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Flood disaster risk mapping in the Lower Mono River Basin in Togo, West Africa

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ABSTRACT

Flooding is the most devastating hydro-meteorological hazard in Togo. For instance, communities in the Lower Mono River Basin needs attention because they suffer the impacts almost every year. This paper focused on assessment and mapping of social flood risk in the Lower Mono River Basin, West Africa. The study combined GIS, Remote Sensing, and indicator-based flood risk assessment techniques in mapping flood disaster risk. The Risk Assessment Framework of Davidson (1997) and Bolin *et al.* (2003) that comprises Hazard, Exposure, Vulnerability and Capacity was adopted for the study. The resultant risk map shows that all the communities are exposed to flood risk but particular ones such as Agbanakin, Azime Dossou and Togbavi are found in areas with relatively high flood risk levels. Positive attitude towards early action and early warning systems, collaboration among disaster relief institutions and appropriate building codes are recommended for reduction of flooding disaster risk.

1. Introduction

Flooding is one of the most devastating hazards worldwide, which affects people's lives, socio-economic and ecological systems [1]. Flood hazards are the most common and destructive of all disasters and are a constant threat to life and property. Each year, flood disasters result in tremendous losses and social disruption worldwide.

Researchers have different views on the conceptualization of flooding based on the sources, impacts, extent or a combination of different factors. Schanze [2], Nyarko [3] and Merz et al. [4] conceptualized flooding as inundation of an area by unexpected rise of water by either dam failure or extreme rainfall duration and intensity in which life and properties in the affected area are under risk. An event becomes a disaster when there is a serious disruption to the functioning of a community involving widespread human, material, economic or environmental losses and impacts, which exceed the ability of the affected community to cope using its own resources [5,6].

European Commission [7], perceived flood risk as the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event. It is important to recognise that flood risks are human or societal concern rather than being an inherent characteristic of the natural system.

It is argued that changes in climate variables especially temperature are likely the major drivers of changes in precipitation and extreme hydrological hazards [8]. It is difficult to distinguish variability and changes in climate-related hazards from the impacts of long-term climate change. Climate change can impact both the intensity and frequency of hazards and the vulnerability of communities to disasters [8]. New evidence also suggests that climate change is likely to change the nature of many types of hazards, not only their intensities, but also the duration and their magnitudes [9]. According to IPCC [9], it is likely that there will be an increase in extreme events such as flooding in West Africa (including Togo), due to uncertainties in rainfall patterns.

In West Africa, most countries are extremely vulnerable to the impacts of flood hazard as a result of limited investment in infrastructures, high building vulnerability, settlements in flood zones, economic dependence on agriculture and poorly resourced institutions [10,11].

The government of Togo, every year, employs the services of institutions such as the Ministry of Environment, the Ministry of

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Territorial Administration, the Ministry of Civil Protection, the Red Cross and among others, to save lives and properties at the downstream end of the Mono River [12a]. Consequently, researchers and other stakeholders have questioned if these acts by the government is a solution to the problem in the era of climate change?

As a result of flooding in 2007, over 127,880 people were affected, 13,764 people were displaced, and dozens were killed in areas located in the river basins in Togo. Again, in 2008, heavy rains caused severe floods in the downstream end of the Mono River Basin, displaced about 20% of the people [13]. After both of the flooding events, food security was threatened as a result of low food production thereby exacerbating inflation from 1% in 2007 to 9.1% in 2008 [14]. Moreover, 300 km of roads and 11 major bridges were destroyed, leading to an increase in transportation costs. Furthermore, the 2010 flooding had great negative impacts on human security as most communities were affected (over 8 communities in Togo) and resulted in a total cost of damages and losses of over US$ 38 million [14,15].

In most studies on disaster risk, social construction of vulnerability is increasingly gaining attention (especially in Europe and West Africa). Social vulnerability describes those characteristics of a population that influence the capacity of the community to prepare for, respond to, and recover from hazards and disasters [16]. Social vulnerability interacts with natural processes and the built environment to redistribute the risks and impacts of hazards and in this way, creates the social burdens of hazards [16–18]. It explains why some communities experience the impacts of a hazard differently, though they experience the same level of flooding or storm surge inundation [16]. In this paper, vulnerability is socially constructed.

Within the past few years, scientists have witnessed considerable developments in the application of spatial technologies to identify, map, and make inventories of resources in different landscapes, including wetlands on floodplains [19–21].

Geospatial techniques such as Remote Sensing and Geographic Information System (GIS) have been useful tools for mapping floodplains and flood disaster risks in most parts of the world and the outputs proved efficient and useful in disaster management planning [22,23]. Research works in different parts of the world have shown that integration of remote sensing data, flood hazard data, and data on socio-ecological indicators within GIS platforms, is an efficient approach to generate flood vulnerability and risk maps for a given area [4,24,25].

The use of indicators and indices to measure attributes of interest for a system continues to lay down momentum in literature [16]. The 1990s witnessed more emphasis on the development of indicators for environmental sustainability as well as for vulnerability assessment [26,27] Moss et al. [28] developed a Vulnerability-Resilience Indicator Prototype model that assessed the ability of different groups to adapt and cope with climate change in different countries. Sullivan and Meigh [29] developed a Climate Vulnerability Index comprised of six indicators encompassing resource, access, capacity, use, environment, and geospatial dimensions. Several studies [27,30–32] have similarly applied indicators for flood risk and vulnerability assessment in different parts of the world and their results proved useful. Indicator approach was adopted in this study because it enables the researchers to identify the underlying socioeconomic factors of the communities.

In the past, efforts to reduce flood risk have involved at least two different approaches: (1) disaster risk reduction, which identified exposed areas, mitigation, and post-event measures; and (2) climate change adaptation, which identified climate change trends and measures designed to mitigate the impacts of future flooding. Although there is no general agreement on the determinants of risk as a result, each factor may be ascertained using different sets of indicators and techniques, depending on the methodology chosen.

Some researchers [3,10,12] looked at flood hazard analysis, using regression model at the downstream of the Nangbeto dam but those studies had not zoomed in to the community level and had also not captured socioeconomic dimensions of the communities, which are fragile to flood risk.

Relatedly, Amoussou et al. [33] used statistical methods to model changes in peak flow of water for a 23-year period but the challenge was that it required a lot of time series data. Schanze [2] used the Source-Pathway-Receptor-Consequence-Model for flood risk analysis but the shortcoming of that model was its over reliance on the negative consequences of flooding. In contrast, flooding has good impacts at times. Reducing the risk and vulnerability of communities to flooding is still a major challenge at present regarding global environmental change, technical and economic constraints.

We consider it important still to have risk and vulnerability maps at community level to identify vulnerable elements to help save lives and properties. Therefore, a comprehensive assessment of flood hazard, risk mapping and analysis of risk are necessary to help reduce disaster risk in the communities. It is worth noting that the community level is the most appropriate for disaster risk mapping if vulnerable regions are to be identified and managed. As a result, the objective of this study was to assess and map flood disaster risk in the Lower Mono River Basin in the Maritime Region of Togo. The study adopted a categorical/qualitative approach to assessing social vulnerability and flood risk.

2. Study area

The study was conducted in the lower part of Mono River Basin in Maritime region, Togo. In the region, six (6) communities including Aklakou-Zongo, Avévé, Adamé, Agbanakin, Azime Dossou and Togbavi in the Lacs district, were part of the study (Fig. 1). As the largest river system in Togo, the entire Mono River occupies an area of about 20,600 km^2 and is 560 km long [34]. The Lacs District is located in the downstream of the river below the Nangbeto Dam [15]. The study area extends between 6° 16' N to 6° 25' N and 1° 42' E to 1′ 49° E: at the immediate south of Bas Mono Fig. 1. To the west is the Vo district and the eastern part is the Republic of Benin, while on the southern part lies the Bight of Benin and the Atlantic Ocean. It covers a land area of about 406 km^2 with an average elevation of about 10 m above sea level. [10].

The study area is located in a relatively low-lying sedimentary formation of the coastal plain. It is believed that the eroded sediments from the highlands of the Plateau and the Central Regions in Togo have been deposited in the Maritime region, which includes the study area [35]. The common groups of soils in the Lacs district are hydromorphous soils, ferralsol, halomorph soils and Gley soil, which does not permit rapid infiltrating of water [10,34]. The soil in this area is high in acrisols, alisols plinthosols, acid soil with clay-enriched lower horizon and low saturation of basis [36]. The Map of the study area is presented in Fig. 1.

3. Materials and methods

3.1. Input data

The study combined both spatial data and non-spatial data sources. As required for flood risk assessment, data on community's exposure, hazard, social vulnerability and capacity measures were obtained through socioeconomic and ecological indicators during a field survey. The topographic map, soil map, river flow times series and population data were obtained from institutions and organizations.

3.2. Flood Risk Assessment Framework and development of indicators

The study adopted the disaster risk assessment framework of Davidson [37] and Bolin et al. [38]. This framework was adopted because it captures disaster risk at both national and local scale. The framework was developed for both global and community-based risks assessment, which makes it more appropriate for this study. Fig. 2 presents the conceptual framework of [37,38]. Davidson [37] and Bolin

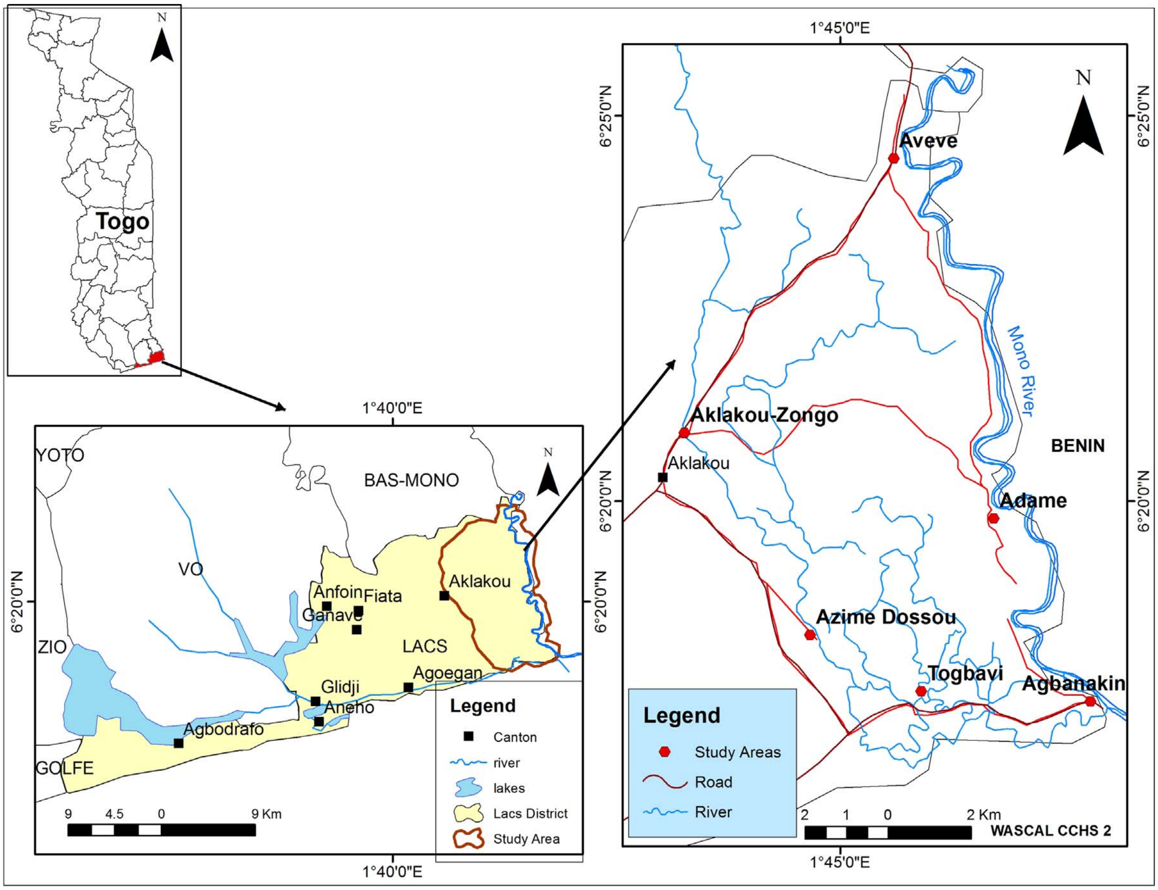

Fig. 1. Maps of the study area in the Lacs District, Togo.

et al. [38] conceptualized flood risk as a function of hazard, exposure, vulnerability, and capacity measures. The study considered the social vulnerability and social flood risk of the communities.

From Fig. 2, the hazard component considered the probability of occurrence and severity of flood in terms of magnitude. The elements at risk such as human structures, population, economic and environmental factors are classified under the exposure. As defined by Davidson, vulnerability includes four dimensions: physical, social, economic and environmental factors. Unlike the German Agency for Technical Cooperation (GTZ) component of the capacity, in this modified framework, the capacity and measures of communities included the ability of social ecological systems to anticipate, cope and recovery from flood disaster, which is adopted from the MOVE (Methods for the improvement of Vulnerability Assessment in Europe) framework [27].

3.2.1. *Developing Indicators for exposure, social vulnerability and capacity assessment*

There are many procedures for developing indicators but the common ones include inductive or deductive procedures [13,15]. In this study, deductive procedure was used in developing the indicators. Socio-economic attributes of a population and the physical attributes of the place are key factors which influence the capacity of a community to adapt to flood disaster. Following the conceptualization of disaster risk by [37], the indicators developed for Community-Based Risk Index by GTZ commonly used in a wide range of hazards including flooding, were adopted and modified to suit this study. To map vulnerability to

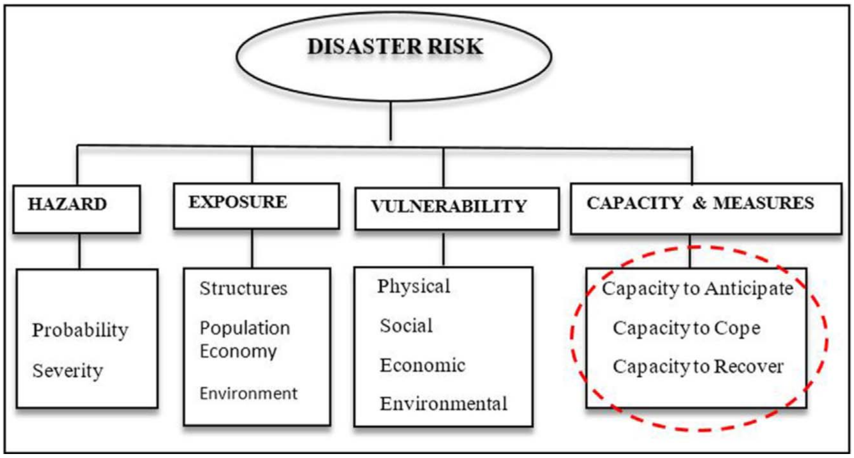

Fig. 2. The conceptual framework of Davidson [37] and Bolin [38]. Modified.

flooding in the Lower Mono River Basin, a survey of the literature identified a range of factors that are relevant to developing socio-economic and biophysical vulnerability indicators. The indicators selected ranged from age, gender, income level, location of building and farmlands, level of education, health status and household arrangements, early warning systems, community awareness and among others. A combination of socio-economic and physical factors such as being physically challenged or proximity to flood sources, increases a community's vulnerability to flooding.

3.2.2. Normalisation of flood exposure, vulnerability and risk indicators

Normalization of the indicators was done following the method of the UNDP's Human Development Index [39]. In order to use this method, the functional relationship between the indicator values and vulnerability were identified. There exist two relationships: positive and negative. The indicators have a positive relationship when they tend to increase vulnerability of a community to flood, while indicators with negative relationship lead to a decreased in the vulnerability to flood of a community.

When the values have positive functional relationship with vulnerability values, normalization is done, using the expression:

$$\mathbf{V_{bc}} = (\mathbf{Y_{bc}} - \mathbf{MinY_b}) / (\mathbf{MaxY} - \mathbf{MinY_b}) \;\ldots. \tag{1}$$

When the values have negative functional relationship with vulnerability values, the normalization is done, using the expression:

$$\mathbf{V_{bc}} = (\mathbf{MaxY_b} - \mathbf{Y_{bc}}) / (\mathbf{MaxY_b} - \mathbf{MinY_b}) \;\ldots \tag{2}$$

Here, V_{bc}stands for the standardized vulnerability value with regard to vulnerability component b, for community c;Y_{bc} stands for the observed value of the same component for the same community; $MaxY_b$ and $MinY_b$stand for the maximum and minimum values of the observed range of values of the same component, for all settlement. The indicators were normalized from 0 to 1 based on the functional relationship between the variables and the risk or vulnerability component. This method was chosen because it takes into consideration, a function of each variable or risk components [32b,39,40].

3.2.3. Social vulnerability, exposure and capacity index

Vulnerability indices guide policy development on vulnerability reduction at national and sub-national scales, and serve as a means of measuring progress towards specific goal [41].

There are several ways of estimating vulnerability index but in this study, equal weights (simple average scores) were used. This was found to be simple and relatively reliable [39]. Each index is obtained by averaging the variable within each component of vulnerability following the expression:

$$AI = \frac{1}{N}\sum_{i=1}^{n} C_i \tag{3}$$

Where AI is the average index of each of the sources of vulnerability, N is the sum of the index and C_i is the value of the index.

It should be well noted that similar steps were followed in order to normalize the indicators for exposure and the capacity measures of the communities. The estimated indices are ranked from 1(high) to 4 (low).

Table 2
Exposure and Capacity Index.

Component	Community	Expo. Index	Rank	Level of Exposure
Exposure	Agbanakin	0.74	1	High
	Aveve	0.68	2	Medium
	Adame	0.66	2	Medium
	Aklakou Zongo	0.30	3	Low
	Azime Dossou	0.67	2	Medium
	Togbavi	0.76	1	High
Capacity Measures	Community	Cap. Index	Rank	Level of Capacity
	Agbanakin	0.64	1	High
	Aveve	0.42	2	Moderate
	Adame	0.23	3	Low
	Aklakou Zongo	0.43	2	Moderate
	Azime Dossou	0.41	2	moderate
		0.22	3	Low

As given in Table 1, a community with the highest vulnerability index was ranked 1, while a community with the lowest vulnerability was 4. The same procedure was used for the classification of the exposure and the level of capacity measures.

The Exposure of communities to flood disaster is considered as a component of risk rather than vulnerability in this study. The normalization of indicators of flood exposure preceded the estimation of exposure index. The indices of the communities were ranked from 1 to 3 (i.e. high to low). This method was based on the best practices, literature review and the authors' knowledge of the study area. As a result, if a community has an index of 1, it was classified under high level of flood exposure, index of 2 was considered as medium exposure while and an index of 3 was classified as low level of exposure.

Similarly, the capacity assessment considered availability of flood disaster training programs, early warning systems, availability of evacuation facilities and etc. These indicators were also normalized and the index of each community was estimated. The community with the rank of 1 was found to have a high level of capacity measures, while a community with a rank of 3 was found to have low level of capacity to face flood hazard (Table 2).

3.3. Flood hazard assessment

This section considered hydrological analysis of the topography and the physical characteristics of the Lower Mono River Basin. The hazard component of the framework refers to flooding thus its characteristics in terms of probability and intensity. To optimally adapt the framework to the study area, the influence of geomorphology and hydrological formation of the floodplains are required. The data sources for this study are given in Table 3.

3.3.1. Hydrological analysis from SRTM (30 m) Digital Elevation Model (DEM)

The Digital Elevation Model (30 m) for the study area was obtained from United State Geological Service Shuttle Radar Topography Mission (SRTM) data, which was in decimal degrees and datum WGS84. The data was obtained from the Consortium for Spatial Information of

Table 1
Normalized scores and social vulnerability Index.

Community	Normalized Scores Phys.	Social	Env'tal	Econ.	Sum	Vuln. Index	Rank	Level of Vuln.
Agbanakin	0.429	0.583	0.782	0.476	2.270	0.57	2	High
Aveve	0.531	0.532	0.297	0.731	2.091	0.52	3	Moderate
Adame	0.480	0.255	0.439	0.594	1.768	0.44	4	Low
Aklakou Zongo	0.777	0.458	0.530	0.372	2.137	0.53	3	Moderate
Azime Dossou	0.933	0.603	0.367	0.589	2.491	0.62	1	Very high Very High
Togbavi	1.000	0.583	0.367	0.550	2.500	0.63	1	

Table 3
Data/Data sources for flood Hazard Assessment.

Data	Description	Source
Population Distribution	2010 Pop. & Housing Census	Department of Statistics, Togo
Soil data	Digitized map	Department of Geography, Univ. of Lomé, Togo
SRTM (DEM)	Resolution (30 m)	CGIAR-CSI (http://srtm.csi.cgiar.org)
Landsat 7 ETM+	Resolution (90 m), 2010	USGS (http://earthexplorer.usgs.gov/)
Mono River Flow Data	Annual Maximum Daily Flow (1944–2011)	Athieme, Benin Hydrological Service
Topographical Map	2013 (scale: 1: 50,000)	Department of National Cartography and the Cadastre, Togo

Consultative Group for International Agricultural Research (CIAT-CSI) website (available at http://srtm.csi.cgiar.org). This was geometrically corrected and all the sinks were filled using the Spatial Analyst tool in the ArcGIS [42].

3.3.1.1. Extraction of hydrological indicators. The various hydrological analyses were carried out in the ArcGIS (10.1), using the Shuttle Radar Topographical Mission's digital elevation model (DEM) with a spatial resolution of 30 m. The study area was clipped using the "*clip raster*" tool in.

ArcGIS tool box. The hydrologic modeling tools in the ArcGIS Spatial Analyst toolbox aided in delineating the physical components of the surface [43]. These hydrological methods were used to identify sinks, flow direction, flow accumulation cells and watersheds.

3.3.1.2. Extraction of flow direction. The depressionless DEM was used to generate a flow direction raster. The flow direction shows the possible direction of water run-off on the elevation model [21,44]. This analysis was performed, using the flow direction tool in ArcGIS 10.1 (*Spatial Analyst tool*).

3.3.1.3. Extraction of flow accumulation and stream network. The flow direction was used as the input data for delineating flow accumulation. The water accumulation was calculated for each cell by determining the number of upstream cells that drain into it. Grid cells with high flow accumulation values are areas of concentrated flow and are identified as stream channels according to a specified water accumulation threshold [25,44]. Grid cells with flow accumulation values of zero are topographic highs or ridges. Areas located close to the flow accumulation path and in particular when a large volume has accumulated upstream are more likely to get flooded [45].

In order to extract a stream network from a flow accumulation layer, a flow accumulation threshold must be chosen. In the literature, there is no agreement on the ideal threshold value for reproducing actual stream networks [46]. In practice, the determination of the threshold was an interactive process in which several values were used until the desired resolution of the stream network was extracted. In this protocol, after testing numerous thresholds, a threshold value of 100 was used. Once the threshold is set, cells with water accumulation greater than the threshold are designated as "stream channel" cells.

3.3.1.4. Extraction of elevation and slope angles. The elevation of a place above sea level affects its exposure to flooding, with low-lying areas at high risk as against highland areas, which are virtually safe from flood hazard [25]. The likelihood of a flood increases as the elevation of a location decreases, making it a reliable indicator for flood susceptibility [24,44]. The elevation of the entire Mono basin was extracted by converting the SRTM's DEM to Triangulated Irregular Network (TIN) in the ArcGIS (10.1) platform. This allowed the generation of the surface features such as elevation, hill shade, contours and slope angle. The output elevation was further reclassified into 5 classes, using equal intervals. The lowest point on the entire basin was 5 m below sea level, while the highest point was 990 m above sea level.

3.3.2. Land use/land cover classification

The term land use is used in a sense of the social and economic purposes for which land is managed. For example, building houses, grazing, timber extraction, and cultivation of food crops. In this sense, supervised classification was carried out with the 2010 Landsat 7 image, using maximum likelihood classification approach. This was done by initially creating training samples. The training samples were taken with a Global Positioning System (GPS) receiver, during a field survey. This was validated through the assistance of expert knowledge. As a result, 4 main classes of land cover were identified in the area. The output land cover classes were water bodies, built-up areas/bares soil, savannah with shrubs, swampy areas and mangroves.

3.3.3. Flood hazard mapping

Flood mapping in this study did not involve flood modeling. The hazard map was generated, using a weighted overlay analysis in ArcGIS (10.1). Using this method, the percentages of influence of land use/land cover, slope, elevation, rainfall data, flow accumulation and soil were chosen based on discussions with experts on the ground and the communities involved [40,47]. Previous studies conducted by Ntajal *et al.,* [32b], revealed that the study area has a flood frequency of 5 years and a magnitude of 847.1 m^3/s, with an exceedance probability of 20%, which served as a guide for flood mapping. The resultant hazard map was further reclassified into three classes (low, medium and high). The colour patches (Red, Yellow and Green) was used to indicate the probability at which a community is likely to face flood hazard. Red colour indicates a high probability, while green colour indicates low probability (Fig. 4).

It should be noted that this paper has not delved into modeling. It rather looked at the combination of physical factors that are likely to expose the community to flooding. This was what called for the expert judgement of the percentages of influence of each hydrological variable based on experience and expert's knowledge about the area. (Table 4).

3.3.4. Generation of the flood risk map

Flood risk maps are important in risk reduction. Creation of shapefiles of the selected communities preceded the risk mapping. An excel spreadsheet containing the indices of exposure, capacity and the overall vulnerability of the communities were created and saved in database (*.dbf*) format and imported into the ArcGIS (10.1) environment. The attribute tables of the data were joined to that of the shapefiles (*.shp*) of the communities. This allowed the generation of flood exposure, capacity and vulnerability maps for the communities in

Table 4
Hazard Components and their percentage of influence.

Hazard Component	% of Influence	Rank
River Flow	25	1
Elevation	21	2
Slope	14	4
Soil	13	5
Land use /Cover	16	3
Flow Accumulation	11	6
Total	100	xxx

Table 5
Flood Risk Components.

Risk Component	% of influence	Decimals
Hazard	33.1	0.331
Exposure	32.3	0.323
Vulnerability	23.12	0.231
Capacity Measures	11.48	0.115
Total	100	1

ArcGIS (10.1) platform. Rank Sum overlay within the ArcGIS (10.1) platform was used to generate the flood risk map.

However, in order to create the risk map, each of the components of flood risk (Hazard, Exposure, Vulnerability and Capacity measures) were given a *percentage of influence* (Table 5) in ArcGIS, according to their relative importance in causing flood [12a,40]. This method was based on literature review, expert knowledge and the authors' knowledge of the study area. The resultant risk map was reclassified into three (3), equal intervals. The process followed the expression:

$$\boldsymbol{Risk} = [(\boldsymbol{H}*0.331 + \boldsymbol{E}*0.323 + \boldsymbol{V}*0.231) - \boldsymbol{C}*0.115)] \qquad (4)$$

Here, $\boldsymbol{R = Risk}, \boldsymbol{H = Hazard}, \boldsymbol{E = Exposure}, \boldsymbol{V = Vulnerability}$ and $\boldsymbol{C = Capacity}$

4. Results and discussion

Flood risk maps are useful information for preparing against flood events. The results are presented here of flood hazard map, exposure, vulnerability, capacity measures (the ability to anticipate, cope and recover from a disaster), identification of the sources of flood risk in the communities. Flood maps are useful as they present the physical extent of risk. Furthermore, easily readable maps give visual impression of flood disasters. As a matter of fact, all the communities in the Lower Mono River Basin are vulnerable to flood disaster risk.

4.1. Physical characteristics of the area and their influence on flood risk

The physical characteristics of the area play a major role in flood risk analysis [13]. Flow accumulation, soil characteristics, elevation, slope angle, and land cover in the Lower Mono River Basin affect the physical exposure and vulnerability of communities to flood risk. They are described in the following sub-sections.

4.1.1. Flow accumulation in area

Flow accumulation shows the cells within the study area where water accumulates as it flows downwards. Areas located close to the flow accumulation path and in particular where a large volume of water has accumulated upstream are more likely to get flooded. Thus, settlements around these cells receive much water during an event of rainfall or any sudden release of water. In this case, the cells in which water accumulates occur in the main channels of the river, which is influenced by the slope angle. Heywood et al. [46] and ESRI [44], penned that Grid cells with flow accumulation values of zero are topographic highs or ridges.

4.1.2. Influence of slope angle

Slope angle, as displayed in degrees, plays a major role on the nature of flooding in the area. Slope changes influences the surface flow and accumulation of water. Similar to the findings of [33], areas with slope angles of 0° to 2° have flat slopes, while areas with slope angles between 3° and 4° have very gentle slope in the Lower Mono River Basin. Communities that stand a higher risk of flood hazard are Agbanakin, Togbagan, Togbavi and Azime Dossou, which are located on low lying part of the landscape as the gradient of slope influences

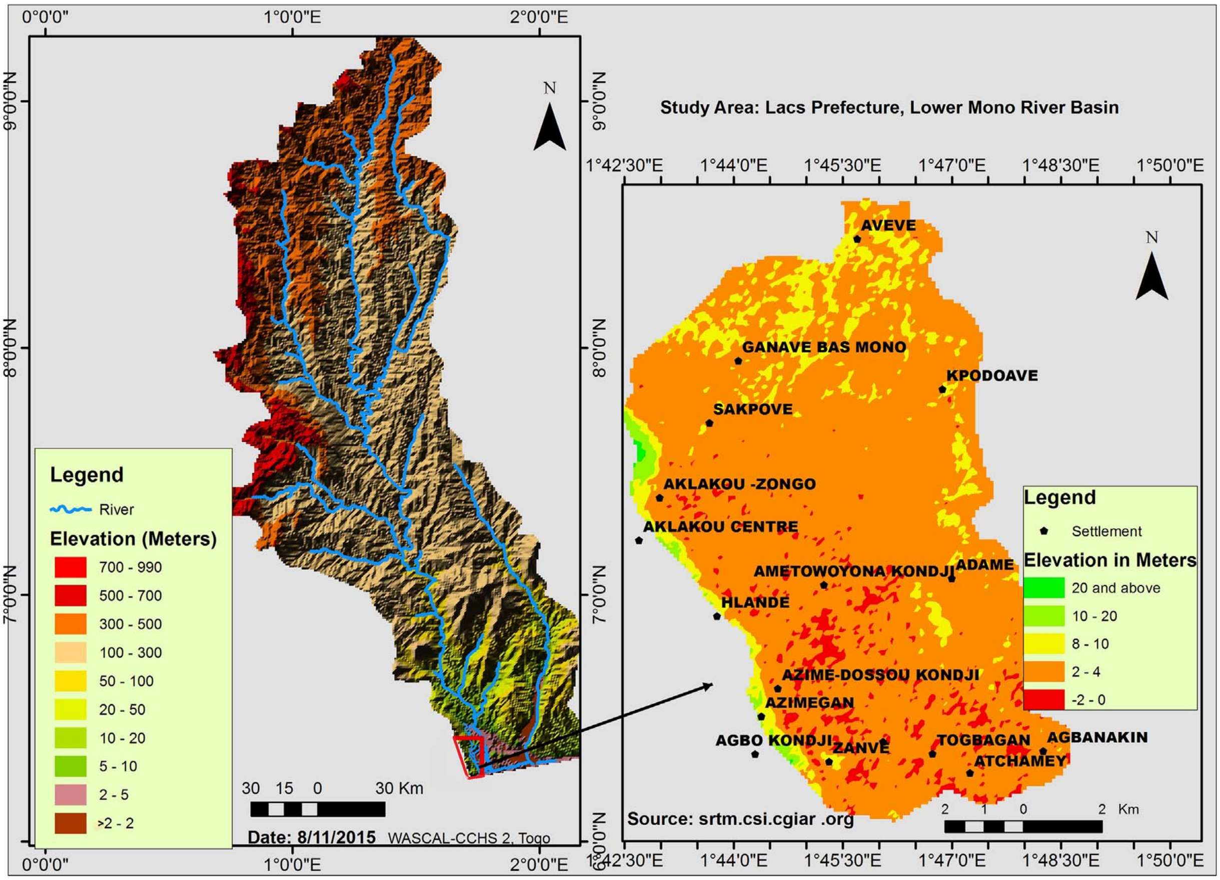

Fig. 3. Elevation of the entire Mono River Basin (Left) and the study area (right).

surface runoff of water.

4.1.3. *Elevation of the area*

The elevation of the entire Basin was estimated and further zoomed-in to the study area. The output maps are given in Fig. 3. The highest value of elevation in the entire basin is 990 m, while the lowest value is 2 m below sea level.

A critical look at the lower part of the Basin, the study area, the lowest elevation is 2 m below sea level. Some communities such as Agbanakin, Togbavi, and Azime-Dossou have elevations, which range from zero 0 m to 4 m above sea-level, while Aveve and Adame communities are located between 4 m and 8 m above sea level, which agrees with the findings of [33], linking to the fact that places with lower elevation stand a higher chance of being inundated with a given clay soil and land cover type. Similar results were found by [24,47] that the likelihood of a flood increases as the elevation of a location decreases.

4.1.4. *Influence of soil composition on flooding*

The hydrological characteristics of the soil influence the susceptibility of an area to flood. The more permeable the soil is; the more water can be transmitted through it. The soils in the Lower Mono River Basin are largely made up of clay (60%) and sandy clay (40%), characterised by low permeability. Nyarko et al. [23] also highlighted that clayey soil does not permit rapid water flow, which causes "puddling" of water. Areas which are composed primarily of these types of soils are prone to a higher flood risk because the floodwater requires a longer time to drain or infiltrate into the ground.

Klassou [34] identified that the common groups of soils in Lacs district are hydromorphous, ferralsol, halomorph and Gley soil, a fact which does not permit rapid infiltrating of water. Ago *et al.* [10] also found that soils in this area are high in acrisols, alisols plinthosols, acid soil with clay-enriched lower horizon and low saturation of basis. The soils easily become saturated with water, which compels excess water to flow on the surface as runoff in areas with steep slopes or become stagnant in case of flat slopes [23,31]. As a result, the flood duration increases, which in turn increases the vulnerability of the people to flood risk. Nyarko [24] reports that the soil type and texture play a role in determining the water holding and infiltration characteristics of an area and consequently affect flood susceptibility in an area.

4.1.5. *Influence of land cover/land use*

The term land use is used in the sense of the social and economic purposes for which land is managed. Many studies have concluded that floods result from factors such as the human intervention in the natural hydrologic cycle, through destruction of vegetation of river basins, and expansion of impermeable surfaces.

As a result, four major land use and land cover classes in the area were obtained (Fig. 4): built-up areas/bare soils, coconut and palm plantations, swampy areas, with scattered mangroves and water bodies. It should therefore be noted that most of the roofs of the building were made of thatch and palm branches and therefore gave a reflectance that is similar to that of bare soils. Mangroves are effective in controlling flooding in an area. Bare soils and built-up areas tend to increase surface runoff when the given slope is steep, thereby reducing the rate of infiltration of surface water, which increases the physical vulnerability of people and forest ecosystems to flood risk.

Wetlands and mangroves are ecosystems that absorb and receive water from the surrounding elevated areas but human occupation of wetlands and mangroves destroys their natural ecosystems and their role in flood prevention. This conforms the results of [24,45] that land cover has a direct influence on a number of parameters in the hydrologic cycle (interception, infiltration, concentration and runoff behaviour) and therefore indirectly on flooding. Deforestation and desertification increase surface runoff of water, which likely lead to flooding given flat slopes, low elevation and impermeable soils. The findings of Pouraghnyaii [48] that removal of the vegetation cover has increased the runoff coefficient from 10% to 15% in the Kasilian Basin (Mazandaran province, Iran) further explains the influence of land cover on flooding.

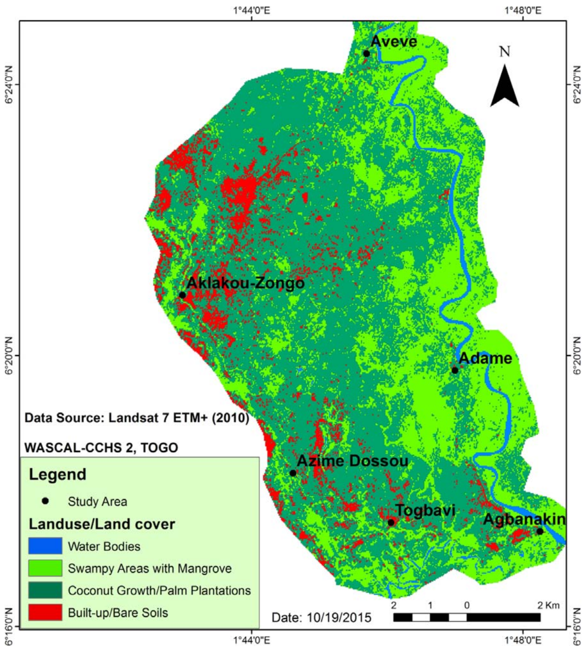

Fig. 4. Land use/Land Cover Classification using 2010 Landsat 7 ETM+ image (30 m; Path/Row: 198/52).

4.2. *Flood hazard map*

Flooding in the Lower end of the Mono River Basin was a result of many factors, which were largely categorised under physical and human characteristics of the area. The flood frequency analysis by Ntajal et al., [32 b], showed that the area has a flood return interval of 5 years and a magnitude of 847.1 m^3/s, with an exceedance probability of 20%, which served as the basis for flood hazard mapping in this study. Fig. 5 (below) is the flood hazard map of the area.

It is observed in Fig. 5 that elevation, slope angle and soil structure are crucial in flood hazard mapping. The hazard map revealed that low

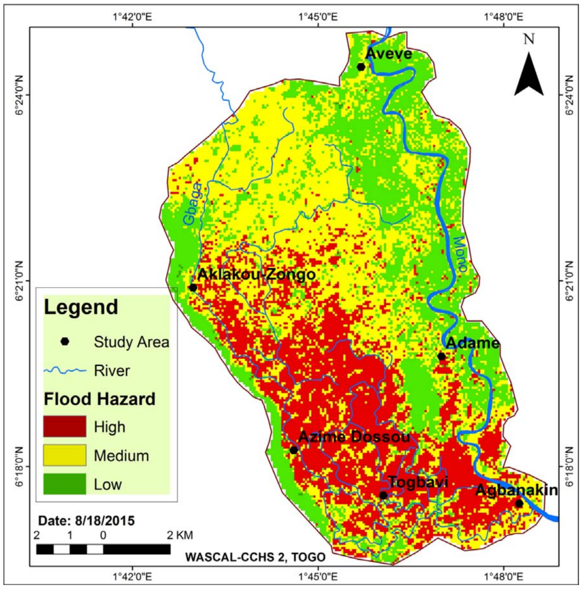

Fig. 5. Flood hazard map of the lower Mono River Basin (Lacs District).

elevation, flat slope angles and clayey soil are factors that tend to increase the exposure of the communities to flood hazard. It must be mentioned that Aklakou-Zongo is located 16 km by road from the main channel of Mono River at Adame but as a result of its location on a lower elevation, it is exposed to a higher level of flood hazard. All communities in the study area are located in floodplain but are exposed to different levels of flood hazard.

Communities such as Aveve and Adame are located very close to the River but stand lower chances of flood hazard due to their relative higher elevation and gentle slope angles, while communities such as Agbanakin, Togbavi and Azime-Dossou are prone to high level of flood hazard partly because they are located in relatively lower elevations with flat slope angles. This conforms the findings of Anoussou [36] that areas located in lower elevations are exposed to a higher level of flood risk.

4.3. Human factors and flood disaster risk in the Lower Mono River Basin

Exposure and vulnerability of communities to flood risk is not limited to only the physical characteristics of the Mono River Basin but also the pre-existing socioeconomic characteristics of the communities. The perception of the communities on their exposure, vulnerability and level of their resilience to flood disaster is very crucial, which are discussed below.

4.3.1. Level of exposure

Exposure of communities to flood risk was considered as a component of risk rather than vulnerability. Fig. 6 shows the levels of exposure to flood disaster in the area. The colour shadings of the communities indicate their levels of exposure to flood. The red shading indicates a high level of exposure, orange – indicates a moderate level of exposure while the green patches indicates a low level of exposure to flooding (Fig. 6).

It is obvious in Fig. 6 that Agbanakin and Togbavi are highly exposed to flooding as compared to Aveve and Aklakou-Zongo. This is not only explained by proximity to the river and the high percentage of people who are exposed to flood but also by the socioeconomic factors. Invariably, most of the people are involved in farming activities, which are located 10 m to 20 m to water bodies. This increased the exposure of farmlands to flooding. Aklakou-Zongo is less exposed to flood risk partly because most of the members of the community are livestock farmers, in most cases their animals are easily quarantined in safer places when they are warned of the likely occurrence of flood event.

Olayemi et al. [49] in 2014 also found a high level of exposure of communities to flood risk in the Yoto district in Togo because 70% of the farmlands and buildings are located in flood zones. High level of exposure of communities increases the level of flood risk of the people, as outlined by Birkmann [50]. Poor building codes happened to be a common factor in all the communities in the Mono River Basin. Location of building, farmlands, and roads in flood zones increases the exposure and susceptibility of people to flood risk. This situation becomes more dangerous among families with higher number of elderly above 60 years and children under 6 years, who would likely need special assistance during flooding.

4.3.2. Level of Vulnerability

The family sizes, level of income, adult literacy, past experience of flooding among others are underlying factors, which affects the level of vulnerability of people to flooding in the communities. Fig. 7 presents the level of vulnerability of communities.

Vulnerability of a place to a hazard or disaster risk is dynamic in both space and time [27]. In Fig. 7, it is obvious that Azime Dossou and Togbavi are highly vulnerable, while Adame was the least vulnerable among the selected communities. The high level of vulnerability of the two communities was partly explained by the fact that 98% of the building are made of mud and bricks supported with "Bamboo sticks", and roofed with either thatch or palm branches. Similar building codes were observed by Kissi et al. [51] in the Yoto and Vo districts in the Maritime region, Togo.

High number of female headed households are the underlying factors, which increased the social and economic dimensions of the overall vulnerability of the communities, which conforms the reports of

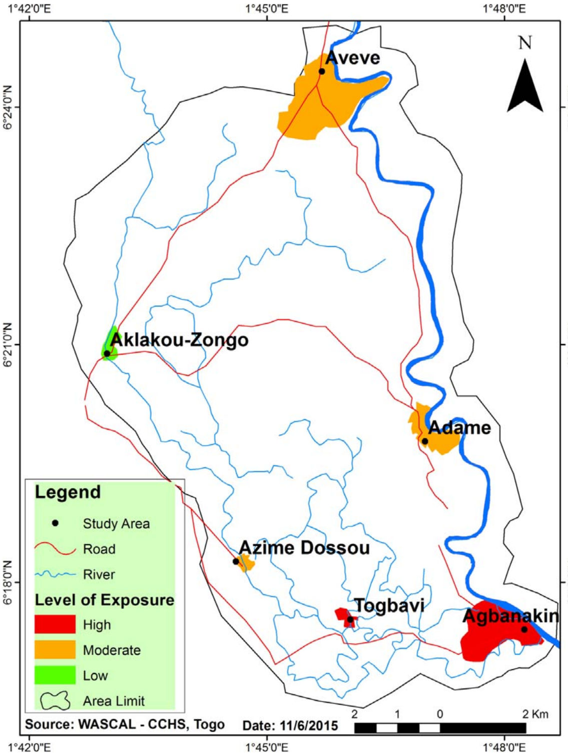

Fig. 6. Flood exposure map.

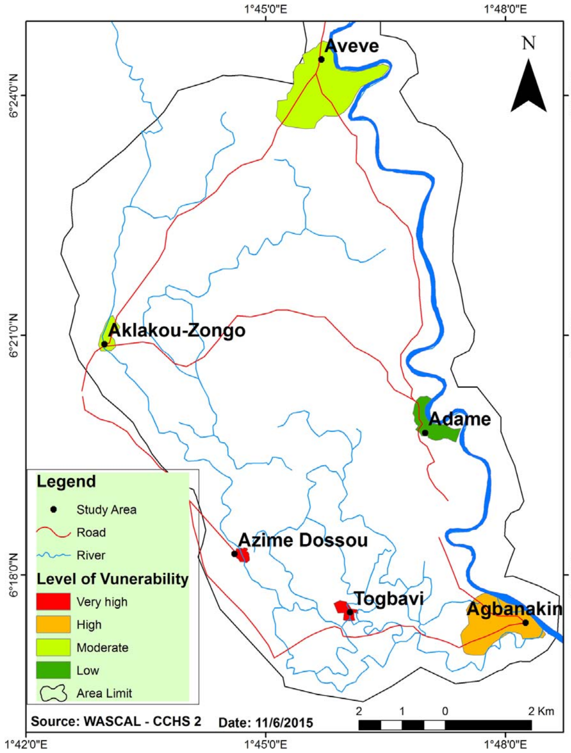

Fig. 7. Flood vulnerability map.

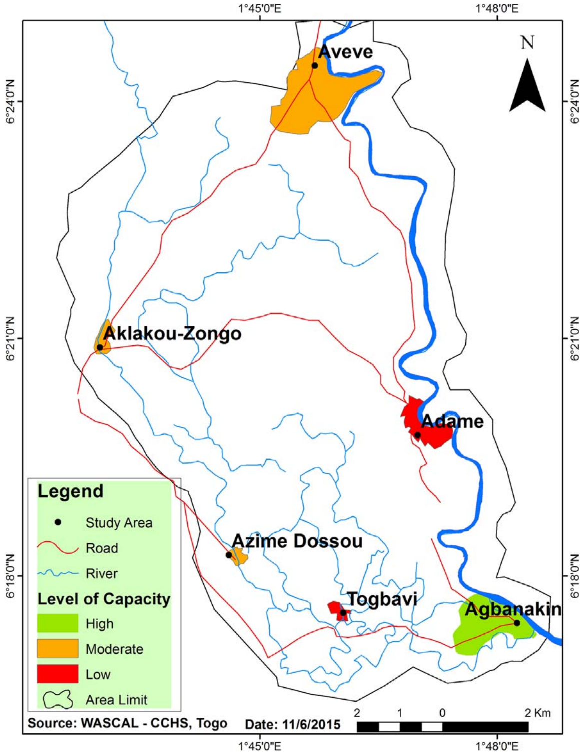

Fig. 8. Map of capacity measures.

[11]. This implies that special attention, material support and mind building are needed in these communities. It could be partially concluded that low levels of income, high number of people with special needs, increases the social vulnerability of communities [16,52].

4.3.3. Level of capacity measures

The capacity of social-ecological systems to anticipate, cope and recover from a threat is crucial for the communities to face flooding (see Fig. 8). The colour shadings of the communities indicate their levels of capacity to flood. The red shading indicates a high level of capacity, orange – indicates a moderate level of capacity while the green patches indicates a low level of capacity to flooding (Fig. 8).

It was observed from Fig. 8 that Agbanakin community had a relatively high level of capacity to face flood disaster, while Adame and Togbavi communities had relatively low levels of capacity to anticipate, cope and recover from flood disaster. Aveve and Azime Dossou also emerged with moderate levels of capacity to face flood disaster. The lower levels of capacity were partly explained by a lack of “Balise” (a flood early warning system, with graduated colours), to alert them of an oncoming flood unless they receive telephone calls from the Togo Red Cross Team and other focal points in the communities.

Inhabitants of Agbanakin are highly aware of the flood disaster and have also formed a committee to disseminate early warning information and educate people on floods. Relatedly, [38,50] stated that a high level of awareness and experience from past disasters give communities a better chance for preparation ahead of hazards. A higher level of capacity measures of communities to face flooding reduces the level of susceptibility and physical exposure of people to flood [4].

4.4. Flood risk map and analysis

As generally stated earlier, flood risk maps aid in planning and preparing against flood disaster. Flood risk mapping as done here, included both physical characteristics of the area and socioeconomic factors of the communities in the Lower Mono River Basin. The various levels of flood risk in the Lower Mono River Basin in Togo are presented (see Fig. 9).

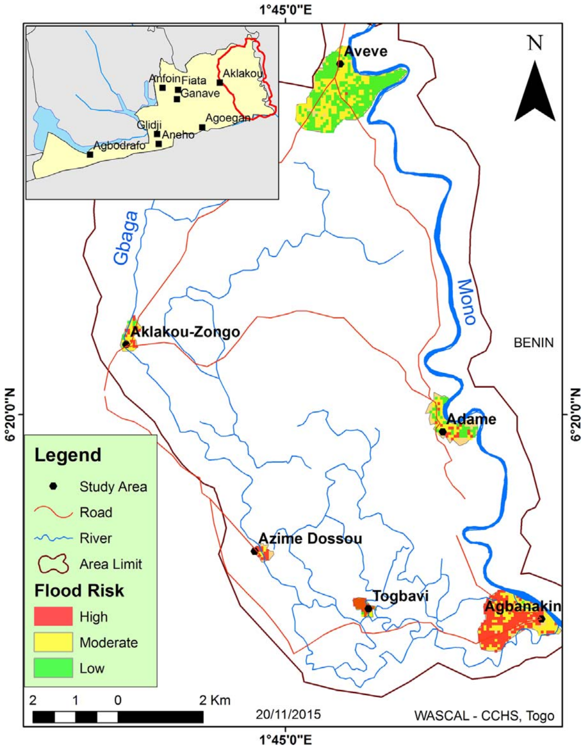

Fig. 9. Flood risk map.

Flood risk mapping is an important step in flood disaster risk reduction as outlined in the Sendai Framework for Disaster Risk Reduction (2015–2030). The flood risk map (Fig. 9) shows that Azime Dossou, Togbavi and Agbanakin communities were likely the riskiest communities. Experience obtained through field observation confirmed that the three communities in the southern part of the area are located in a relatively low-lying swamp with scattered mangroves. The soils are largely hydromorphs, which easily becomes saturated and does not permit rapid infiltration of water as reported by [10,24]. The three communities are also surrounded by Gbaga and other tributaries of the Mono River. Though, the Agbanakin community appeared to have a high level of capacity to face flood disaster but the source of its flood risk is the pre-existing factors of exposure and vulnerability. Aveve and Adame are likely to face a lower level of flood risk partly explained by the physical characteristics of the areas. They are found on gentle slopes and relatively located five to eight metres (5 m to 8 m) above sea level, although they are located very close to the main channel of the Mono River.

[10,33] reported similar results, which indicated that the higher levels of flood risk in the communities were mainly due to the physical characteristics of the area. Generally, the communities have access to early warning information because of the formations of Red Cross focal points and the “Mother's Club” to help in evacuation of flood victims and recovery processes. All the communities proved to have some level of experience from past flood disasters in the area.

It should be noted that accumulation of sediments in the river channel, through erosion from upstream and deposition at the downstream reduces the channel's depth, which hinders the smooth flow of water into the sea. As a result, a little rise in the volume of water compels the river to overflow its banks, a fact that probably causes flooding. These factors of river dynamics affect the risk profile of the surrounding settlements.

Invariably, similar studies at the community level in the Lacs district are not known. The results of the study, which combines both field observation and remotely sensed data conforms to theoretical expectations. For instance, information about soil type, elevation obtained from other sources was in agreement with the field observation. Clayey soil, flat slope angles and low lying areas, are highly prone to flooding or floodplain inundation as [3,23] reported in their studies of the Volta River in Ghana. in partial conclusion, the results gave a good starting point to reducing flood risk that could be improved upon. For instance, the reliance of the communities on the early warning system is encouraging.

5. Conclusion

The analysis of flood risk in the Lower end of the Mono River Basin revealed that communities such as Azime Dossou, Agbanakin and Togbavi are located at the lower elevation, which exposed them to floods compared to Aveve and Adame, which are located on relatively higher elevations (4 – 8 m above sea level). It should be noted that the source of flood risk in the Lower end of the Mono River Basin was not only the extreme high rainfall but also the improper regulation of the Nangbeto dam, given the pre-existing socioeconomic factors of the communities. It was found that flood disaster risk mapping gave an optimal means of combining remote sensing data, socioeconomic and ecological data in defining the flood risk of the area. Flood risk mapping gave a good visual impression about the various levels of flood hazard and flood risk in the area, which are useful in disaster planning and designing of flood early warning systems.

It should also be noted that flood risk is complex and dynamic as it includes hazards, exposure and vulnerability. It is crucial to consider these dynamics within a community with respect to time and location of the community. The mitigation of flood risk can be accomplished through managing the hazard, reducing the exposure and vulnerability, while building the adaptive capacities of communities. Therefore, developing flood mitigation strategies need a collective effort from the communities, institutions, organizations and governments to help secure human security. The results of the study give information regarding what could be done about preparedness, prevention as well as response in the various communities.

Limitation of the study

The resilience of the communities to flood risk is crucial in reducing disaster risk, but was not fully covered in this study, since it was not its main focus.

Author contributions

Joshua Ntajal and Benjamin L. Lamptey designed the study, developed the methodology, and wrote the manuscript. Joshua Ntajal performed the fieldwork, collected the data, and conducted the computer analysis while Benjamin L. Lamptey, Ibrahim Bahari Mahamadou and Benjamin Kofi Nyarko supervised and edited the work.

Conflict of interest

The authors declare no conflict of interest.

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