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URBAN FLOOD IMPACTS, FLOOD WATER QUALITY AND RISK MAPPING OF OLODO AREA, IBADAN, NIGERIA

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ABSTRACT

This study assessed urban flood impact, flood water quality and vulnerability around Olodo area of Ibadan region, Nigeria. The study employed remote sensing and GIS techniques in creating vulnerability and risk maps. Digital terrain model (DTM) was used to get the topography of the study area. Footprints of buildings along the Egberi riverbank and flood plain in Olodo were created in the GIS environment from high resolution satellite imagery. Buffering operation was conducted to classify the buildings into risk zones based on closeness to the riverbank using ArcGIS 10.0. The study revealed that 326 buildings were within the very vulnerable and vulnerable zones because they were less than 15.2m away from the riverbank. The characteristics of water quality change during the flood and non-flood periods. TSS, DO, NOD, and COD were all higher during the flood event. Microbial analysis showed that water quality levels in the floodwater exceeded water quality standards (e.g., the coliform excess from 10 to 10,000 times), and thus this may be a health risk for local people during flood events. Concentration of *Escherichia* coli (*E. coli*) ranged from 484 to 1290 cfu/100 mL during flooding compared to 192 to 295 cfu/100 mL after flood. Salmonella was found to be high ranging from 659 to 1840 cfu/100 mL during flooding compared to 530 to 1034 cfu/100 mL after flooding.

Keywords: Building footprint, Remote sensing and GIS, Urbanization, Urban flood, Vulnerability mapping, Egberi River

INTRODUCTION

Rapid urbanization, intense economic activity, and climate change are increasing major disaster risks in many urban areas of the world (UFCOP, 2016). Climate change is an attributed cause of disasters such as flooding because when the climate is warmer it results to; heavy rains. A closer look of disasters such as flooding reveals that they are induced by complex mix of drivers such as people living in dangerous places, poor governance, environmental degradation, inadequate early warning and lack of preparedness by the public and authorities, all interlinked with challenges of development (Bathrellos et al., 2017). Furthermore, relative sea level will continue to rise around most shoreline more frequently (Abolade *et al*., 2013). Frequency and magnitude of river flood events generally coincide with increases and decreases in heavy rainfall events (Melillo, *et al*., 2014; Mallakpour and Villarini,. 2015). Urbanization, urban growth and inrproper urban planning aggravates flooding by restricting flood water channels, covering large parts of the ground with roofs, roads and pavements, obstructing sections of natural channels and building drains that ensure that water moves to rivers faster than it did under natural conditions (Nolan and Maron, I995; ActionAid,2006; UFCOP,2016).

Populations and residential quarters along riverbanks and floodplains are at risk of inundation, in addition to causing substantial impacts on the environment, including damages on aquatic fauna and flora, and bank erosion (Miguez et *al*., 2015; UFCOP, 2016; Olatona *et al*., 2018). According to the 2015 Global Assessment Report by United Nations Office for Disaster Risk Reduction, natural disasters such as flooding lead to economic losses of almost US$250 billion each year (UNISDR, 2015). Flooding in 2010 affected 178 million people worldwide, representing 56 per cent of all disasters and affecting 87 per cent of the globally reported population impacted by disasters (Guha-Sapir *et al*., 2012; Jha *et al*., 2012; Munich Reinsurance Company, 2014).

In July 2012, large amount of water spilled from low-rise sections of the Egberi River resulted into flood affecting several people and their properties in Olodo area of Ibadan, Nigeria. Frequent floods could disrupt ecosystems by displacing aquatic life (washing away of aquatic organisms), impairing water quality, and increasing soil erosion. Floodwaters typically contain a significant fraction of contaminants such as heavy metal, gasoline, polycyclic aromatic hydrocarbons, raw sewage and associated macro pollutants that accumulate in the urban environment from different human activities (Doocy *et al*., 2013; Rui *et al*., 2018). These eventually get into bodies of water, such as lakes, rivers and streams, in the event of runoff or flooding after precipitation (Horton, 2006; OECD, 2006. Doocy *et al*., 2013). Outbreaks of waterborne infectious disease occur after an extreme water-related weather event in both developed and developing countries (Rui *et al*., 2018). For instance, in flood prone areas such as Bangladesh, there has been an increase in disease outbreaks, such as hepatitis E, cholera and leptospirosis, particularly in areas with poor hygiene and displaced populations (Nguyen *et al*., 2013). Deterioration of surface water quality is considered acceptable as an exception during flooding hence generally overlooked, even in comprehensive flood risk assessments such as the European Union directive on the assessment and management of flood risks (Doocy *et al*., 2013; Phung *et al*., 2016). Furthermore, lack of resources and delegation of resources to other needs such as evacuation or emergency management and weak enforcement of water quality monitoring guidelines can be attributed to the observed lack of water quality assessment studies and water quality monitoring during flood events in developing countries (European Parliament; Council of the European Union. 2007). There should be early and genuine engagement of affected communities and other stakeholders in order to ensure that their knowledge and opinions are fully incorporated in the investigation on flood risk (WMO, 2008a; Renaud, *et al*., 2013).

Urban areas such as Ibadan, Nigeria are particularly vulnerable to perennial flooding due to inadequate and obstructed drainage system; changes in ecosystem through the replacement of natural and absorptive soil cover with concrete; and deforestation of hillsides (Nguyen *et al*., 2017). In the absence of accurate and up-to-date information on flood hazard and its vulnerability, decision-makers may fail to take timely actions or make incorrect decisions. At present, one of the ways to study and understand flood behaviour is by generating flood risk map (Olatona *et al*., 2018). Flood risk maps portrays the potential damages that could occur as a result of a range of flood probabilities, by identifying populations, buildings, infrastructure, residences and environmental, cultural and other assets that could be destroyed. It creates clear, rapidly-accessible charts and maps, which assist the administrators and planners to identify areas of risk and prioritize their mitigation/response efforts.

The applications of GIS for hazard and vulnerability mapping has potential for identification of coping mechanisms, overall risk, urban hazards and conflict zones (Jha *et al*., 2012; Adelekan, 2016).This study assessed urban flood risk, and produce flood vulnerability map around River Egberi, Olodo area in Ibadan, Oyo State, Nigeria using remote sensing and GIS techniques. The study also assessed the quality of floodwater in the area.

The study area

Olodo is a community in the outer part of Ibadan, south-western Nigeria. It is located between latitudes 7°34'28" and 7° 57'44" N and longitude 3°56'2" and 3°93'38" E (Figure 1) with average an elevation of 301 meters above sea level. It covers approximately an area of 191 square kilometres and with population of 286,573.

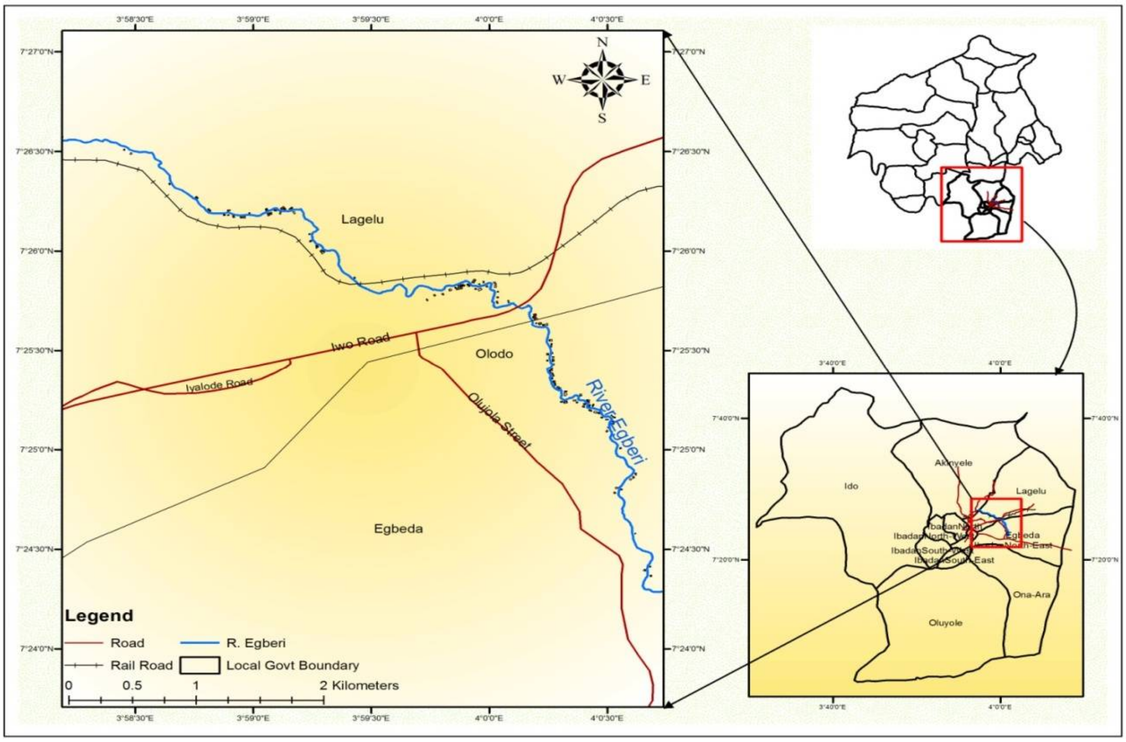

Figure 1: Study Area

The study area is characterized by two seasons (i.e. wet and dry seasons). The wet season, which is between March and October, is influenced by the moist maritime South-West monsoon winds blowing inland from the Atlantic Ocean that brings high rainfall. The dry season occurs from November to February when the dry dust laden winds blow from the Sahara desert. Average daily temperature varies between 25°C (77°F) and 35 °C (95°F), almost throughout the year. The area is underlain by basement complex rocks, which are mainly metamorphic rocks of Precambrian age with granite, quartzite and migmatite as the major rock types. The minor rock types include pegmatite, aplite and diorite. The soils were formed from the underlying rocks especially granite gneisses, quartz-schist, biotite gneisses and schist.

METHODS

Data Acquisition

A 2014 Landsat OLR/TIR satellite imagery of the area was georeferenced and registered to the geographic space and then the land cover and vegetation information were extracted. The images were downloaded from the official website of Global Land Cover Facility (GLCF)–(http:// www:glcf.umiacs.umd.edu). The imageries were then processed in the Geographic Information System (GIS) environment. Ground truth information were collected and combined with the images to assess the accuracy of image classification. All data were developed into Universal Transverse Mercator (UTM) coordinate system, zone 31N, with World Geocoded System (UTM WGS 84) projection parameters.

Data Preparation

ArcMap 10.0 GIS software was used to analyze vector and raster data to produce the flood risk and vulnerability map. ArcMap was used to conduct the spatial analysis. Furthermore, 'onscreen digitizing' of features from the satellite image was done to delineate the geomorphic features from the image. The composite index of flood hazard in the study area was computed from data derived from the topographical, land cover, geomorphic and population related data. Integration of all these data were done in a GIS environment to prepare a final Flood Hazard map.

Spatial Analysis

In order to enable accuracy of inundation modelling as well as to secure the identification of the endangered structures, detailed and accurate digital elevation models (DEM) were utilised. The DEM was generated from the vectorised contour lines. ArcMap 10.0 was used to do a digital elevation model (DEM) to get the topology of area of study. Contour analysis was done on the satellite imagery to extract the contour of the study area. The spatial analyst hydrology tool was used to generate the flow direction, flow accumulation, pour point and watershed area.

Flow Direction and flow accumulation

The Shuttle Radar Topography Mission data (SRTM) imageries were used to generate DEM (Digital Elevation Model) which was used also to get the flow direction, flow accumulation and watershed area of the study. To map flood risk area, cells were defined as river by setting a flow accumulation threshold of 6.5 km.

Buffer Based on Distance for Flood Risk Mapping

Buffers of distances to the drainage were created to signify vulnerability to flood. Generally, river corridors, for streams and rivers with drainages greater than 5.18 sqkm, were defined and mapped by assigning a corridor of 15.24 meters on either side of the stream, measured horizontally and perpendicularly from the top of each stream bank. This is the minimum recommended vegetated buffer distance within the river corridor to give resistance to flood water velocities in the near-bank region and increase the stream bank stability necessary to achieve and maintain equilibrium conditions (WMO, 2008b).

Normally, residential buildings are required to be at least 30m away from major water channels; this is to prevent exposure to flooding and to protect watersheds. In this study, the distances were classified into three categories with the first distance of 15.24 m to indicate areas along the drainage that were highly susceptible to flood. The second distance to river was thus set at 30.4m. Furthermore, another distance of 45.6m to river was set to identify areas that were less vulnerable to flood (WMO, 2008b).

Building footprints

Building footprints are the area on a project site that is used by the building structure and is defined by the perimeter of the building plan (Sritarapipa and Takeuchi, 2017; Khatriker and Kumar, 2018).. Building footprint information is an essential component, and geospatial technologies helps in creating this large mass of data inputs for designing and planning smart cities (Khatriker and Kumar, 2018). Accurate building footprint data are essential for construction of urban landscape models, assessment of urban heat island effect, and estimation of building base elevation for flood insurance. The high-resolution (meter -level) remote sensing image from Google Earth was used to generate the building footprints map for the study area (Hu et al., 2014). Building footprint map of the study area around the Olodo River (Figure 2) shows those buildings that were in the area and those that were vulnerable or affected by the flooding event. An automated method was used to extract the building footprints based on high-resolution image from IKONOS data.

Floodwater quality sampling

Flood water sampling for analysis was limited to few accessible locations affected by flooding comprising of three locations on flooded streets and two locations along open waters (upstream and downstream). Samples were taken during the rising and receding time of flood water. An average of three samples were collected per location in 2 litre kegs for physical and chemical analysis, and one litre Nalgene™ polyvinyl bottles for microbiological analysis. All water samples were stored in 4^{o}C icebox and taken to laboratory for analysis within 24 hours (Nguyen *et al*., 2013). Water quality parameters such as temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, fecal coliform, and Salmonella were determined from the representative water samples collected during and after the flooding event. Temperature, pH, and electrical conductivity (EC) were measured *in situ* using Hanna combo portable meter (Nguyen *et al*., 2013).The Hanna combo meter was calibrated with buffer 4 and 9, rinsed with distilled H_2O, inserted into the sample, and allowed several minutes to stabilize before values were recorded. DO was determined by Winkler Azide Modification Titrimetric, while the DO method was used after five days for BOD. Chemical oxygen demand (COD) was determined using a strong oxidizing agent (potassium dichromate) $K_2Cr_2O_7$ and sulphuric acid at 148°C with back titration (Nguyen *et al*., 2013). Total Suspended Solids were determined gravimetrically (Nguyen *et al*., 2013). Microbiological water analysis is mainly based on the concept of faecal indicator bacteria. Faecal coliform was also measured, using Escherichia coli (*E. coli*)as an indicator organism. *E. coli* were recovered and enumerated via culture-based most probable number (MPN) techniques in compliance with EPA guidelines (APHA, 2012). Salmonella concentrations for water samples were determined by the method described by Krometis *et al*. (2009). The media were boiled using Electro thermal bath. Plate count analysis was conducted using McConkey agar and the plates were incubated at 37°C for 24 h to detect red colonies on the incubated Petri dishes. The plate were examined, then left for another 24 h at room temperature and re-examined. All analyses were performed by the membrane filtration technique with Millipore filters and equipment (Millipore Corp., Bedford, Mass). The assays for detection of faecal coliform and Salmonella were conducted within 24 h of sample collection. All samples were determined in triplicate.

Data Analysis

Geographical Information System (GIS) Techniques was applied in the prediction of flooding risk and vulnerability map of the study area. This was achieved by creating a digital database of selected variables such as elevation, relief, soil, rainfall, land use etc. ArcMap GIS 10.0 software was used for the overlay techniques in GIS to show risk and flood prone areas.

RESULTS AND DISCUSSION

Figure 2 shows the rainfall data for 16 years (1997-2016). Average rainfall in the raining season ranged from 142 mm in April to 190 mm in June 2016, while average temperature ranged from 24.1°C to 28.6°C. Climatic data for the area shows high intensity rainfall leading to the devastating flood in the study area (Figure 2 and 3). Annual rainfall varies between 1997 to 2016 with the peak periods been 1999, and then 2007 to 2012. The amount of rainfall has not changed overtime but the intensity and duration is a major problem leading to flooding. A report by Nigerian Meteorological agencies has indicated considerable signals of a changing climate with variability in rainfall and warmer temperature (Krometis, 2009).

Figure 2: Rainfall Data for the Study Area between 1997-2016

Peak periods of rainfall such as 1999, 2009, 2012, 2013, and 2016 coincided with reported incidences of flooding which great impacts on the people in different parts of the region. According to the National Emergency Management Agency (NEMA), 30 out of Nigeria's 36 states were affected by the 2012 floods, which were termed as the worst in 40 years and the rainfall data showed that 2012 had highest rainfall in the past 20 years (NIMET, 2008). Large amount of water spilled from low-rise river sections resulted into flood affecting several people and their properties in Olodo area. Residential areas were mostly affected by flooding which accounts for the high percentage vulnerability and about thirty houses were swept away by the flood while forty people lost their lives (Adelekan, 2016). The emerging pattern of higher-intensity rainstorms in recent years has resulted in increased runoff arising from reduced vegetation cover over the city, a higher percentage of artificial surfaces and poor drainage systems, which trigger flooding (Jha *et al*., 2012; World Bank, 2014;Nguyen *et al*., 2017).

Flood Risk Assessment

The flood risk assessment was based on buffer distance of 15.24m to the river was selected as high-risk zone because some buildings were within the vulnerable area. Figure 3 shows the building footprint of the study area derived from Google Earth Engine.

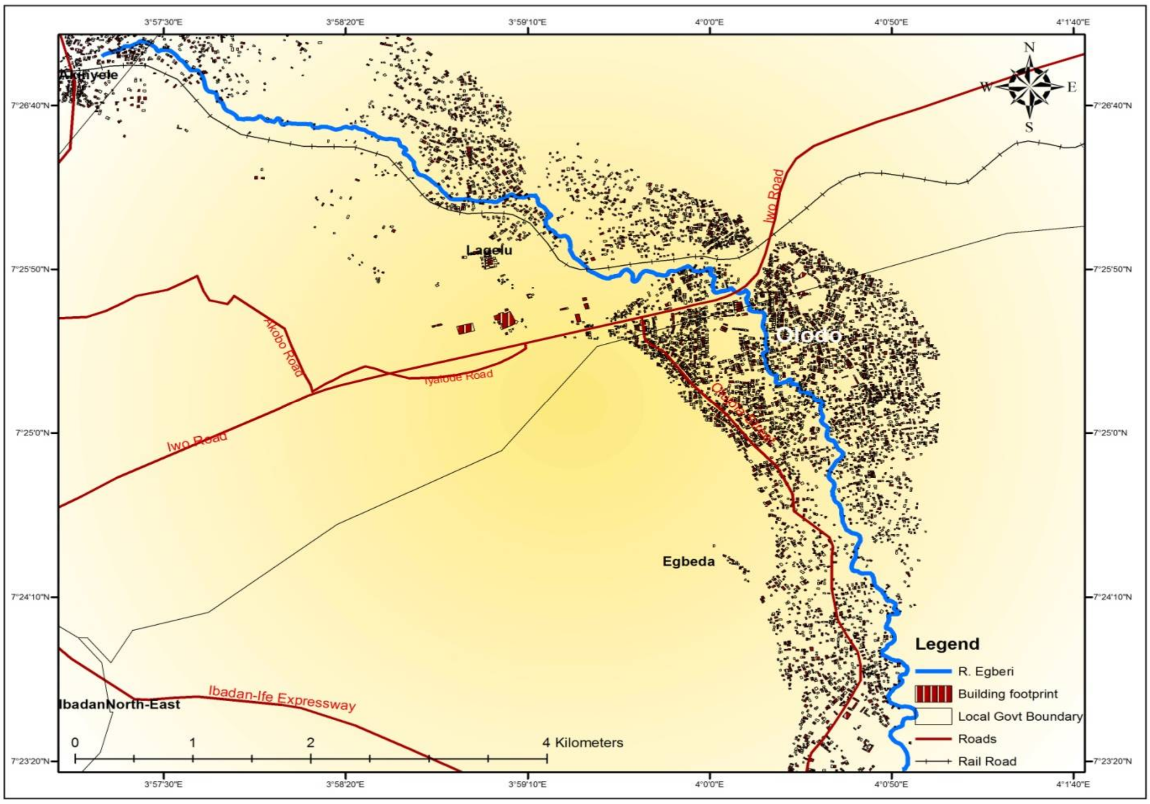

Figure 3: Olodo Building footprint and its environs

The maps produced were overlaid on the building footprint using the overlay functions in ArcGIS to produce the vulnerability map. Based on the buffering analysis in Figure 4, thirty-three (33) buildings out of the 8135 buildings in Olodo and its environs were within ≤ 15.2m setback from the riverbank, which makes them highly susceptible or highly vulnerable to flooding (Ward *et al*., 2002). 192 buildings were within ≤ 30.4m buffered zone from the riverbank that indicated moderate vulnerability, while 7910 buildings were within ≥ 45.6m buffered zone from the riverbank indicating low vulnerability.

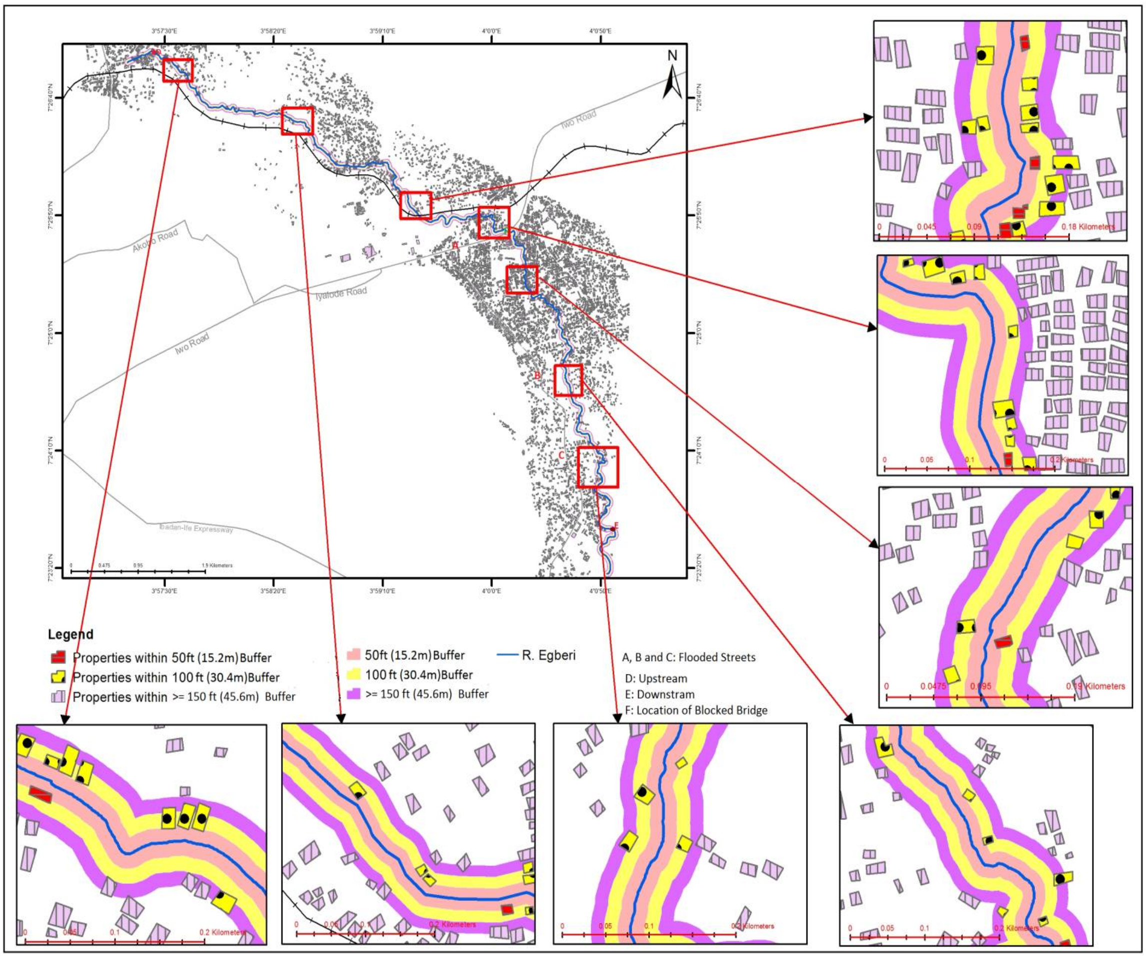

Figure 4: Building vulnerable to the flood risk using 50ft buffer

Construction of buildings within setbacks, poor floodplain and river channel management, the use of the rivers and drainage channels for solid waste disposal (Figure 5) have resulted in the inundation of many parts of the study area during heavy rainfall (Adelekan, 2016). Recently, the National Emergency Management Agency (NEMA) reported that on June 20, 2017, over 300 houses are affected by the flooding that accompanied the five-hour downpour in Ibadan, which include houses in the Olodo area. Majority of the buildings were illegally constructed without approvals from the authority. Observation and investigations showed that majority of the buildings in these areas have no building permits or approval as they were built on fragile lands. Unplanned land use pattern and other human activities in the area also influence the peak discharge of floods by modifying how rainfall are stored on and run off the land surface into streams (Nguyen *et al*., 2017). Sediment and debris carried by floodwaters can further constrict a channel and increase flooding especially at the upstream of culverts, bridges, or other places where debris collects (World Bank, 2014).

Figure 5: Blockage of River Channel with solid wastes

Figure 6 shows one of the houses affected by the inundation with the flood height on the walls. This building is one of the illegal and unapproved houses build along the floodplain of the river. The building blocked the river channel thus constricting the flow of the river. It is an abandoned building now due to constant threat of inundation by floodwater.

Figure 6: Flood height after the flood

Quality of floodwater

The quality of the floodwater during and after the flood was assessed and the results presented in Table 1. The parameters determined were the basic water quality parameter especially in relation to domestic water use and public health. Temperature ranges from 26.3 °C to 28.6 °C during the flood while it was slightly lower after the flood. The pH value of flood water ranged from 7.6 to 8.45 while electrical conductivity EC ranged from 655 to 982 $\mu S\ cm^{-1}$ during the flood.

Table 1: Physical Properties of Flood Water during and after the Flood

Parameters		**During Flooding**			**After Flooding**		
		Min	Max	Mean±SD	Min	Max	Mean±SD
Temperature °C		26.3	28.6	27±0.34	25.8	27.2	26±0.52
pH		7.61	9.56	8.64±2.12	7.38	8.26	7.53±0.02
EC	**μScm^{-1}**	655	982	748±20.52	469	558	485±15.00
TSS	**mgL^{-1}**	206	478	342± 12.70	194	357	264±10.50
DO	**mgL^{-1}**	2.47	13.6	7.20±0.52	1.42	9.03	3.50±0.20
BOD	**mgL^{-1}**	15.01	26.24	18.20±3.00	11.01	18.43	10.32±2.55
COD	**mgL^{-1}**	156.2	247.2	183±28.15	127.8	165.5	134±16.50

TSS value in the river during the flood was very high, reaching up to 478 mgL^{-1} while it reduced to 357 mgL^{-1} after the flood. Dissolved oxygen value in floodwater ranged from 2.47 to 13.6 mgL^{-1}compared to DO of 1.42 to 9.03 mgL^{-1}after the flood. BOD_5 was high during the flood, reaching up to 26.24 mgL^{-1} while the highest BOD after the flood was 18.43 mgL^{-1}. COD value for the flood water ranged from 156.2 - 247.2 mgL^{-1} during flooding and the value was reduced to 127 – 165.5 mgL^{-1} after the flood.The characteristics of water quality change during the flood and non-flood periods (Adelekan, 2015). There was a slight change in the flood water temperature from maximum of 28.6 °C reducing to 27.2°C, which can be attributed to the lower temperature of the rainwater outflow than the temperature of the river water. The mean pH of the flood water was 8.64 ± 2.12 with a maximum of 9.56 during high flood. The pH decreased slightly from 7.38 to 8.26 when the flood receded. Average pH was within the limit specified 6 and 9 for stormwater (Hayashi *et al*., 2013). Eroded materials carried by runoff into the river caused high values of EC found during the flood. TSS value in the river during the flood was very high, reaching up to 478 mgL^{-1} while it reduced to 357 mgL^{-1} after the flood. Total suspended solid (TSS)is a parameter used in water quality, which gives a measure of turbidity of water. suspended solid cause the water to be milky or muddy looking. Studies have shown that high TSS can reduce light penetration in the water thus limiting primary production and subsequently affecting aquatic organisms. Dissolved oxygen in floodwater ranged from 2.47 to 13.6 mg L^{-1} O_2, which was slightly above the USEPA standard of 12.7 mg L^{-1} O_2. DO indicate the health of an aquatic environment, the vital metabolism of aerobic organisms and respiration depends on the amount of oxygen dissolved in water (USEPA,1994). Low DO value between 1-5 mgL^{-1} may reduce the growth rate of fishes when continuously exposed, while a value below 1 mgL^{-1} can be fatal to fishes when exposed more than a few hours.

The higher DO during the flood is almost certainly due to the active mixing of the water (thus aerating it) during the flood as compared to aeration at a slower rate in the calmer flows post-flood. BOD values during and after the flood exceeded the 6 mgL^{-1} O_2 limit value for the good ecological status of rivers (Gołdyn, 2000; Barałkiewicz *et al*., 2014; Udofia *et al*., 2014). Flood water is known to be particularly high in pollutants especially at the initial stage. This is because the 'first flush' of storm water washes stagnant water and contaminants that is characterized by low oxygen and highly polluted with waste into streams and rivers (Mohamed Basri *et al*., 2015).BOD_5 is the amount of oxygen used over a five-day period by microorganisms as they decompose the organic matter in water bodies at a temperature of 20° C (68° F). High BOD_5 and suspended solids can lead to decrease in oxygen concentrations because of the microbial decomposition of organic matter(USEPA. 2003). High concentrations of DO, BOD and TSS during high flood stage may be due to fact that major portions of the river contained huge solid waste dumped by residents which showed that the river was already contaminated before the flood. The flood caused serious contamination during the high flood stage due to flushing of eroded materials, sediments, human and animal wastes; garbage and food refuse into the river. However the period after flood represented a period of recovery in which the river is less contaminated because these materials had been carried away. The mean COD for the flood water was 183 mgL^{-1} during the high flood compared to 134 mgL^{-1} after the flood. COD recorded in this study was higher than the USEPA acceptable value of 20 mgL^{-1} for unpolluted surface water quality and the 120 mgL^{-1} for stormwater. High COD is an indication of high rate of chemical oxidation of organic substances at some of the sampling locations. Generally, COD is always higher than that of BOD_5 because many organic substances can be oxidized chemically but not biologically. Studies have shown that flooding can cause significant increase in the concentrations BOD5, COD, and TSS which usually tend to increase during the flood phase and then return to pre-flood levels (USEPA, 1994; Nguyen *et al*., 2013). The effect of inundation on urban surface water quality is usually temporary depending upon the type and concentration of the contaminants of the receiving surface waters and flood water and their dilution rate (Gołdyn, 2000; Doocy *et al*., 2013).

Microbial Content of flood water

Microbial contaminant concentrations in the street flood water in the study area were examined and the results are presented in Table 2. The concentration of *Escherichia* coli (*E. coli*) ranged from 484 to 1290 cfu/100 mL during flooding compared to 192 to 295 cfu/100 mL after flood. Salmonella was found to be high ranging from 659 to 1840 cfu/100 mL during flooding compared to 530 to 1034 cfu/100 mL after flooding.

Table 2: Microbial Content of water during and after the flood

		E.coli (cfu/100 mL)	**Salmonella (cfu/100 mL)**
During Flooding	Min	484	659
	Max	1290	1840
	Mean	750	845
	SD	30	25
After Flooding	Min	192	530
	Max	295	1034
	Mean	238	668
	SD	12	20

The analysis showed that water quality levels in the floodwater exceeded water quality standards (e.g., the coliform excess from 10 to 10,000 times), and thus this may be a health risk for local people during flood events. *Escherichia* coli (*E. coli*) count ranged from 484 to 1290 cfu/100 mL, while the total Salmonella count ranged from 659 cfu/100 mL to 1840 cfu/100 mL during the flood phase. However, after the flood the concentration slightly reduced (Table 2). *E.coli* had been known as familiar pathogenic bacteria that exist in floodwater (Barałkiewicz *et al*., 2014).The concentration of *E.coli* in the floodwater exceeded the limit (1 cfu/ml) for criteria of recreational water (full body contact) (Mohamed Basri *et al*., 2015). *E. coli* belongs to the faecal coliform group and is specific to the intestinal tract of warm-blooded animals and cause human diseases such as enteropathogenic which causes diarrhea in children especially in developing countries, and enterotoxigenic *E. coli* which causes traveler's diarrhea (Mohamed Basri *et al*., 2015).

CONCLUSION

Erection of buildings in the flood prone area and blockage of drainage channels by indiscriminate municipal solid contribute a lot in the Olodo area. The study revealed that many buildings in Olodo area were built in vulnerable zones, which made them prone to flooding. The study revealed that 326 buildings were within the very vulnerable and vulnerable zones because they were less than 15.2m away from the riverbank. The characteristics of water quality change during the flood and non-flood periods. TSS value in the river during the flood was very high, reaching up to 478 mgL^{-1} while it reduced to 357 mgL^{-1} after the flood. In addition, EC, DO, BOD, and COD were also found to be higher during the flood compared to after the flood. The higher DO during the flood is almost certainly due to the active mixing of the water (thus aerating it) during the flood as compared to aeration at a slower rate in the calmer flows post-flood. The flood caused serious contamination during the high flood stage due to flushing of eroded materials, sediments, human and animal wastes; garbage and food refuse into the river. The concentration of *Escherichia* coli (*E. coli*) ranged from 484 to 1290 cfu/100 mL during flooding compared to 192 to 295 cfu/100 mL after flood. Salmonella was also found to be high ranging from 659 to 1840 cfu/100 mL during flooding compared to 530 to 1034 cfu/100 mL after flooding. The concentration of *E.coli* in the floodwater exceeded the limit (1 cfu/ml) for criteria of recreational water (full body contact). This could lead to the spread of water-borne diseases. Equally, long after floodwaters have receded, water-damaged buildings may harbour mold growth, drinking water may remain contaminated, and residual pools may provide breeding grounds for bacteria.

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