city. Controlling rapid urbanization through the rigorous implementation of urban planning remains a major challenge for the town authorities. With more than 100 km^2 of urbanized area, the waterproofing of the surfaces and the anarchic occupation of *non-aedificandi* areas enhance the vulnerability of populations to these risks of floods.

Climate variability is also contributing to the exacerbation of these flood risks with the disruption of the rainfall regime characterized by rainfall surpluses and deficits, early rains during dry months (December, January and February), and heavy downpours during some years in the town. These results are similar to those presented by SUCHEL and TSALEFAC [1993], which showed that 1983 and 1984 years were characterized by high variability in precipitation with deficits in 1983 and surpluses in 1984 exceeding 30% in annual average in Yaoundé. According to these authors, the June-August quarter has the greatest contribution, since this quarter's surplus compared to the average reaches 140% in Yaoundé, which means that the small dry season did not manifest itself in its usual field. This situation was also observed in the works of ABOSSOLO & *al.* [2015] which argued that the regular climatic disturbances in the town of Yaoundé lead to the increase of floods. To protect the town from these floods, the Yaoundé city council has since a decade opted to run away people from high-risk areas and to reforest swampy lowlands and high-peaks slopes for their revitalization. For their part, the inhabitants of the town grouped into quarters development committees spontaneously organize sanitation work which consists in cleaning gutters and removing household waste without waiting for the assistance of the city councils. This is the same observation made by ASSAKO ASSAKO [2012] about the beautification operation and MABOU [2003] on the participatory development in the city of Yaoundé.

IV. CONCLUSION

The study on the vulnerability of populations to floods in the city of Yaoundé within the context of climate variability shows that the problem of floods is related to the combination of geographic, climatic, socio-demographic and environmental factors. The relief of the town consists of a set of hills interspersed by marshy valleys, climatic disturbances characterized by rainfall surpluses during some months and erratic dry season rains, urban growth and anarchic urbanization as well as the environmental incivility of inhabitants who dump solid waste into river beds or throw it into the nature, are the main factors that exacerbate the floods experienced in the town capital. (Have a look at this sentence again, it is seems as if something is missing. The sentence is not complete, and therefore not syntactically correct)These floods are all the more recurrent because they reproduce almost every year and affect a large number of people, leaving families completely affected by desolation. To prevent these risks of flood, the Yaoundé City council has initiated, for more than a decade now, a vast project of people displacement from risky areas and their reforestation. With the support of donors, the city council has also initiated a series of sanitation projects under the "PDUE" and "PADY" programmes. Populations try as much as possible to adapt to the phenomenon through general interest works which consists in cleaning gutters and removing garbage in their quarters, the raising of the foundations of houses, the construction on stilts, the development of pipes around houses to evacuate runoff and install cinder block walls onto the verandas of houses to prevent the overflow of these runoff. All these strategies, although deployed by the various stakeholders, do not always enable them to avoid floods in the city and to build a truly sustainable city.

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