Vulnerability Assessment of Flash Floods within Buea Municipality Using Field and Remote Sensing Techniques: Case of the 2020 flash flood

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Abstract: - Flash floods are usually associated with short, high intensity rainfall and they are characterized by short response time between 4-6 hours. This study sought to assess the following: i) the causes of flash floods in Buea Municipality; ii) the effects of the 2020 flash floods and damage assessment in two of the most affected localities (Bonduma and Sandpit); and iii) the social and physical parameters that increase vulnerability to flash floods in Bonduma and Sandpit. A descriptive research design was used to identify the causes and effects of flash floods in Buea. The 2020 affected areas: Bokwai, Bonduma, Bokoko, Great Soppo, Buea Town and Bokwaongo, were selected using purposive and stratified sampling method. Questionnaires, key informant interviews, focus group discussions and observations were used to collect field data. SPSS version 23 was used to analyze the data. The ENSURE and Flood Vulnerability Index methodology were used to carryout physical and social vulnerability assessment respectively in the two most affected localities. Parameters were chosen for the physical (building type, and construction properties) and social (age, employment status, education) vulnerabilities. Field ground truthing was used to collect field data, while satellite imagery from the Landsat sensor (Landsat TM and Landsat 8) was used to get land use/land cover changes for the sampled communities for the past 32 years (1986 to 2018) analysed using ENVI 5.1. GPS coordinates were collected from field mapping, and supplemented with shape files of buildings extracted from the OpenStreet Map software to assess damage and delineate the flash flood 2020 affected areas processed using ArcGIS 10.7. Findings from this study revealed that the main causes of flash flood as per the respondents' perspective were: heavy rainfall (41.5 %), wanton clearing of vegetation (17 %), climate change (15.6 %), topography (25.9 %), unsustainable building practices (43 %) and poor waste disposal practices (57 %). While the main effects as observed during the 2020 flash floods were: damage to infrastructure (37.6 %), agricultural losses and loss of life. A significant decrease (-46.95 km^2) was observed in the area covered by plantation/farmland; while settlement significantly increased (29.93 km^2). These two land cover classes were the major contributing factors to flash floods in the affected localities. Vulnerability analyses showed that Bonduma had a moderate vulnerability index of 3 compared to Sandpit with a low to moderate vulnerability index of 2.5 for the physical and social vulnerability classification on a scale of 5. The flash flood map generated showed that, 146 houses were affected within a surface area of 103,873 m^2 in Sandpit locality while in Bonduma just 94 houses were affected by the 2020 flash flood within a surface area of 134,429 m^2. Vulnerability assessment of flash floods within the two selected localities in Buea Municipality showed Bonduma to be more vulnerable.

Key-Words: - Flash floods, physical vulnerability, social vulnerability, ENSURE methodology, land cover, Buea

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1 Introduction

The occurrence of flash floods is a natural phenomenon and a globally pervasive hazard arising from the sudden release of water due to heavy rainfall, or the sudden release of impounded water in a dam occasioned by a landslide, ice jam in a river or because of a glacier lake outburst [1]. A major difference between a flash flood and a riverine flood is the short basin response to rainfall, which allows for very short lead time for detection, forecast and warning [2]. Furthermore, anthropogenic pressure on the land and spatial expansion processes for both rural and urban settlements in areas exposed to flood risk, lead to flood vulnerability.

Physical vulnerability assessment is often carried out after flood events on affected buildings for parameters such: building type and building materials [3]. This pattern of research began after it was realized towards the end of the twentieth century, that the effects of disasters within a population were unevenly distributed, with some of the localities and population subgroups afflicted disproportionately by disaster outcomes [4, 5].

Vulnerability reflects the characteristics of a person, group of people in terms of their capacity to anticipate, cope with, resist and recover from the impact of the natural hazard [6]. The physical factors that have influence on vulnerability to flash floods are: land cover and land use, nature of the population (age, health, mobility), degree of built-up areas, type of buildings and the ability to forecast and strategize for imminent hazardous events [7]. Social vulnerability assessment detects the population most at risk and can help to determine the emergency responses that may be essential for temporary shelters and evacuation parameters [8]. Social vulnerability indicators include: age, employment status, coping capacity, awareness and education.

In the last three decades, flash floods have become one of the most severe natural hazards worldwide [9]. Majority of these occurrences have been linked to global warming and climate change [10]. Flash floods are responsible for 44% of the death caused by natural hazards worldwide, especially in arid regions [11].

In Africa, extreme flash floods are often experienced in the Mediterranean countries and tend to be greater in magnitude compared to the inner continental countries, where they occasionally produce catastrophic damages [12]. For example, since the year 2000, numerous flash floods events have been recorded along the Egyptian Red Sea Coast, which has experienced 30 medium and large events this century alone [13]. In East Africa, at least 65 people were killed in flash floods and mudflows due to two months of relentless rains which began in October 2019 [14]. Kenya was the hardest hit with 132 recorded deaths and 17,000 displaced people [14]. Also, in Kenya's mountainous areas of Elgon, flash floods have become an annual event, claiming a number of lives and properties due to failure of dykes [14].

In Cameroon, flash floods have become the main fatality producer from convective storm related events in various regions of the country like in the South West, Littoral, Central, West, North West and Far North [15] and they make up 12 % of all natural hazards that occur yearly in the country [16,17]. The rate of disaster occurrence of flash floods in Cameroon is on the rise with changing climatic regimes. Towns such as Santchou (West Cameroon) in 2017 and 2020 recorded losses resulting from flash floods, which were rare scenarios before this period [18]. Limbe, a city in the West Coast of Cameroon found SW of Mount Cameroon is noted for its yearly experiences of floods especially during the rainy season. The 2011, 2014 and 2018 floods in Limbe affected about 3000 people within the neighbourhood of Mabeta, Mbonjo, Clerk's quarter, Towe and Motowoh [19]. Recently in 2023, the city of Limbe was drenched by continuous heavy rains from 18 to 19 July 2023 that resulted in flooding and landslides which directly affected 1,600 people; destroyed close to 250 homes and business premises and led to the death of at least 3 people with others injured [20]. The flooding was largely due to run-off water and unplanned construction, which prevented water from circulating normally. Recently, Tiko Municipality that comprise of Tiko and Mutengene towns found in the SE flank of Mount Cameroon, began experiencing flash floods. Its August 2018 and 2022 flash floods in Tiko town generated landslides resulting in severe damage to major road infrastructure, and properties, large losses to agricultural crops and poultry (over 3000), and even deaths [21].

The city of Buea which host most of Mount Cameroon volcano is not just vulnerable to volcanic eruptions and its associated hazards, flash floods have proven to be the most recent hazards in Buea with the latest being the 18th March 2023 flash floods that left two dead, 4 injured, directly affecting an estimated 900 persons in Bova, Bokwai and Buea Town neighbourhoods were several houses and business sites were destroyed [22] displacing thousands of people. This flood was triggered by a short period of torrential rains that transported significant amount of remobilized pyroclastic material from Mount Cameroon at high velocity. Prior to this flash flood, the March 2020 flash flood which is the topic of discussion in this work occurred leaving one dead and several properties destroyed.

This study therefore sought to assess the parameters that enhanced vulnerability to flash floods within Buea municipality. Specifically, it sought to: i) identify the causes and effects of flash floods in the Buea Municipality; ii) assess the factors that influenced social vulnerability of the exposed community; iii) assess physical vulnerability of the built environment to flash floods; and iv) map out the 2020 flash floods affected areas. In order to reduce disaster risk to flash floods in the city of Buea, it is vital to assess the vulnerability of flash floods because more people and property are being placed in harm's way or in places of higher risk under conditions of increasing and more diverse vulnerability. Without effective flood risk management, the scale of the impact of flood disasters on people, property, local industry, and economics in the Buea municipality, will increase [23].

1.1 Description of Study Area

Buea sub division is located between latitudes 9.2632° and 4.1560° N of the equator (Fig.1). Buea is the capital of the South West Region of Cameroon (Fig.1) located on the eastern slopes of Mount Cameroon volcano which is the most active [24] and highest mountain in West-Central Africa at 4100 m above sea level [25]. As at the 2013 census results, the city of Buea hosted an estimated population of ~300,000 inhabitants [26]. This number has significantly increased as the population today is estimated at ~ 500,000 people. This increase is linked to the influx of internally displaced persons (IDPs) fleeing other parts of the SW and NW Regions of the country which are more affected by the on-going civil strife.

Buea is characterized by a tropical monsoon climate with an average temperature of 27°C high and 17°C low, with the hottest month being February and the coldest August [27]. Temperature in the area varies from an average of 25.5 to 27 °C at the base of the mountain to about 32 to 35 °C during the hottest months (March and April). However, at the summit, temperatures can be as low as 4 °C. The decrease in temperature for each 100 m increase in altitude is 0.60 °C and humidity remains at 75-85 % due to marine influence and the incidence of mist and orographic cloud formation. [28], reported that, this area has two distinct seasons, the very wet season (between June and October) and dry seasons (between November and May). It has an average monthly rainfall of ~373 mm. The south western sides of Mount Cameroon have a continuous wet rainy season reaching 10,000 mm a year at Cape Debundscha and a tropical climate at low sea level. On the other hand, the north and eastern sides of the mountain lie in a relative rain shadow receiving just about 2,000 mm per year. In general, the region receives ~3,500 mm of rainfall per annum.

The relief of Buea is dominated by Mount Cameroon (~4100 m high), a stratovolcano which is made up of intercalations of erupted volcanic lava and pyroclastic material [24]. Volcanic materials from previous eruptions have been weathered over the years and today, they form excellent agricultural lands, which favour the cultivation of many melliferous trees. It is also characterized by steep valleys with a dense forest cover, together with dry valleys and rock cliffs marked by escarpments, and a few swift streams [29]. Buea municipality is branded by a dendritic drainage pattern. Mount Cameroon region has predominantly rich volcanic soils of recent origin [30]. These soils are mostly found on young volcanic rocks and are fertile. The rich volcanic soils in the area explain the presence of the Agro-Industrial company, the Cameroon Development Corporation (CDC) in the area. CDC has taken advantage of the fertile soils and has established vast banana, tea, rubber and palm plantations in the region.

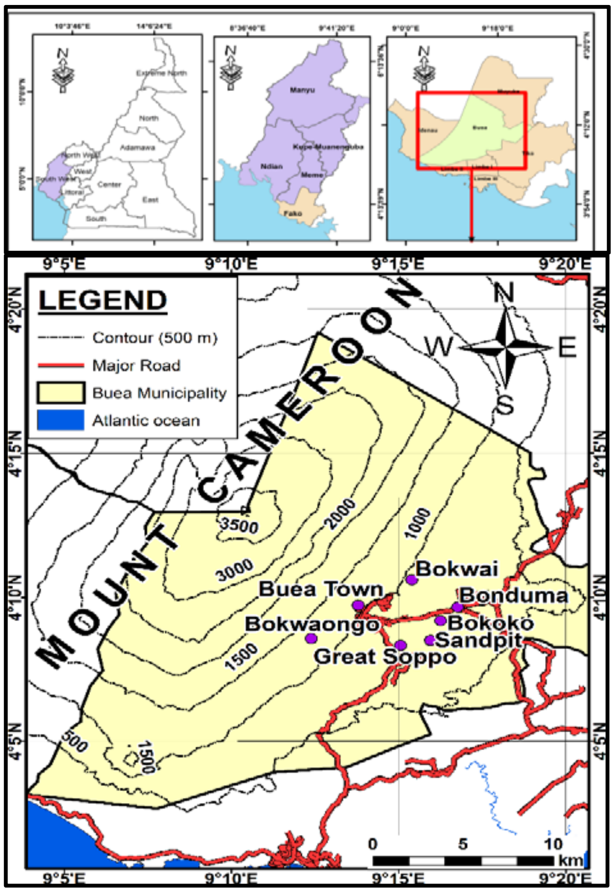

Fig.1: Map of Buea municipality showing the sampled localities. Inset: maps of Cameroon, the South West Region and Fako Division (Buea within red rectangle)

2 Materials and Methods

2.2 Data Collection and Instrumentation

2.2.1 Research Design

A descriptive research design that provided quantitative and qualitative data was used in this study to determine the causes and effects of flash floods. While the Enhancing resilience of communities and territories facing natural and Na-tech hazards (ENSURE) methodology [31] was used for the physical vulnerability assessment. The Flood Vulnerability Index tool adopted from [32] was used to assess social vulnerability.

2.2.2 Questionnaire Administration

In the realization of specific objectives one and two, which was linked to determining the causes and effects of flash floods with emphasis on the 2020 flashfloods, purposive and proportionate sampling methods were used to obtain the sample size. Six (6) localities were purposively selected based on the impact of the 2020 flash flood in these areas. The chosen localities included: Bokwai, Bonduma, Bokoko, Great Soppo, Buea Town and Bokwaongo localities being those highly affected by the 2020 flash floods in the Buea Municipality (Fig.2).

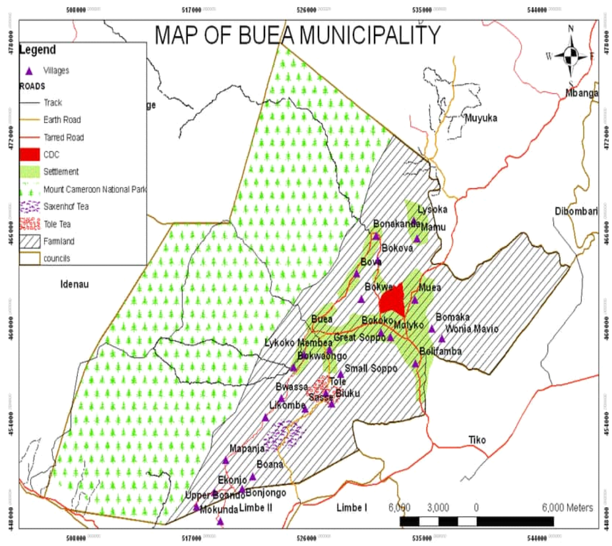

Fig.2: Map of Buea Municipality showing all the localities that make up the municipality

The target for questionnaire administration for these objectives were households. The equation of [33] (1) was used to realize this.

$$n = \frac{N}{1+N(e)^2} \text{ ----------------------- (1)}$$

Where: n = sample size; N = the total number of households per locality and e = 0.5.

These 6 localities had a total of 34,300 households [34]. Using equation 1, a sample size of 399 households were obtained to be used for the study. [35] equation (2) was further used to get the household proportion to be sampled for each of the 6 localities as presented in Table 1.

$$n_h = n\, {}^{Nh}/_{N} \text{ ---------------------------(2)}$$

Table 1: Ratios as per household population in the locations

Location	No. of households	Sample size
Buea Town	3,000	35
Bokwaongo	2,000	23
Bonduma	6,000	69
Bokwai	1,000	12
Bokoko	300	3
Great Soppo	22,000	256
Total	34,300	398

The questionnaire had open-and closed- ended questions which were administrated to household heads and household members from the ages of 18 years and above. The age 18 years was chosen because, it is a stage in life when people are legally considered mature and can take full responsibility of their actions. This data was supplemented with key informant interviews using an interview guide. The interviews targeted individuals who were knowledgeable about the flash floods, in the selected localities. Additional information was obtained by the research team through field observation at the 2020 flash flood affected sites with the aid of a checklist and collection of field photographs. Lastly, focus group discussion (FGD) sessions were held with a range of 6-12 persons in each of the selected 6 localities. Participants of the FGDs were purposively selected by the traditional rulers in the respective localities.

2.2.3 Landcover Analysis

Land cover analyses was carried out for a period of 32 years (1986 to 2018) to supplement the data on objective one as to the causes of flashfloods. The images used were obtained free of charge from the United States Geological Survey (USGS) website from the Landsat Thematic Mapper (TM 1986) and Landsat 8 (2018) satellite sensors (Table 2).

Table 2: Satellite Data

Satellite/ Sensor	Date of scene	Spatial Resolution	Number of bands
Landsat Thematic Mapper	12/12/1986	30 m	7
Landsat 8	18/08/2018	30 m	14

These images were acquired already georeferenced (UTM 32N, WGS 84). They were processed using the ENVI 5.1 software to determine changes that had occurred over time using Bands 7, 5, 4 and 2 respectively. The images were classified using the maximum likelihood supervised classification option into 6 classes: lava (cooled material from past eruptions from Mount Cameroon); montane forest (dense network of trees found in the uppermost part of Mount Cameroon); lowland forest (dense network of trees with think canopy found at the flanks of Mount Cameroon); plantation/farmland (large-scale agricultural land owned by the Cameroon Development Corporation (CDC) for economic generation; and small scale agricultural land owned by local farmers for subsistence purposes); settlement (area consisting of buildings (administrative, commercial and residential)); road infrastructure and gardens) and cloud cover. The classified images were used to detect changes that had occurred using the change detection confusion matrix in ENVI 5.1. The statistics generated were interpreted.

2.2.4 Physical and Social Vulnerability assessment

In the realization of objective 3, the Flood Vulnerability Index adopted from [32] was used to assess social vulnerability; while the ENSURE methodology [31] was used for the physical vulnerability assessment. Using purposive sampling, two localities were chosen for these assessments. The two localities chosen were: Bonduma and Sandpit (a sub-section of Great Soppo; see Table 1). The criteria used in the selection of these localities was based on the fact that they were among the areas most affected by the March 2020 flash floods. Purposive sampling using equation 2 [35] was further used to select the household respondents based on their age and knowledge/experience of the flash flood using the statistics provided by [34] presented on Table 3.

Table 3: Ratio of household per community

Location	No. of households	Sample size
Bonduma	6000	25
Sandpit	1000	19
Total	**7000**	**44**

Following the Flood Vulnerability Index of [32], a set of parameters were chosen for the social vulnerability alongside demographic and the parameters were: age, level of education, employment status, reasons for presence in risk zone and the coping strategies. Using the ENSURE methodology check list, the following parameters were checked to assess physical vulnerability: 1) foundation depth and type; 2) basement existence; 3) shape of buildings with regards to openings; 4) maintenance conditions; 5) floor rigidity; 6) building material; 7) material used in construction; 8) type of building; 9) elevation of first floor with regards to flash floods; and 10) conditions of embankments. For critical infrastructure, the following parameters were checked: 1) type of road (paved or unpaved); 2) road network (poor or good); 3) position of water pipes (underground or exposed); 4) bridge (present or not, condition, materials) and 5) electricity and communication line (position and condition). Numbers ranging from 1 (very low) to 5 (very high) were allocated to assess the vulnerability.

2.2.5 Delineating the 2020 Flash Flood Affected Areas

This was realized through field ground truthing of the two selected most affected localities: Bonduma and Sandpit. GPS coordinates were collected at these sites and the data transported in ArcGIS 10.7.2 to demarcate the affected surface areas in these localities. Using Openstreet Map data on building infrastructure, further estimation was made to know the number of houses that were affected in these localities.

2.3 Data Analysis

Quantitative questionnaire data for the 399 targeted households were entered into a pre-designed SPSS 23.0 spreadsheet database which has in-built consistency. Data range and validation checks were performed in order to identify invalid codes. Data was made of scale and categorical variables and they were explored using frequency tables. Open-ended

questions were analysed through a process of thematic analysis where responses were grouped into major themes and quotations given to describe these themes. Data from the interview guides and FGD sessions were transcribed and presented as qualitative data. Field observations were presented as qualitative data and the collected photographs used to illustrate the information presented.
Data analysis for physical vulnerability assessment of buildings within the Buea Municipality, involved a comparative analysis and scoring. For the social vulnerability, field data was coded and transferred into Microsoft excel for analysis. It was analysed and presented on tables.
The GPS coordinates collected for the two communities were input into ArcGIS 10.7.2 together with building infrastructure for the area collected from the Open Street Map website. This information was used to delineate the most affected areas in Bonduma and Sandpit.
The collected GPS coordinates were used in combination with the shapefiles for the affected buildings to produce maps in the ArcGIS 10.7.2 software for the 2020 flash flood affected areas and calculate the affected surface areas. These coordinates were inserted into an excel sheet and transferred to the GIS software (ArcGIS 10.7) for this process to be realized. Microsoft Office Excel Version 10.0 was used to produce graphs and statistical tables from the quantitative data generated from the questionnaires.

3 Results

3.1 Causes of flash floods

3.1.1 Natural Causes

Findings from this study as per the respondents revealed that the natural causes responsible for flash floods in Buea Municipality were: heavy rainfall (41. 5 %), topography (25.9 %), wanton clearing of vegetation (17 %) and climate change (15.6 %) (Fig. 3). Heavy rainfall is believed to play a significant role in flash flood occurrence in Buea municipality due to the fact that the March 2020 flash flood occurred after a period of intense rainfall, same with the recent March 2023 flash floods. This points to the fact that these flash floods are associated with heavy rainfalls, characterized with low percolation and infiltration rates arising from poor drainages and lack of vegetation cover in the area.

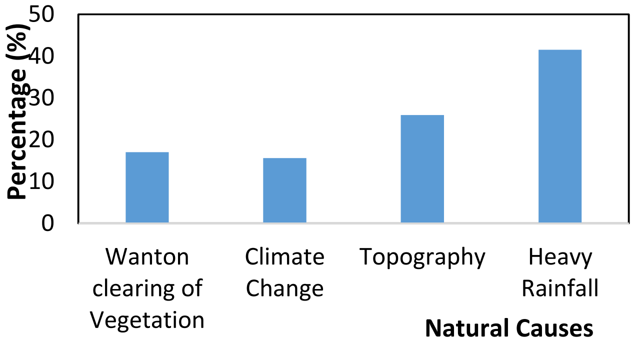

Fig.3: Plot showing the natural factors which are believed to be responsible for flash floods in Buea Municipality

3.1.2 Anthropogenic Causes

A. Respondents' Perception

The two main anthropogenic causes of flash floods in the municipality as cited by the respondents were: poor waste disposal practices (57 %) and unsustainable building practices (43 %) (Fig.4a&b).

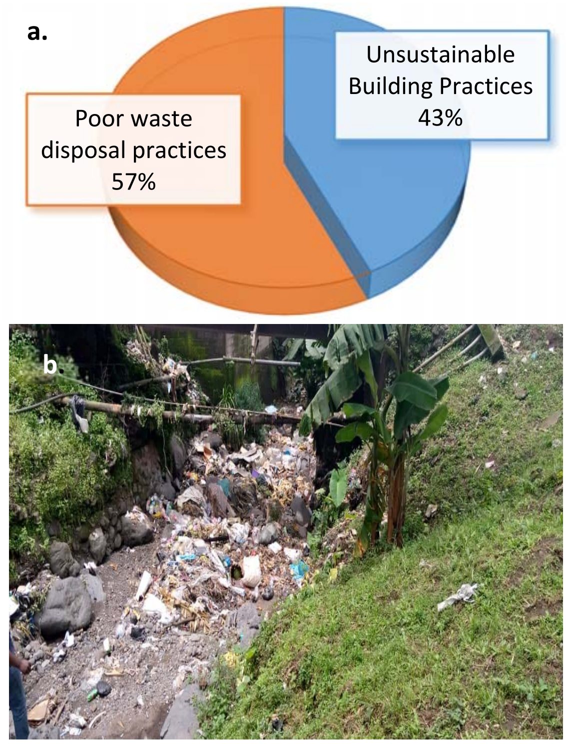

Fig.4: Anthropogenic causes of flash floods represented on: **a.** pie chart and **b.** photograph showing poor waste disposal within a water channel in Bakweri Town (a locality in Buea)

B. Landcover Analyses (1986-2018)

Change detection carried out on the identified land cover classes (6) produced the statistics presented in Table 4.

Table 4. Change Detection Statistics between 1986 and 2018

Land cover Classes	Years	
	1986 Area (km^2)	2018 Area (km^2)
Older Lava	66.09	61.82
Recent Lava	2.61	9.19
Montane Forest	19.98	8.63
Lowland Forest	84.55	103.77
Plantations / Farmland	112.56	65.6
Settlement	18.74	48.67
Cloud Cover	58.25	18.3

From Table 4, a significant decrease (-46.95 km^2) was obtained in the surface area covered by plantation/farmland; while settlement significantly increased (29.93 km^2). There was a -4.27 km^2 reduction in older lava attributed to weathering and erosional processes that had occurred over time causing the lava to disintegrate into soil. The increase in recent lava (4.58 km^2) resulted from the recent Mount Cameroon volcanic eruptions in the years 1999 and 2000. For the montane forest, the percentage change detected was 84.60 % and the net change obtained was -11.36 km^2. The -11.36 km^2 indicated a reduction in the montane forest from 1986 to 2018 (Fig.5). This reduction can be attributed to recent volcanic eruptions that produced lava which led to the destruction of the montane forest. Also, the culture of burning the vegetation during the dry season could also have contributed to the reduction. Increase in the lowland forest over the years could be attributed to legislature that demarcated the forest area at Mount Cameroon as a forest reserve (Fig.5).

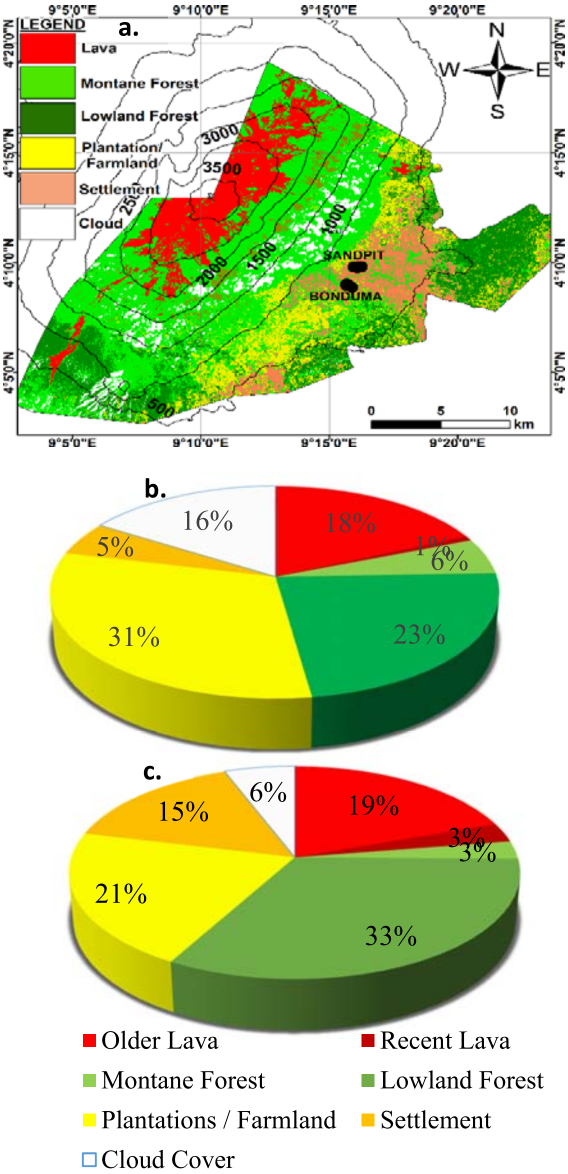

Fig.5. Illustrations showing: **a.** supervised classified image of 2018 showing the different land covers in the Buea Municipality in 2018; **b & c.** total surface areas (%) covered by the different land covers in Buea Municipality in 1986 and 2018 respectively.

3.2. Effects of the 2020 flash floods

Taking the case study of the 2020 flash floods and the impact it had on buildings; 37.65 % of the respondents cited that they incurred minor damages to their houses; while 10.59 % registered complete damage (Fig. 6). In terms of other losses caused by the 2020 flash floods, 25 % mentioned agricultural losses; 15 % mentioned the death of animals; 35 % mentioned the loss of household items; while <5% mentioned the loss of human life.

From the key informant interviews carried out, there were losses incurred by farmers during the 2020 flash floods specifically in localities with less self-regulatory measures. Further damage analysis carried out using ground control points and Openstreet data revealed that, approximately 94 houses were affected by the March 2020 flash floods in Bonduma, occupying a total surface area of ~ 134,429 m^2 (Fig.7). While in Sandpit, ~ 146 homes were situated in the affected area (~ 103,873 m^2). In both localities, agriculture and settlement were the main land use activities.

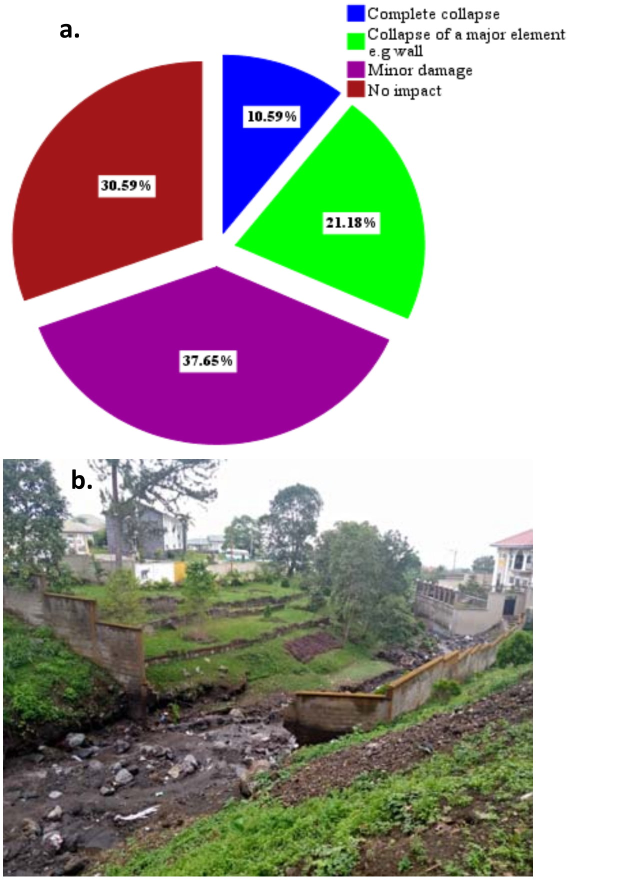

Fig.6. Physical impact of the 2020 flash floods on buildings represented on: **a.** pie chart and **b.** damaged wall at Federal Quarters (Mountain Hotel Area)

The map in Fig.7 backed by field observation showed that, the most affected houses and roads were located in the centre of Sandpit. While in Bonduma, the most affected areas and houses were those towards the Bokwai road (Fig. 1).

3.3 Vulnerability to flash floods

3.3.1 Social Vulnerability Assessment

Looking at the socio-demographic characteristics of the respondents in Bonduma and Sandpit, most of them were females (52%) characterised with an equal proportion of teenagers and adults (39 % each); single (46 %), did not own the houses they lived in (60 %) and were government employed/owned private businesses within the Bonduma and Sandpit localities (Table 5).

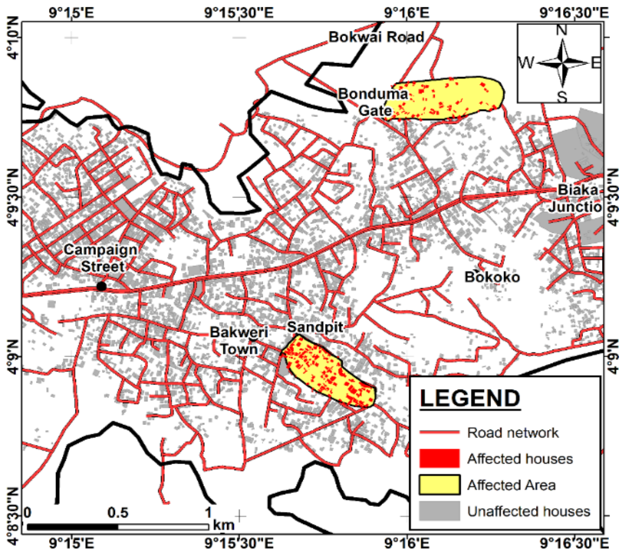

Fig.7. Flash flood affected areas in Bonduma and Sandpit. The yellow colour represents the affected areas while the red colour represents the affected houses.

A good percentage (37 %) of the population earned above 100,000frs (> $165) and lived in homes occupied by 4-6 persons (48 %). A good number of them had inhabited these localities because of cheaper rents and proximity to their job site / schools (Table 5).

Using the Flood Vulnerability Index, findings revealed that 47 % of the population in Sandpit were above 35 years old, while the dominant age range in Bonduma was between 18-35 years (48 %) (Table 6). In terms of education, in both localities the dominant percentage of the educated ones had attained higher education (42 % in Sandpit and 68 % in Bonduma) with just ≤ 5 having no formal education.

In terms of employment, 68 and 40 % of the respondents in Sandpit and Bonduma respectively had permanent employment while 4 and 32 % respectively were engaged in part time jobs (Table 6). Unemployment in both localities ranged between 21 and 28 %. In both Sandpit and Bonduma, ~ 68 % of the respondents were aware that they were living in flash flood prone areas. However, their reasons for settlement ranged from: had no alternatives since they owned the houses (40%), presence of cheap and affordable house rents (20-31%), had inherited land (15%) and the ability to control the runoff water (Table 6). In both localities, over 60 % of the respondents attested that they have constructed embankments and raised their foundations as coping strategies to flash flood hazard (Table 6).

Table 5: Socio-demographic characteristics of respondents in Bonduma and Sandpit

Characteristics	Frequency	Percentages (%)
Gender		
Male	21	48
Female	23	52
Marital Status		
Single	21	46
Married	17	37
Widow	04	11
Widower	02	06
House Ownership		
Owner	18	41
Tenant	26	59
Reasons for Habitation		
Cheap Rents	10	20
Cheap Land	8	15
Proximity to school/work place	5	15
Others	21	50
Monthly income (FCFA)		
20,000-36,000	7	16
40,000-60,000	12	27
80,000-100,000	8	18
> 100,000	17	37
Household Size		
1-3	13	30
4-6	21	48
7-10	9	20
> 10	1	2
Household Population		
Children	10	22
Teenagers	17	39
Adults	17	39
Breadwinner		
Father	20	45
Mother	11	25
Others	13	30
Total	**44**	**100**

3.3.2 Physical Vulnerability Assessment

A total of 44 buildings were assessed in the Bonduma and Sandpit localities within Buea municipality, using the ENSURE methodology as presented in Table 7. In both Sandpit and Bonduma, most of the buildings were constructed using reinforced concrete; they were single buildings, with low floor elevation and characterized with superficial foundations.

Table 6. Social Vulnerability Characteristics of respondents in Sandpit and Bonduma

Characteristics	Sandpit (%)	Bonduma (%)
Age (Years)		
18-35	20	48
36-50	47	32
51-55	33	20
Education		
No formal	5	4
Primary	16	4
Secondary	37	24
Higher	42	68
Employment Status		
Employed	68	40
Unemployed	21	28
Part-time	4	32
Reason for habitation		
Inherited land	15	20
House owner	23	40
Cheap and affordable rents	31	20
Runoff is controllable	31	20
Mitigation		
Embankments	79	32
Raised Foundations	21	68

However, the foundations looked good and solid, well maintained in Sandpit while those of Bonduma were poorly maintained. Notably, over 80 % of the houses were located parallel to the direction of the water channels with very well constructed gutters made of concrete embankments in both localities. These buildings were observed to have numerous openings that could easily be sealed with sediments and they had no basements.

From field observation the houses built with wood were more vulnerable to floods when compared to the reinforced concrete houses. This was because, the wood absorbs water during flood episodes and depreciates over time. Thus, even though most of the houses were in good condition, their elevation with regards to flash floods was not good. The single buildings with low elevation were more vulnerable to flash floods because properties are easily destroyed once water inundates them due to the lack of space to keep properties safe when compared to those in storey buildings.

Table 7. Physical vulnerability assessment of buildings to flash floods in Sandpit and Bonduma

Characteristics	Sandpit (%)	Bonduma (%)
Building typology		
RC house	89	100
Wood house	11	-
Types of buildings		
Storey	16	8
Single	84	92
Number of floors		
>2floors	16	8
1 floor	84	92
Elevation of first floor		
Low	47	28
Medium	21	56
High	32	16
Connection among parts		
Good	74	96
Poor	26	4
Floor rigidity		
Rigid	68	88
Non-rigid	32	12
Foundation depth		
Deep	32	24
Superficial	68	76
Condition of foundation		
Good	68	94
Poor	32	6
Maintenance condition		
Good	53	35
Poor	32	55
V. good	15	10
Position of House to Drainage System		
Parallel	89	79
Perpendicular	11	21
Condition of gutters		
Good	68	96
Poor	32	4
Quality of openings		
Easily sealed	98	100
May not	2	-
Existence of basement		
Non-existence	100	96
Existence	-	4

NB: RC = reinforced concrete

Storey buildings and buildings on elevated pillars (soft-storey buildings) fared better because as the water level rises, properties could be transferred to the upper floors and thus will be preserved. For storey buildings with lower elevations, water could easily seep in through the foundations since most of them were in good shape but superficial and low. Despite their low elevation level, the foundations were in good conditions and well maintained (Table 7).

In Sandpit, majority of the houses were situated parallel to the direction of the water channel. This implied that flood water did not have direct access to most of their houses but only affected those that were situated within and /or close to the water channel. Houses found close to water channels in this locality suffered from erosion and land subsidence making these sites risky to the inhabitants and their children. Over time, once all the soil has been removed, the water starts eroding the base of the foundation of these houses as observed during fieldwork. To address this problem, some house owners living at the banks of these water channels have constructed embankments and others made use of sand bags placed around their building to prevent the water from eroding the soil and subsequently their foundations.

The absence of basements in these houses made them less vulnerable to flash floods. This is because basements are the lowest part of a house and thus easily inundated by flood waters.

The sampled houses in Bonduma were all reinforced concrete, single, had rigid floors but poorly maintained with medium elevation. These houses were mostly affected because of the elevation level and poor maintenance. Just like in Sandpit, the position of the water channels in Bonduma was parallel to the houses. However, unlike in Sandpit, a good number of the water channels/gutters had embankments with few in poor form which led to the water overflowing and inundating some houses. Some of the gutters in Bonduma were extremely deep and wide in some areas due to absorption of water by the soil thus, making it loose.

From the parameters evaluated in Table 7, the vulnerability level of buildings in Sandpit and Bonduma was classified thus: a) building type (very high vulnerability); b) building materials (very low vulnerability); c) floor elevation (moderate vulnerability); d) foundation (moderate vulnerability); e) building maintenance (high vulnerability); f) building position (low to high vulnerability); g) drainage system (moderate to high vulnerability) and h) building shape (very low to low vulnerability) (Table 8).

Table 8: Vulnerability levels of buildings in Sandpit and Bonduma

Building infrastructure								
Location	**Aspect parameters**							
	a	**b**	c	**d**	**e**	**f**	**g**	**h**
Sandpit	Red	Green	Orange	Orange	Orange	Blue	Yellow	Blue
Bonduma	Red	Green	Yellow	Yellow	Orange	Orange	Orange	Green

NB: Green= Very low Vulnerability (1); Blue = Low Vulnerability (2); Yellow = Moderate vulnerability (3); Orange = High Vulnerability (4); Red = Very High Vulnerability (5)

Further assessment carried out for critical infrastructure (road network, water pipes, bridges, electricity poles and cables; and communication network) showed that in both Sandpit and Bonduma, over 80 % of the roads were unpaved, poorly maintained but considerably utilized (Table 9). Unpaved roads during floods can experience collapse of certain part of the road which can reduce its usability. This was observed in some roads within the sampled community which were eroded by the 2020 flash floods leaving the road in a bad condition.

The observed water pipes in these localities were mostly exposed to the surface, with most of them; broken or rusted. Most of the pipes seem to be exposed by the run off of the floods that washed away the soil. The exposed pipes were vulnerable not only to contamination but to moving cars which could cause them to break in case they drive pass on it.

About 70% of the bridges in Sandpit were poorly constructed with wood across the water channels and most of the wood were already depreciating (Table 9). This made the bridges risky for the users. Even though there were a few bridges across the gutters under construction, they seemed abandoned. The electricity and communication lines and poles in both localities were aeriated and of good condition making them less vulnerable to flash floods.

Both communities showed very high vulnerability for the road condition (Table 9). These roads are the basic transport infrastructure in the area and link these localities with others. Therefore, if the roads are in bad condition with very high and high vulnerability level for the bridges, it only exposes these communities to flash floods because when the water comes, it spread across the bad roads due to the lack of good drainage channels.

Additionally, the water pipe conditions in both localities showed high vulnerability level due to the fact that most of the pipes were exposed and some cracked. Electricity and communication lines showed low and very low vulnerability, meaning they were in good shape and did not pose any form of harm to both localities during flash floods occurrence or prior to flash flood.

A summary of the physical vulnerability analyses as presented on Tables 7, 8 and 9 for buildings and critical infrastructure respectively, revealed that Bonduma has a moderate vulnerability index (3) to flash floods while Sandpit has low to moderate (2.5) vulnerability. This can be attributed to the nature of the critical infrastructure, building type, maintenance, position and drainage system in these localities.

Table 9. Physical vulnerability assessment of critical infrastructure in Sandpit and Bonduma

Characteristics	Sandpit (%)	Bonduma (%)
Road network		
Paved	10	17
Unpaved	90	83
Road Condition		
Good	10	17
Poor	80	83
Road usability		
Poor	37	57
Medium	53	26
High	10	17
Position of water pipes		
Underground	42	33
Exposed	58	67
Condition of water pipes		
Rusted	43	36
Not rusted	57	64
Condition of bridges		
Good	30	25
Poor	70	75
Availability of Bridges		
Yes	47	65
No	52	35
Materials used on bridges		
Resistant	30	100
Weak	70	
Electricity and communication lines		
Aerial	100	100
Underground		
Conditions of electric poles		
Good	63	82
Poor	37	18

4 Discussion

The natural causes of the 2020 flash floods in Buea Municipality which primarily included heavy rainfall, topography, vegetation removal and climate change are consistent with studies carried out by [36] in Western Kenya, who also associated heavy rainfall to flash flood occurrence. Vegetation cover is important in checking the speed of water and holding it back so that the effect of the flash flood water is minimized and the loss of life, property, soil erosion and biodiversity is controlled. [37] found out that loss of vegetation cover increases the chances of flash floods through run-off.

Climate change has been attributed to be one of the leading causes of flash floods in the world today ([38]. However, climate variability plays a more significant role in the flash floods of Buea municipality, than global climate change. Topography was also cited by the respondents to significantly contribute to flash floods in the municipality. This was tied to the fact that Buea municipality is located on the slopes of Mount Cameroon, making flash flood run off to move with speed hence causing impact as was realized by [39] in seasonal flow forecasting Africa.

Anthropogenic causes of the 2020 flash floods in Buea municipality based on questionnaire analyses, were linked to poor waste disposal practices and unsustainable building practices. Poor waste disposal practices cause flash floods through blocking of water paths and raising of the water path floor ([17]. The population in Buea municipality has significantly increased (~ 500,000 people now from 130,000 in 2010; [26]) in the last two decades linked to the creation of the University of Buea and other higher institutions of learning and the ongoing civil strife in Anglophone Cameroon. Increased population means increased waste with limited facilities to handle the waste [17]. The municipality has very narrow drainages. The act of constantly cleaning these drainages without creating bigger channels, does not help the situation. This result conforms to that of [40], who reported that poor drainages and uncontrolled dumping of household waste amongst other material greatly enhance flash floods.

Increased population has also resulted to unsustainable building practices that do not conform to building regulations in the municipality. This factor has also significantly contributed to the occurrence of flash floods in the study area. The adoption of poor building practices such as over clustering has altered the natural drainages resulting to increased surface run-offs which generate flash floods [36].

Plantation/farmland and settlement were the two land cover classes that showed a significant change. The decrease in plantation/farmland contradicted the study carried out by [41] in the Madarsu Basin Northern Iran who registered an increase in agriculture from 1960 to 2003 and attributed the increased in agriculture to population increase in the Madarsu Basin of Northern Iran. The decrease in plantation/farmland at the flanks of MC, significantly increases the probability of flash floods as cited by [37]. The increase in settlement witnessed between 1986 and 2018 within Buea Municipality, conforms to the analogy by [36] that population increase has resulted to over clustering of buildings which have altered the natural drainages thus causing increase run-offs which produce flash floods.

A study by [42] in Nyando district, revealed that the effects of flash flood such as loss of livelihood, change in ecosystem and loss of plant and animal lives are felt by the poor members of the society. This assertion was corroborated with field evidence, which projected that people living within the study area were subjected to abject poverty. Additionally, there were no self-regulatory measures put in place for the community members to mitigate the impacts of these floods.

The map of the flood affected areas in Bonduma and Sandpit (Fig.7) is in line with [43], whose findings indicated that, the 2007 extreme flooding inundated the Nasia community in Ghana had cut-off road access to some other communities.

The generated results from the social vulnerability index, revealed that majority of the respondents were dependants (children and teenagers) which increases vulnerability to flash floods. This conform to what [44] said that very young and elderly people are more vulnerable to natural hazards such as flash flood. Majority of the households were inhabited by single women with a few widows who are also in the category considered to be most vulnerable to natural hazards. This supports [45] who said that the effect of disasters is not neutral. According to [46, 47], in the study of visual representation of gender in flood coverage in Pakistan, disasters magnify existing inequality, reinforcing the disparity between men and women with regards to vulnerability and the capability to cope with its consequences.

Most of the respondents were educated and fully aware of their exposure to flash floods yet still persisted in inhabiting these localities. This is in alignment to what [48] observed in Bangladesh that higher level of education may result to increased asset ownership where damage costs from floods events are higher for wealthier households in absolute costs. However, flooding damage cost represent a lower proportion of the total income and capital of wealthier households. Another study by [49], confirmed that the participants who demonstrated good knowledge of understanding factors that contributed to local floods susceptibility and disaster risk, including geographic features such as flat topography, high numbers of vulnerable people and bungalows, stayed in place.

Most of the respondents affirmed that they could cope and implement mitigation strategies to cope with the hazard. This is in line with the studies of [49], whose participants agreed they could cope with the floods hazard and outlined supporting each other in their community during flood preparation and response as a means of limiting its effects.

A significant percentage of the respondents were employed though still living in flash flood prone areas due to low income. This conforms to the research of [50] in New Orleans, who observed that not only do poorer and marginalized populations often live in highly exposed zones with less employment and housing opportunities, they are also less protected by formal institutions such as those that provide disaster mitigations and recovery assistance.

Findings from this study for physical vulnerability assessment in Sandpit and Bonduma revealed that houses with lower elevation levels were more vulnerable to inundation during flash floods. This finding is in alignment with studies carried out by [51] in her study on physical vulnerability assessment to flood in Saint Lucia which revealed that the height of buildings above the ground is important for floods.

Also, the results from this study revealed that reinforced concrete is the most used material for construction of houses in both localities. This conforms to the result of [51] who found out that, reinforce concrete materials out of the eight-materials type used in her study location was the most used wall material by the people of the Dennery village because of its resilience in withstanding the impact of fast water currents with debris.

Embankments were used as a mitigation measure to control flood waters from entering into homes in both localities. This contradicts the research of [52] in a study carried out on the impact of coastal embankment on flash floods in Bangladesh. Their result proved that construction of embankments instead generated more problems to worsen their yearly floods. Taking the case of the 2020 floods, these measures were only partially effective in the affected communities due to the large scale of destruction that ensued.

The foundation of buildings in both localities had moderate vulnerability level. This is in line with a study by [53], who found out that buildings could be surrounded with flood water, at high depth or velocities, but their resistance due to construction materials, structure and foundation reduces their vulnerability.

Findings from this study indicated that building position had low to high vulnerability to flash floods. This contradicted with the study of [53] which proved that, if flash floods are not able to cause significant damage because of the building location/position on the flood plain, the presence of other buildings/ infrastructure, or existing mitigation measures, then their vulnerability will never be high.

The topography of Sandpit is less steep, while that of Bonduma is steeper. This is in line with [40], study carried on the correlation between flood disaster and topography in Zhaoqing City. Their findings revealed that the lower the terrain absolute height and less degree of terrain changes, the more vulnerable the flood disaster.

For the critical infrastructure parameters, road network showed high to very high vulnerability in both communities. This result is in line with [54], whose findings proved flooding posed an important threat to roads, and can lead to massive obstructions of traffic and damage to road structures, with possible long-term effect.

Communication lines had low to very low vulnerability. This conform to the study of [55] whose findings showed that communication lines are found to be located away or at elevations free from flooding effect. The electricity poles were in good conditions and not affected by the flash floods which is similar with [55] study that revealed electricity infrastructures to be at low-risk disruption due to flooding.

According to the drainage system of both localities, it showed that Bonduma had a high vulnerability and most affected while Sandpit had moderate vulnerability. This conforms to the fact that Bonduma was more affected during the 2020 flash floods due to some secondary causes like poor drainage compared to Sandpit and the other 5 localities sampled in this study.

5 Conclusion

The findings from this study revealed that vulnerability to flash floods in Buea Municipality had both natural and anthropogenic causes. The natural causes included: heavy rainfall, rugged topography, wanton clearing of vegetation, climate change and siltation. The anthropogenic causes were: unsustainable building practices, poor waste disposal practices, landcover changes characterized with reduced vegetation (plantation/ farmland) and increased unplanned settlement. The effects of the 2020 flash floods were: loss of life, death of animals, destruction of crops, property damage (roads and buildings) and soil erosion. The map produced that delineated the 2020 flash flood affected areas in Bonduma and Sandpit revealed that, 146 houses over a total surface area of 103,429 m^2 in Sandpit were affected, while 94 houses over a surface area of 134,429 m^2 were affected in Bonduma. Settlement and agriculture were the dominant land use practices in both communities.

The social vulnerability assessment in Sandpit and Bonduma revealed that majority of the respondents were above 35 years, well-educated and were aware of the area being prone to flash floods. However, due to their personal attachment to the area such as being in possession of inherited land and ownership of houses, cheap and affordable rents, proximity to school/work site made them to stay in place and develop coping strategies like construction of embankments and raised foundations

Physical vulnerability assessment of buildings and critical infrastructure in Sandpit and Bonduma revealed that Bonduma is more vulnerable to flash floods compared to Sandpit. The physical vulnerability and the critical infrastructure indicators ranged between very low to very high vulnerability with the building type being the most vulnerable with very high vulnerability index while, building materials and building shape were the least vulnerable to flash flood in both localities. For the critical infrastructure, the findings showed road condition was the most vulnerable and electricity and communication lines being the least vulnerable to flash floods. Since these floods have become a yearly event, it is recommended that early warning systems should be installed and awareness raised in Buea Municipality for effective resilience against flash floods effects.

This study made use of both field and remote sensing methods to establish the elements that enhance vulnerability of flash floods in Buea Municipality. Even though the methods used are not novel to flash flood study, the use of mixed methods provided a detailed procedure to construct the flood vulnerability indices through different methodological approaches using a wide range of social and physical parameters; and weighting. This approach required that data was collected from several sources which included: field observations/ measurements and photographs using the ENSURE methodology; respondents' perception using the flood vulnerability index and questionnaire administration; satellite image analysis and acquisition of building shapefiles in the affected localities from the Open Street Map software. This mixed methodology gives this study an edge over other flood vulnerability studies that made use of just one of the methods utilized in this study because it gives a holistic view of the social and physical parameters that enhances the fragility of Buea municipality to flood inundation. In addition, this methodology can also be applied to other flood prone localities within Cameroon and other parts of the world to address social and physical vulnerability to flood hazard. The methodology also goes ahead to provide major stakeholders within Buea Municipality such as the mayors and other relevant authorities with practical data to mitigate current flood vulnerabilities of the sampled localities in the study and reduce losses caused by future flash floods.

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