1. Introduction

Flood risk zone mapping is an important first step in the proper management of future flooding events and to develop adequate mitigation measures (Elmira, 2016). In particular, development of flood vulnerability maps at the local government level can achieve a better result than the conventional national maps because it can identify rural dwellers and small holder farmers that are at risk (Asare-Kyei, Forkuor, & Venus, 2015). Flood vulnerability maps are useful tools in identification of populations and elements at risk and to guide early warning system and preventive measures. They are needed in spatial planning to prevent development in flood prone areas and for implementation of a flood insurance scheme (De Moel, Van Alphen, & Aerts, 2009).

West Africa has witnessed frequent floods due to high variability in rainfall patterns, geographic location and general low elevations. In the last three decades, the sub-region has witnessed a dramatic increase in flood events, with severe impacts on livelihoods, food security and damaging properties worth millions of dollar (Armah, Yawson, Yengoh, Odoi, & Ernest, 2010). In 2007, for example, a series of anomalously high rainfall events caused severe floods which affected more than 1.5 million inhabitants in West Africa. This has resulted in the destruction of farm lands, destruction of infrastructure, outbreak of disease epidemics and the loss of human lives (Bruman, Pablo, & Maarten, 2010). In 2012, flooding along the river Niger, the principal river in West Africa, resulted in the death of 81 and 137 people in Niger and Nigeria, respectively, while displacing more than 600,000 people (Integrated Regional Information Network [IRIN], 2013). The frequency of occurrence of extreme events is expected to increase as result of projected increase in extreme rainfall that may “have dire consequences for the sub-region’s agricultural sector and food security in West Africa” (Intergovernmental Panel on Climate Change [IPCC], 2014).

Abakaliki Local Government Area (ALGA) is popularly known for rice (Olivia sativa) farming in Nigeria because of the availability of large expanse of swampy areas adequate for rice cultivation. The Nigerian Hydrological Services Agency (NIHSA) in 2014 listed ALGA of Ebonyi State among the moderate flood risk areas in the country. Every year, farmers lose significant quantities of their farm produce due to inundation of crop fields by seasonal flooding. Due to the lack of locally relevant and functional flood hazard maps for mitigation and adequate response to flood hazards in this area, farmers do not have required knowledge of the extent of flood coverage in that part of the country.
Despite the major impact of floods on the livelihoods of the people living in the low lying regions of West Africa, few attempts have been made to delineate the boundaries of flood intensity to indicate areas that are vulnerable to flooding (Asare-Kyei et al., 2015). The limited researches that were conducted on flood mapping in Nigeria have used remote sensing data aided by Geographic Information Systems (GIS). However, they lack certain basic principles in hydrological modeling and prediction which can be added into flood simulation and mapping in the country for better outcome (Komolafe, Suleiman, & Francis, 2015).

This paper reports on a recent study conducted to explore the application of GIS and some hydrologic models in flood extent mapping especially for data scarce environment at community level in ALGA in South-eastern Nigeria. The overall objective of the study was to develop detailed flood hazard map at a fine spatial resolution with aim of providing information for early warning, risk preparedness and to put in place adequate response mechanism.

2. Material and method

2.1. Description of study area

The study was conducted in ALGA of Ebonyi State, South-eastern Nigeria (Figure 1). The geographical coordinate lies within 06°04'0" N Latitude and 08° 65'0" E Longitude. ALGA occupies the eastern axis of Ebonyi state, covering a land area of about 584 km². The area is characterized by high relative humidity of about 71–75% and surface temperature of 26°C to 31°C with mean temperature of 30.4°C. There is a bimodal rainfall pattern from April to July and September to November with a short spell in August (Figure 2) and a long-term average rainfall of 1,296 mm. Hydrologically, the area is located within the derived savannah zone of South-East Nigeria, lying within the plains of Ebonyi River, Iyiudele and Iyiokwu Rivers that are also tributaries of Cross River (Figure 1). The inhabitants are predominantly agrarians raising livestock and crops at both subsistence and export levels. Major crops for national and international markets are rice, cassava and yam (Ogbodo, 2013).

2.2. Data sources and methods

2.2.1. Data sources

We made use of digital elevation model from ASTER which is a joint product of the Japanese Ministry of Economy, Trade and Industry and the United States National Aeronautics and Space Administration (NASA). The data have a vertical accuracy of 17 m at 95% confidence level, and a horizontal resolution on the order of 75 m. The land cover data were obtained from Landsat8 imagery which was downloaded from USGS website.

We used soil map from the Harmonized World Soil Database (HWSD) version 1.2 produced in 2012 by the International Institute for Applied System Analysis (IIASA) for soil type and texture classification. The soil
map has 1 km resolution. We obtained Rainfall data from the Nigerian Meteorological Agency (NIMET), Abakaliki area synoptic station. Topographic map of Ebonyi State covering the study area and the shape files of the administrative boundary and settlements for the study area were gotten from the ministry of lands and survey, Abakaliki.

2.2.2. Run-off estimation models
The methodological approach that was employed in this research work is diagrammatically summarized in Figure 3 as described by Asare-Kyei et al. (2015). Hydrological modeling (flood risk zone mapping) was achieved by using combined application of the rational hydrological model and arithmetic overlay operation. First, the study area was delineated into sub-catchments using ArcGIS10.3 software. Secondly, a modified version of the rational model was used to estimate the run-off of the respective sub-catchments based on rainfall intensity, and a run-off coefficient. Finally, the arithmetic overlay operation was applied in a GIS environment to integrate the output of the hydrological model with other flood causal factors such as elevation to determine a flood intensity map for the sub-catchments. Flood prone zones were eventually defined through a reclassification of the flood intensity map to derive the Flood Prone Index (FPI) which determines the flood prone zones of the area. This approach involves retrieving data values from all flood covariates and then calculating peak

![Figure 3. Modified modeling flow diagram for relational-rule-based flood assessment.](image)

![Figure 2. Seasonal distribution and long term annual average rainfall in ALGA. Source: authors' analysis using raw data from 1997–2016.](image)
run-off rates using the rational model. The covariates for flood are land use/land cover (LULC), soil type and soil texture, slope, elevation, rainfall and drainage area (Morjani, Zine and Ali., 2014).

2.2.3. Determination of peak run-off using the rational model

The rational model belongs to the group of lumped hydrological models which treats the unit of analysis as a single unit whose hydrological parameters (e.g., rainfall) are considered as average values. The model is given by the equation

\[ Q_p = 0.0028 \times C \times I \times A \]  

where, \( Q_p \) = Peak run-off rate (m³/s) \( C \) = run-off coefficient (–), \( I \) = rainfall intensity (mm/h), \( A \) = drainage area (ha). A constant (0.0028) is required to convert the original units in North American system (where the model was first developed) to an international system such as cubic meters per second (m³/s). The model operates on a number of assumptions including: (1) the entire unit of analysis is considered as a single unit; (2) rainfall is uniformly distributed over the drainage area; (3) estimated peak run-off has the same chances of reoccurrence (return period) as the used rainfall intensity (I) and (4) the run-off coefficient (C) is constant during the rain storm.

The strength of this model lies in its simplicity for application and its suitability for a homogeneous area. As a result, this model has a wide application in the calculation/estimation of peak run-off rate for the design of different drainage structures and flood hazard map production (Nyarko, 2002). The model converts rainfall in the catchment into run-off by calculating the product of the rainfall intensity in the catchment and its area, reduced by a run-off coefficient (C, with a value between 0 and 1) which depends on the soil type, land cover and slope in the study catchment. The run-off coefficient provides an estimation of how much rainfall is lost through infiltration, interception and evapotranspiration. This means that the run-off coefficient of a catchment can be seen as the fraction of rainfall that actually becomes run-off. Therefore, accurate estimation of the run-off coefficient is vital to the successful implementation of this method.

2.2.4. Sub-catchments delineation

Digital Elevation Model was used for sub-catchment delineation and slope analysis. The study area was delineated into 17 sub-catchments by clicking on the spatial analyst tools in ArcGIS environment after all the sinks had been filled to make it more perfect. The filled elevation data layer was maintained and used later for the integration of peak run-off and elevation to determine run-off concentration at different elevations. The Hydrology tool was expanded to perform various hydrological analyses such as flow direction, flow accumulation, stream order, stream to feature and subsequently sub-catchment determination. The sub-catchments which were generated in a raster format were immediately converted to polygon by clicking on the conversion tool under spatial analyst tools. The conversion of the raster format into polygon was necessary in order to calculate the areas of the sub-catchments and also to build the attribute table in the ArcGIS environment.

2.2.5. Peak run-off map development

Within each sub-catchment, more than one LULC types and slope exist. In order to find a run-off coefficient that will represent a given sub-catchment, average values were taken based on the different LULC types. The DEM was also converted to percent slope in ArcGIS and was reclassified into three classes; slope less than 2%; slope between 2% and 6%; and slope greater 6%. Based on Table 1, which specifies a run-off coefficient for a particular LULC type and slope, the average values of run-off coefficient for each sub-catchment were computed based on the number of LULC that occur in each sub-catchment. Knowing the run-off coefficients (C), rainfall intensity (I) and areas (A) of each of the sub-catchment within the study area, the discharges (Qp) for each sub-catchment likely to cause flooding is obtained.

2.2.6. Flood covariates and acquisition methods

2.2.6.1. LULC analysis. LULC maps of the catchment were generated by classifying moderate spatial resolution (30 m) multitemporal Landsat images which were processed prior to analysis. The LULC data were generated for three periods namely, 1986, 1996 and 2016 exploring changes in the LULC type overtime.

| Runoff Coefficient, C | Soil Group “A” | Soil Group “B” | Soil Group “C” | Soil Group “D” |
|-----------------------|----------------|----------------|----------------|----------------|
| Slope gradient (%)    | <2 2–6 >6     | <2 2–6 >6     | <2 2–6 >6     | <2 2–6 >6     |
| Forest             | 0.08 0.11 0.14 | 0.10 0.14 0.18 | 0.12 0.16 0.20 | 0.15 0.20 0.25 |
| Farmland           | 0.14 0.18 0.22 | 0.16 0.21 0.28 | 0.20 0.25 0.34 | 0.24 0.29 0.41 |
| Bare Land          | 0.65 0.67 0.69 | 0.66 0.68 0.70 | 0.68 0.70 0.72 | 0.69 0.72 0.75 |
| Residential        | 0.33 0.37 0.40 | 0.35 0.39 0.44 | 0.38 0.42 0.49 | 0.41 0.45 0.54 |

Source: (Bengtson, n.d.).
The different bands of the Landsat imagery were combined in ArcGIS environment to form composite, and the composites were further processed into mosaic raster prior to analysis. Supervised classification was conducted on the Landsat imagery to reveal four broad LULC classes after training samples and signatures were created (using training sample manager), saved and imported in ArcGIS environment. These land use classes identified were (1) agricultural land; (2) forestland; (3) bare land and (4) settlements (i.e., built up areas). Training and validation data for these classes were obtained from field campaigns conducted between December 2017 and March 2018. Training and validation samples for the classification were generated by overlaying the training and validation data (polygons) on the satellite image and extracting the corresponding values.

### 2.2.6.2 Soil type and texture

The Harmonized World Soil Database (HWSD) which was used for soil classification is an image file linked to a comprehensive attribute database where information on soil mapping units, soil texture for top and sub soils and several other soil properties are stored (Food and Agricultural Organization [FAO], 2009). Based on these information, the extracted soil map of the area was reclassified into the four main soil hydrological groups (A–D) defined by the United States Soil Conservation Service (USDA, 2009).

### 2.2.7. Integration of GIS model

The GIS Model (GISM) as presented in Figure 3, was adopted and modified for analysis (Asare-Kyei et al., 2015). The model uses four main stages for flood risk zoning including (1) the generation of the different maps of the study area using satellite data, elevation map and field survey; (2) the inclusion of these data into the GISM and building of attribute tables; (3) the use of arithmetic overlay operation to combine the hydrological model with the geographic information system model and (4) The creation of flood vulnerability map for the area under study.

Finally, the elevation layer and the peak run-off layer were combined using arithmetic overlay method in ArcGIS to generate the flood hazard intensity map at different elevations. The model combines DEM and discharge map within GIS environment to determine flood risk areas. The arithmetic overlay method involves two main stages:

1. Determination of run-off concentrations (Figure 7(a)) within various segments over the landscape.
   \[ X + Y = Z_{ct} \]  
   (2)
2. Estimation of values that can be used to infer potential areas likely to be in flood with any storm event (Figure 7(b)).

where \( X \) (m) is the Digital Elevation Model; \( Y \) \((m^3/s)\) represents total discharge; \( Z_{ct} \) \( (m^3/s/m) \) is the run-off concentration at various elevations; \( Z_{FRA} \) is the value for flood risk areas.

In order to explicate the map for easy understanding, a recategorization was done to redefine five flood hazard intensity categories, viz. very high, high, moderate, very low and low risk zones. The natural breaks recategorization method in ESRI’s ArcGIS was used for this purpose (Kazakis, Ioannis, & Thomas, 2015; Xiao, Shanzhen and Zhongqian, 2017).

### 3. Results

#### 3.1. LULC changes from 1986 to 2016

The LULC changes for the study area between 1986 and 2016 are as presented in Figure 4. The results show that there have been changes in the various LULC (forest, agricultural lands, bare lands and settlements) from 1986 to 2016. However, only settlements (built-up areas) show significant change from what it used to be over the years (1986–2016). This indicates that there is correlation between LULC and flooding in the area.

In 1986, forestland covered 4,107 ha (7.7%) of the catchment, agricultural land accounted for 38,919 ha (72.6%), bare land accounted for 7,860 ha (14.7%) of the catchment while 2,730 ha (5.1%) were covered by settlements (built-up areas). In 1996, 3,530 ha (6.5%) of the study area were forest, 41,130 ha (76.7%) of the study area were agricultural land, 5,190 ha (9.7%) of the study area were bare land, while 3,770 ha (7%) of the study area were covered by settlements. By 2016, the following observations were made: forest covered 3,720 ha (6.9%), agricultural land covered 38,090 ha (71%), bare land covered 5,300 ha (9.9%) while settlements covered 6,510 ha (12.1%) of the study area.

#### 3.2 Soil textural class and elevation of the sub-catchments

The result of the soil classification revealed that the study area is predominantly Nitisols (NT) (Figure 5) representing the hydrological soil group “C” which is characterized as shown in Table 2 below. High elevation values are concentrated in the upper Ebonyi River (60 masl); upper Iyiokwu River and Ezza Abia sub-catchments while lower Ebonyi River, Iyiokwu River and Obiahu Ibom records very low elevation. The lowest elevation (15 masl) was observed in the southernmost part of Ebonyi River.
3.3 Peak run-off analysis

The map of the peak run-off rates (m$^3$/s) shows the distribution of run-off within the sub-catchments in the area studied (Figure 6 and Table 3). The Ebonyi river sub-catchment generates the highest amount of run-off in excess of 9782 m$^3$/s while the Igbegu sub-catchment generated the lowest (0.03 m$^3$/s).

3.4 Flood hazard intensity map

This map was produced by overlaying the peak run-off layer with the elevation layer through arithmetic overlay method as discussed in Section 2.2.7 (Figure 7(a,b)).

### Table 2. Hydrological soil groups.

| Soil Groups | Infiltration Rate (in/hr) | Description | Relative Run-off Potential |
|-------------|---------------------------|-------------|---------------------------|
| A           | >30                       | Sand, Loamy Sand | Low                      |
| B           | 0.15–30                   | Sandy loam, Loam | Moderate                 |
| C           | 0.05–0.15                 | Silt Loam, Sandy Clay Loam | High                   |
| D           | 0.0–0.05                  | Clay loam, Silt clay loam, Sandy clay & Clay | Very high               |

Source: (National Engineering Handbook (Chapter 7), 2009).
A reclassification was done on the flood vulnerable areas map to produce five classes which represent the Hazard Index. The index ranges from 1 (very low flood hazard intensity) in some part of upper Ebonyi River sub-catchment to 5 (very high flood hazard intensity) in the lower part of Ebonyi River sub-catchment. The final flood hazard map is represented in a graduated color (Figure 8). The map shows that about 33% of the catchment falls within very high flood hazard areas that cover sub-catchments such as Ebonyi River, Iyiokwu River and Igbegu. On the other hand, the very low flood hazard areas account for 44% of the study area covering sub-catchments such as upper Iyiokwu, upper Ebonyi, Ndiegu, Okpuituma and Ezza Abia. The very high flood hazard intensity zone is concentrated in Ebonyi

![Figure 6. Map showing peak run-off discharges of sub-catchment.](image)

![Figure 7. Maps of run-off concentration (a) and flood vulnerable areas (b).](image)

| Sub-catchments | Area (km²) | Run-off coefficient (C) | Rainfall intensity (mm/h) | Discharge (m³/s) |
|----------------|------------|-------------------------|--------------------------|-----------------|
| Igbegu         | 0.07       | 0.42                    | 414.2                    | 0.03            |
| Aja            | 582        | 0.25                    | 414.2                    | 169             |
| Ndiegu         | 1085       | 0.21                    | 414.2                    | 264             |
| Upper Iyiokwu  | 883        | 0.56                    | 414.2                    | 573             |
| Ohachikwe      | 539        | 0.38                    | 414.2                    | 238             |
| Obiegue Ibom   | 1099       | 0.21                    | 414.2                    | 267             |
| Iyiokwu River  | 7365       | 0.38                    | 414.2                    | 3245            |
| Upper Ebonyi   | 4770       | 0.38                    | 414.2                    | 2102            |
| Okpuituma      | 1025       | 0.21                    | 414.2                    | 250             |
| Idda           | 503        | 0.25                    | 414.2                    | 146             |
| Ezza Abia      | 0.10       | 0.52                    | 414.2                    | 0.06            |
| Agbaje         | 1632       | 0.34                    | 414.2                    | 644             |
| Opanana        | 654        | 0.34                    | 414.2                    | 238             |
| Agalegu        | 747        | 0.61                    | 414.2                    | 528             |
| Enyigba        | 538        | 0.33                    | 414.2                    | 206             |
| Ebonyi River   | 22195      | 0.38                    | 414.2                    | 9782            |
| Amachara       | 1267       | 0.38                    | 414.2                    | 558             |
river sub-catchment that is characterized by the highest run-offs and the lowest elevation of 9782 m³/s and 15 m, respectively, resulting in the greater percentage of the sub-catchment to fall within the very high flood hazard zone (Figure 8).

4. Discussion

From the result of LULC change detection, it can be seen that between 1986 and 1996, forest and bare land areas decreased by 1.2% and 5%, respectively, while agricultural land and settlement (built-up area) increased by 4.1% and 1.9%, respectively. This shows that forest and bare land areas have been converted to either agricultural land or settlements during this period.

Again, between 1996 and 2016, forest area increased by 0.4% probably due to government intervention via afforestation. During this period, agricultural land decreased by 5.7% while settlements areas and bare land increased by 5.1% and 0.2%, respectively. This increase in areas covered by settlement and bare land between 1996 and 2016 could be attributed to high influx of people to the state capital. It is important to mention that part of the study area became a state capital in 1996 which led to rapid increase in population.

Soil classification based on the soil attributes in the harmonized world soil database shows that the soil properties in the study area influence high run-off generation which can ultimately lead to flooding. Areas with low elevations fall in the category of high flood intensity zone while areas with high elevations fall within low flood intensity zones in the Flood hazard Index (FHI). This indicates that elevation plays a major role in flooding.

High run-off has a positive correlation with increased susceptibility of flood hazards. This is consistent with the key informant interviews with experts which revealed that communities within Ebonyi River and Iyiokwu river sub-catchments experience more frequent flood events and more people suffer from flood impacts when compared to other sub-catchments. As reported in Islam and Sado (2000), the high flood risk in Ebonyi River and Iyiokwu river sub-catchments is related to hydrological parameters.

Our findings through focus group discussions and key informant interviews with community members also revealed that flooding has been an issue in the catchment. The state government in collaboration with the federal government has channelized the two major Rivers (Iyiokwu and Iyiudele) which are responsible for major floods within Abakaliki metropolis in a bid to control the impact of flooding in the area. The channelization was done between 2013 and 2015 through the ecological fund and it has greatly reduced the frequency and severity of flooding within the metropolis. However, other areas which are not within the metropolis continue to witness different intensities of flooding.

5. Conclusion

Our study elaborated an approach to synthesize the relevant database in a spatial framework to produce
a flood vulnerability map of ALGA through the application of simple hydrologic models and arithmetic overlay operations in ArcGIS environment. Coupling of these hydrological modeling with GIS and remote sensing techniques in this study has shown the potential for accurate flood risk zone mapping. With this method, flood risk of various land uses can be determined with a greater accuracy. This could allow for more accurate estimation of most flood risk elements and identification of flood safe areas in order to prioritize developmental efforts. The study identifies rainfall intensity, LULC changes, soil properties and elevations as major factors that influence flooding hazard.

The flood mapping showed that Ebonyi river sub-catchment has a very high flood extent followed by Iyiokwa River, Iyiudele River and Obiahu Ibom sub-catchments. Therefore, early warning system development and mitigation interventions must be put in place in these areas. Accordingly, policy makers and development planners can make use of this study to develop appropriate early warning system and flood mitigation measures and consequently reduce the effects of flooding on the livelihoods of rural small holder farmers in the study area by taking cognizance of the spatial extent of flooding in the area. This study provides important information that can be useful for decision-makers to prioritize developmental efforts at local government levels.

We urge agricultural extension workers in the state to step up their game in educating farmers on the use of early maturing species and the importance of upland rice farming to reduce crop inundations by seasonal flooding. Sustainable flood awareness campaign/program is encouraged even in periods without flooding to continuously inculcate the culture of resilience on the communities.

A major limitation of this work, however, is that the hydrological model used does not consider some important factors that determine the magnitude of flood such as antecedent moisture conditions. We recommend an assessment of flood depth in further research on the study area to take the above limitations into account.

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