Journal of Geographic Information System, 2023, 15, 580-596
https://www.scirp.org/journal/jgis
ISSN Online: 2151-1969
ISSN Print: 2151-1950

Flood Vulnerability Mapping: A Case Study of Okoko Basin, Osogbo

Toyosi Beatrice Adedoja[1*], Oladimeji Samuel Popoola[1], Taofeek Abayaomi Alaga[1], Adesola Elizabeth Akindejoye-Adesioye[2]

[1]Cooperative Information Network, National Space Research and Development Agency, OAU Campus, Ile-Ife, Nigeria
[2]Flood Hazard Research Centre, Middlesex University London, London, UK
Email: *dadatoyosi@yahoo.com

How to cite this paper: Adedoja, T.B., Popoola, O.S., Alaga, T.A. and Akindejoye-Adesioye, A.E. (2023) Flood Vulnerability Mapping: A Case Study of Okoko Basin, Osogbo. *Journal of Geographic Information System*, **15**, 580-596.
https://doi.org/10.4236/jgis.2023.155029

Received: July 12, 2023
Accepted: October 28, 2023
Published: October 31, 2023

Abstract

This study employed Geographic Information System (GIS) and remote sensing approach to analyze the flood vulnerability areas in the Okoko basin area of Osogbo in Osun state, Southwestern Nigeria. High-resolution imageries, a Topographic map of the study area and a TCX software program (Version 2.0) were integrated using ArcGis (10.7). Some of the causative factors for flooding in the watershed were taken into account which are: Land use, Distance of buildings to drainage, Digital Elevation Model, and Slope. This study aimed at mapping the flood-vulnerable areas along the Okoko basin of Osogbo. In developing a flood risk/flood hazard map of the study area, and determining the level of expected disaster, a multi-criteria analysis was utilized. The factors considered were ranked in five classes with the highly vulnerable areas having the highest score of "5". These factors were weighed according to the estimated significance of causing flooding. The study revealed that the study area has an estimated area of 17.85 km^2 of which 14.2 km^2 falls within the vulnerable areas while 3.6 km^2 is on the least vulnerable areas. Moreover, out of 16,829 buildings in the study area, 8204 buildings were found susceptible to flood disasters. This research attempts to equip decision-makers to make accurate decisions and also serves as a mitigation measure for flood disaster management.

Keywords

Hazard, MCA (Multicriteria Analysis), Floodrisk, TCX Software

1. Introduction

The incidence of severe rains and their effects on river discharge result in flooding within communities along riverbanks and where there are poor drainage gsystems and landforms [1]. A flood is a temporary condition of partial or complete inundation of two or more acres of normally dry land area or areas with properties [2]. The term is also used to describe the sudden and unexpected rise of water to a specific depth, which can be the result of dam failure or prolonged and intense rainfall putting the lives and property of people and other animals in the area at risk [3] [4]. Flooding is still one of the most frequent types of natural disasters reported globally today [5] [6]. Floods can cause widespread devastation, resulting in loss of lives and damages to personal properties as well as critical public infrastructure. WHO (World Health Organisation) reported that from 1998 to 2017, floods affected more than 2 billion people worldwide [7]. People who live in flood plains or non-resistant buildings, or lack warning systems and awareness of flooding hazards are most vulnerable [8] [9].

Recent years have seen an increase in the frequency and severity of flooding as a natural calamity that recognizes no geographical limits. They are inevitable and, as a result, they can cause death through factors including population displacement and environmental degradation [3] [10] [11] [12]. In Africa, flooding is a serious problem as most African countries lack the technological and financial resources to combat its impacts [13]. The periods between 1996 and 2005 were noted for its floods devastating effects on the continent of Africa, with 290 flood disasters in Africa alone [14]. This resulted in the death of 8183 people, and 23 million people were affected and caused economic losses of $1.9 billion [15]. Furthermore, many instances of flooding due to multiple days of rainfall have been recorded by media outlets and aid agencies across Sub-Saharan Africa [3] [16]. Since gaining its independence from Portugal in 1975, Mozambique has been hit by flooding practically annually, with costs running into the millions of US dollars per time [17].

Seasonally, Nigerian residents especially communities within the banks of Rivers are flooded to the extent that damages are caused to human lives and other properties. In 2012, 30 of 36 states in Nigeria were affected by flooding killing 363 people and displacing over 2.1 million people [18]. It was estimated that about ₦2.6 trillion were lost. The 2012 floods were termed the worst in 40 years and an estimated 7 million people were affected [19].

Death rates in Nigeria are among the highest in all of West Africa. Villages and farmland have been wiped out in the north due to flooding [3]. However, the Nigerian Meteorological Agency has warned that Osun is among the areas that are prone to flooding, Several Areas within Osogbo, the capital city of Osun State in Nigeria, have suffered severely from incessant flood occurrences, which necessitated flood vulnerability mapping. The significant case is the Osogbo flood incidence which according to The Nigerian Tribune and Guidian newspaper led to the death of a citizen and countless losses after hours of rainfall, in September 2016 affecting areas such as Rasco, Oke Onitea, Obate, in Oke Bale, Gbonmi, Fiwasaye and Testing Ground [20] [21] [22]. Likewise, numerous areas of Osogbo, the capital of Osun State in Nigeria, have endured severe flooding on a regular basis, necessitating the creation of flood vulnerability maps [23]. With all these, flood risk/flood hazard is important to determine the level of expected disaster in the study area. Flooding has been an ongoing issue in Nigeria, with official records dating back to 1951 [24]. However, research and development efforts are still working to gather nationwide information to help address problems like encroachment, flood inundation, and identification of flood-prone areas. Until more robust and lasting solutions to flooding challenges are found, research will likely continue [25]. This recent study provides a new fine-scale mapping and analysis of flood vulnerability specifically in the Okoko area of Osogbo, Nigeria. While previous researches have examined flooding hazards more broadly across Nigeria, few studies have quantitatively mapped vulnerability at the local scale of a specific urban watershed, as this study has done for the Okoko basin through the application of Geographic Information Systems (GIS) and remote sensing. A localized analysis like this may likely be key to addressing the ongoing challenge of flooding nationwide. The four factors namely Land use, Slope, Dem and Drainage are considered the primary drivers of flooding and are often the most available or accessible data for researchers [26]. Soil characteristics, geology, and rainfall data require specialized collection or modeling efforts. Moreover, these factors are relatively straightforward to parameterize and weigh in flood models [27] [28]. Soil and geology parameters involve more complexity. Simpler models with only 3 - 5 factors have shown good predictive skills for the identification of flood-prone areas in some contexts [29] [30]. Adding more parameters does not always improve model accuracy. Key data like rainfall intensity, soil types, and geology often vary significantly within a study area. Choosing broader factors like slope and land use facilitates larger-scale analysis. Finally, limited time and resources in some of this work have allowed for prioritizing the main geomorphic factors that most directly influence flooding [31] [32]. More parameters could be added in the future for finer analysis.

2. Methodology

2.1. Study Area

Okoko basin lies between Latitudes 7˚45'19.88"N and 7˚48'42.24"N and Longitudes 4˚33'18.22"E and 4˚35'46.49"E (**Figure 1**) and has an elevation of over 500 m above sea level, covering an area of approximately 17.85 km^2. River Okoko is one of the major rivers that drain into the river Osun from the southeast [33]. For residents living downstream of the river, and especially for the factories situated along its course, this river provides the primary source of water. The prominent communities within its locality include Jasa, Oloyin, Adiloju, Atapara, oke Osun and Otapa. Based on the 2006 National Population Census, the total number of inhabitants of Osogbo was estimated to be approximately 300,000 people [34].

Geologically, the study area comprises majorly the Precambrian basement terrains which form part of the pan-African mobile belt in the eastern part of West African craton [23] [35]. The climate in the region is tropical hinterland type with a mean annual temperature of about 27˚C. Predominately, the Osogbo soil

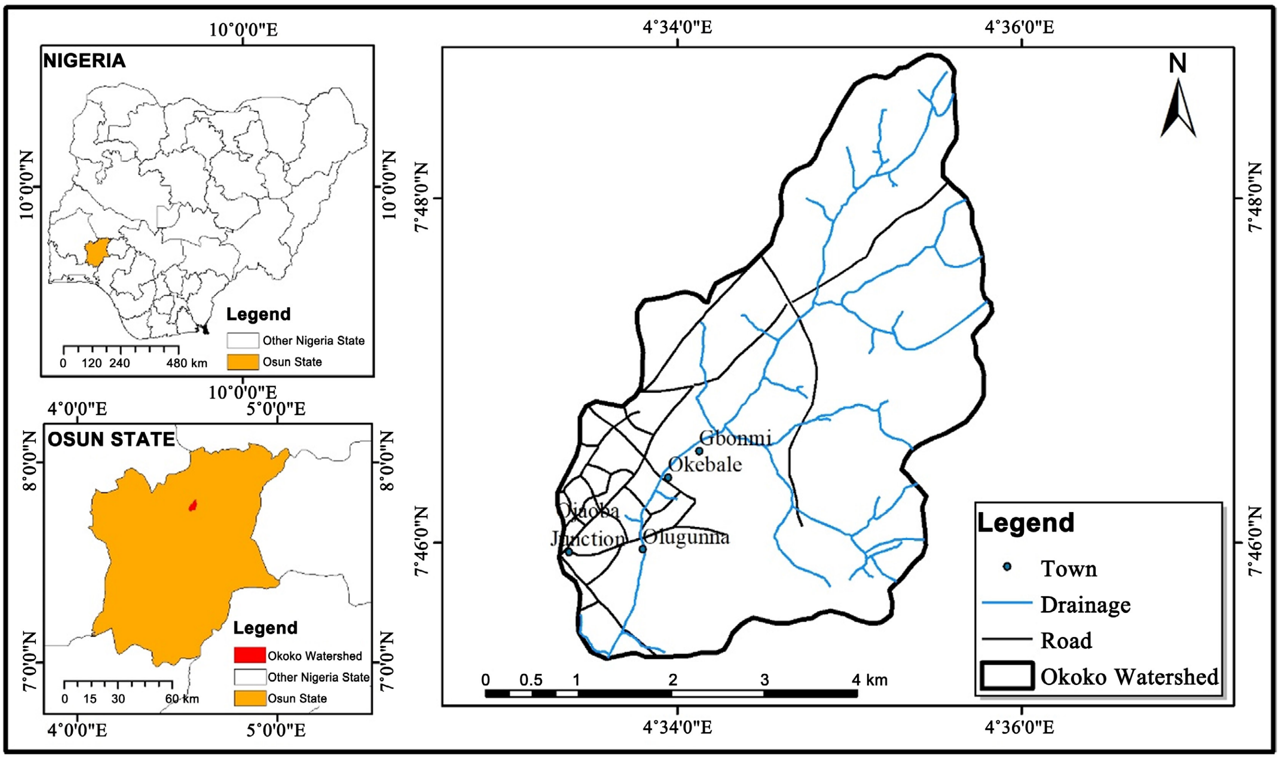

Figure 1. Map of Osun state showing study area.

is rich in coarse and granite rocks [36]. The Osogbo is located with the lowlands tropical rainforest vegetation but due to human interference of uncontrolled lumbering activities, Agriculture, and fuel wood harvesting have since metamorphosed into a secondary forest and derived savannah [23]. The annual rainfall ranges from 1650 mm to 1700 mm, mostly within March/April to October. Most time of the year the study area experiences double maximum rainfall in July and October as it pecks [37]. The relative humidity ranges from 75% to 90% annually [35]. Osogbo where the study area is located holds her annual mega-festival tagged "Osun Osogbo Festival". Osun Osogbo festival is known around the world and attracts a huge number of visitors all over the globe.

2.2. Materials and Methods

This study utilizes both primary and secondary spatial and non-spatial data to assess flood risk in the Okoko basin as shown in **Figure 2**. Primary spatial data consists of Ground Control Points (GCPs) acquired in the field using a Global Positioning System (GPS) receiver (Ashtech 12XL handheld) to geocode satellite imagery and digitized features. Secondary spatial data includes a 30-meter resolution digital elevation model (DEM) derived from the Shuttle Radar Topography Mission (SRTM) obtained from the United States Geological Survey (USGS) [38]. The SRTM DEM was selected for its high precision and consistency in representing topography. Additional secondary data comprises high-resolution Landsat 8 satellite imagery to provide land cover detail and a drainage map of the study area [25]. Non-spatial data was obtained via expert judgment through a pairwise

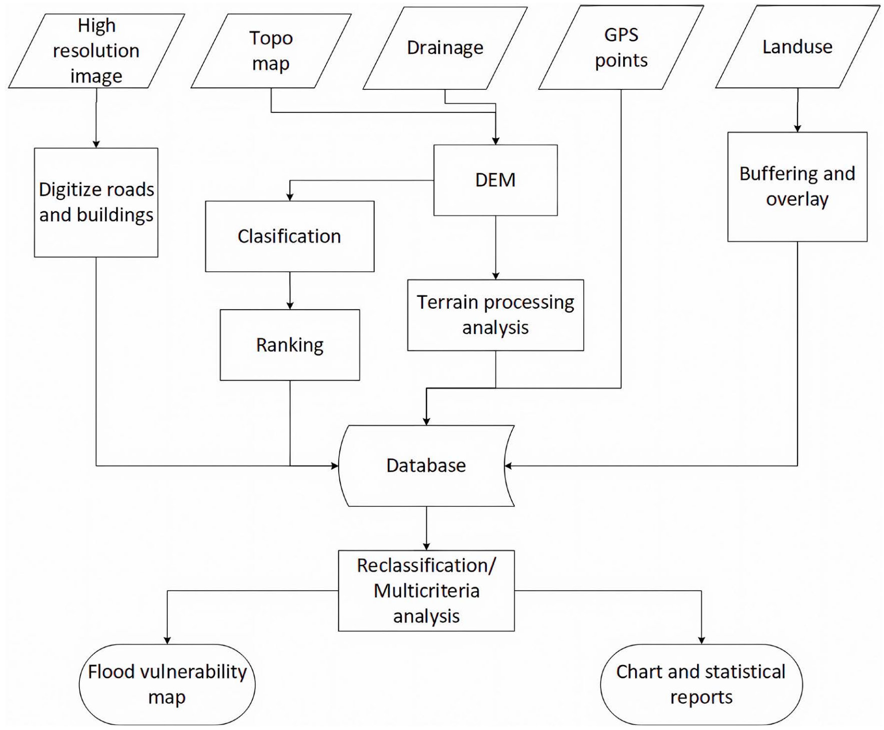

Figure 2. Flow chat of the method.

comparison process to determine the weighted contributions of different factors to flood susceptibility, including land use (6.7%), slope (20%), DEM (40%), and drainage (33.3%) [39] [40]. These weightings were applied to spatial layers in the flood risk mapping. GIS analysis combined spatial data layers after ensuring alignment accuracy between satellite imagery, digitized features, and DEM through overlay and assessment of GCP coordinates [41]. Flood risk zones were delineated based on estimated vulnerability to the weighted susceptibility factors. All layers are converted to a common scale, ranked flood vulnerability scores assigned to classes, and weighted according to determined susceptibility influence. The layers are integrated using weighted overlay in ArcGIS ModelBuilder to produce a flood susceptibility index map. The output map is validated using historical flood event locations and the fine resolution of the SRTM DEM and Landsat imagery enabled local-scale mapping of areas prone to flooding in the basin [25]. By integrating primary field data with secondary spatial data and non-spatial expert knowledge, this methodology provides a robust approach to delineate and characterize flood hazards in the Okoko basin. The multi-layer spatial analysis and locally calibrated risk weighting support granular mapping of flood vulnerability.

3. Results and Discussion

The multifaceted phases of analysis undertaken in this study have facilitated a profound comprehension of the influential factors contributing to flooding and the identification of vulnerable areas within the Okoko watershed. This knowledge serves as a foundational basis for the subsequent recommendations that this study will proffer in terms of flood control and proper management. The primary findings of this investigation are succinctly delineated as follows:

1) Land Slope Analysis: The study, as presented in **Table 1**, discloses that a significant portion of the study area is characterized by sloping terrain. Specifically, more than half of the land exhibits varying degrees of slope. Steeply sloped landscapes are inherently prone to erosion and flooding due to reduced water retention capacity, leading to the rapid runoff of water and the erosion of topsoil nutrients.

2) Slope Map Classification: The Slope map, as illustrated in **Figure 3**, has been categorized into five distinct slope degrees. These classifications encompass the following ranges: (0 - 1) degrees representing areas with simple topography, (2 - 3) degrees indicating gentle slopes, (4 - 6) degrees signifying moderately sloping regions, (7 - 12) degrees representing steeply sloping areas, and regions with slopes exceeding 13 degrees denoting very steeply sloping terrain. Each of these classes provides valuable insights into the regions that hold the potential for flood risks within the study area.

- (0 - 1) degrees—Simple Topography: Areas falling within this class feature remarkably gentle slopes, effectively rendering the terrain nearly flat. Consequently, these regions are susceptible to flooding during heavy rainfall events, as the flat terrain inhibits rapid water drainage, resulting in water accumulation. As a result, these flatlands become prone to waterlogging and localized flooding during the rainy season. The implementation of proper drainage infrastructure and planning is imperative to effectively manage and mitigate flood risks in these areas.
- (2 - 3) degrees—Gentle Slope: Regions characterized by gentle slopes exhibit improved drainage capacity compared to areas with simple topography. Consequently, the risk of flooding is diminished in these regions, as water can flow more efficiently. Nevertheless, these areas may still experience flooding during intense or prolonged rainfall events. Adequate land use planning, such as the avoidance of construction in flood-prone zones, can significantly reduce the potential impacts of flooding in these areas.
- (4 - 6) degrees—Moderately Sloping: This class encompasses areas with moderately sloping terrain, which is inherently advantageous for agricultural practices due to its ability to facilitate efficient water drainage.

Table 1. Slope analysis.

Slope Analysis	Land Area %
0 - 1 Simple slope	26
2 - 3 Gently sloping	48
4 - 6 Moderately sloping	21
7 - 12 Steeply sloping	4
>13 Very Steeply sloping	1

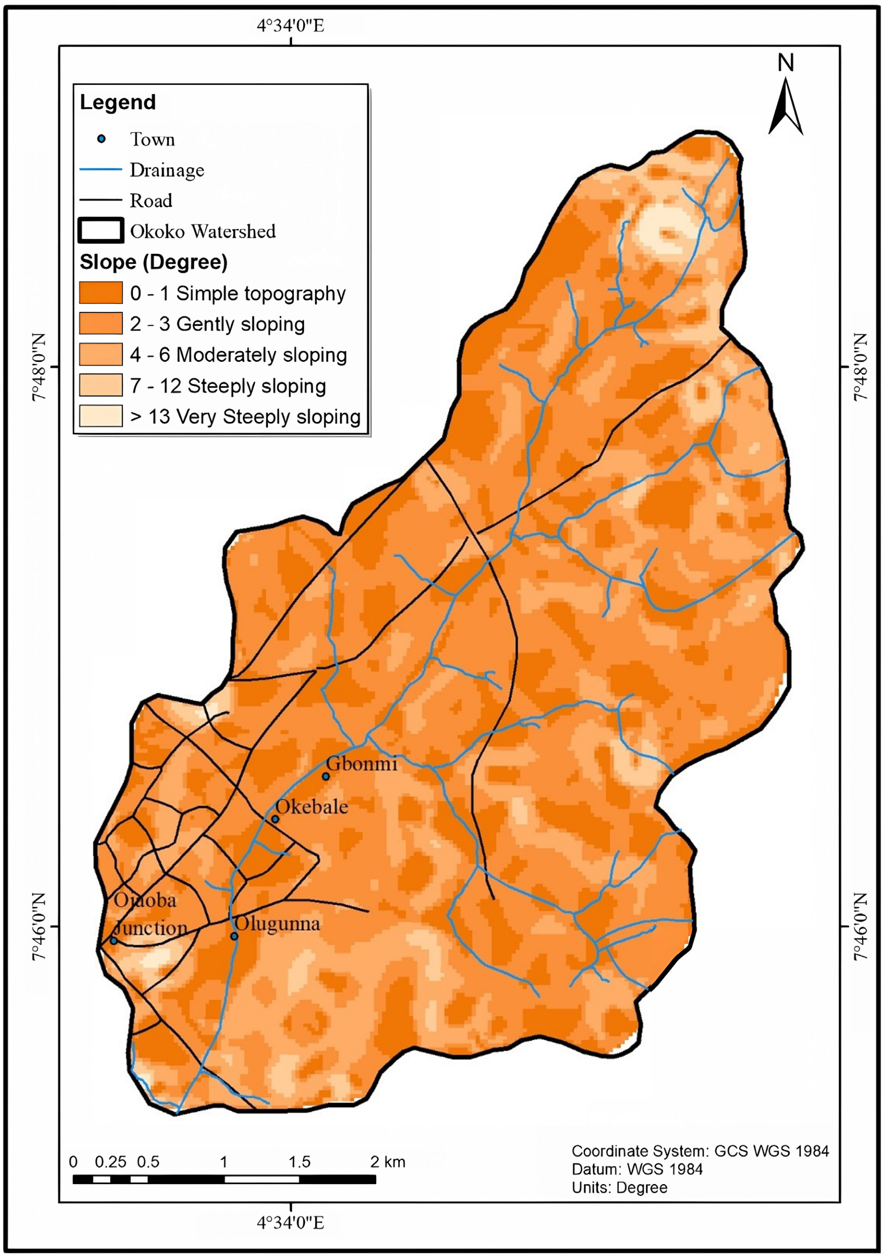

Figure 3. Slope map of the study area.

- (7 - 12) degrees—Steeply Sloping: The class comprises steep slopes, which can have significant implications on the environment. Steep slopes are highly susceptible to erosion, landslides, and gully formation, particularly during intense rainfall or seismic events. These areas may not be suitable for intensive agriculture due to erosion risks. Conservation practices, such as terracing and afforestation, are crucial for minimizing erosion and maintaining slope stability.
- Above 13 degrees—Very Steeply Sloping: Areas falling under this class are extremely steep and are subject to severe natural hazards. The implications of very steep slopes include high erosion rates, frequent landslides, and limited

land use options. These regions are often ecologically sensitive, and human activities should be carefully planned and regulated to avoid irreversible environmental damage.

The slope map observed in **Figure 3** also describes the terrain's characteristics and their implications on the environment and human activities. This comprehensive understanding sets the stage for to identify potential hazards, and making informed decisions about land use planning and conservation strategies. Proper management and conservation efforts are therefore essential for sustainable development and the protection of natural resources in the study area.

The Digital Elevation Model (DEM) map of the study area, as depicted in **Figure 4**, has been instrumental in delineating five distinct elevation classes, each of which offers valuable insights into their respective vulnerability concerning flooding. These classes are elaborated upon as follows:

- Areas with elevation between (290 - 318) meters: This category encompasses regions characterized by relatively low-lying elevations, rendering them particularly susceptible to flooding during episodes of heavy rainfall and elevated river levels. The terrain in these areas closely resembles natural floodplains, facilitating the accumulation and dispersion of water during flood events, as visually illustrated in **Figure 5**. As a consequence, properties and critical infrastructure situated within these zones face a heightened risk of inundation. To effectively address this vulnerability, a suite of floodplain management strategies, including the construction of levees, flood control channels, and the implementation of zoning regulations, should be strongly considered.
- Areas with elevation between (319 - 330) meters: Within this elevation range, the topography gains slightly higher ground compared to the preceding class in **Figure 4**. Although the risk of flooding is diminished in this category, it is important to acknowledge the potential for occasional flooding during extreme weather events. These areas often serve as transitional zones bridging the floodplain and higher elevation regions. To mitigate potential flood impacts, the implementation of proper drainage systems and comprehensive flood management measures becomes imperative.
- Areas with elevation between (331 - 341) meters: This class encompasses areas situated at moderately elevated terrain, rendering them less susceptible to flooding. The diminished risk of flooding in this range can be attributed to the lower propensity for water accumulation and the efficient flow of water toward lower-lying zones. Nevertheless, it is essential to recognize that localized flooding may still occur, particularly during severe storms, especially in areas characterized by inadequate drainage infrastructure.
- Areas with elevation between (342 - 353) meters: Positioned at a higher elevation compared to the preceding classes, this range is characterized by a decreased susceptibility to flooding. Although some vulnerability remains, as observed in **Figure 4**, the elevated terrain offers a degree of protection to properties and infrastructure during flood events. This intermediate elevation range represents a transitional zone with a reduced risk profile.

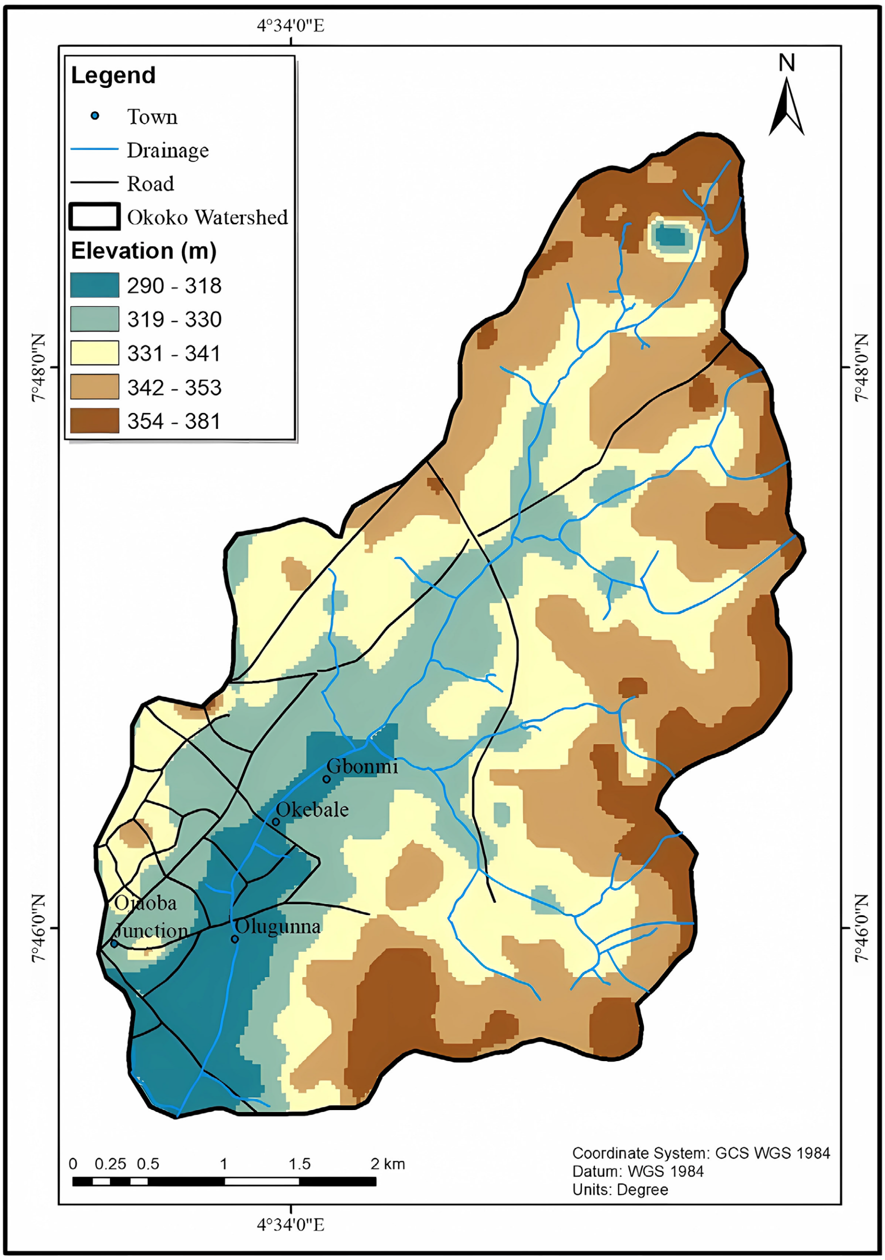

Figure 4. DEM map of the study area.

- Areas with elevation between (354 - 381) meters: Marking the highest elevation category within the study area, this region exhibits significantly reduced vulnerability to flooding and is generally considered safe from most flood events. The elevated slope enhances water drainage efficiency, thus diminishing the risk of inundation. However, it is imperative to remain cognizant of the potential for flash flooding in steep terrains, where intense rainfall can swiftly generate rapid runoff.

These distinct elevation classes provide a valuable foundation for understanding the varying degrees of vulnerability to flooding within the study area. This understanding is pivotal for the development and implementation of targeted flood

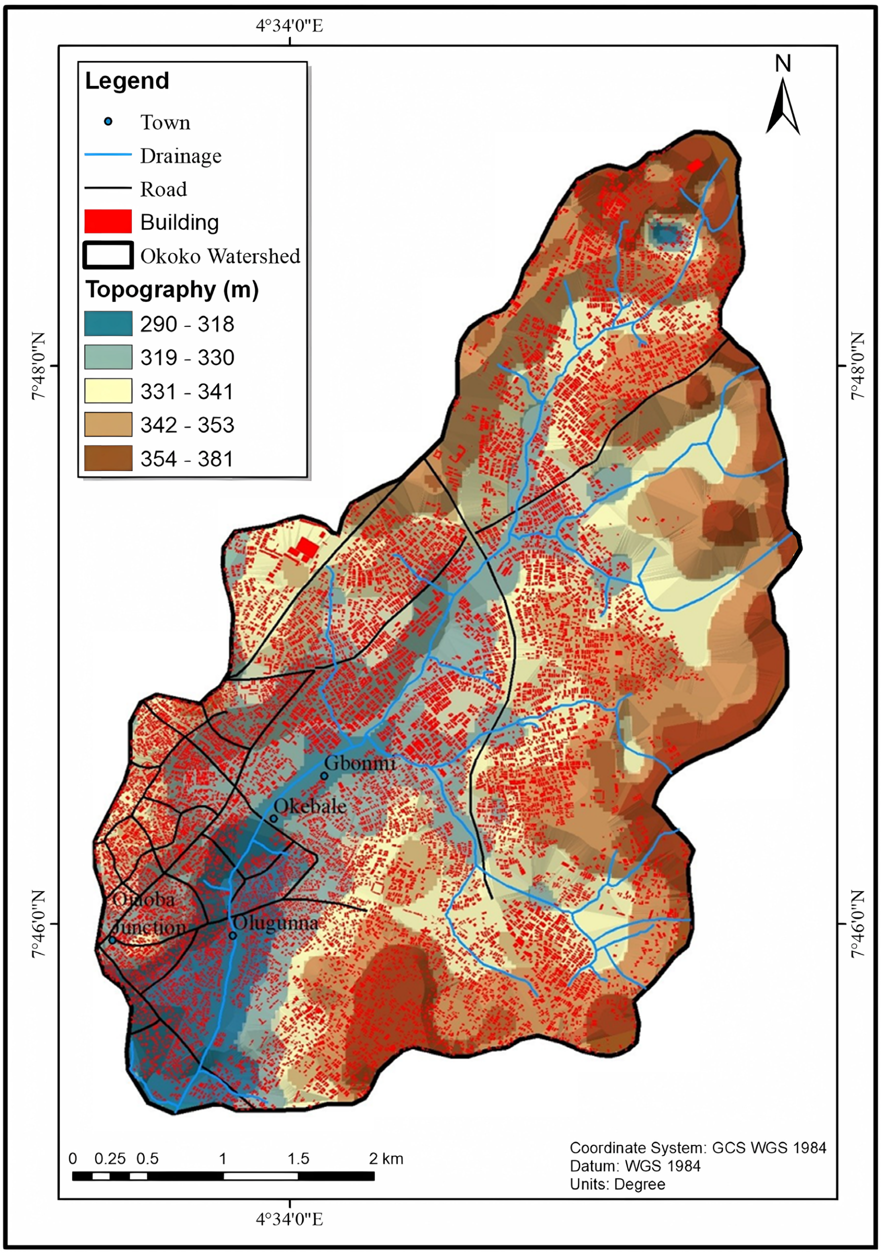

Figure 5. Topography map of the study area.

mitigation strategies, tailored to the specific needs and risks associated with each elevation category. Furthermore, it emphasizes the importance of comprehensive floodplain management practices and infrastructure development to safeguard communities and infrastructure against the impacts of flooding. Leveraging this information derived from elevation distributions in **Figure 4** is instrumental in pinpointing flood-prone areas within the basin. This knowledge is instrumental in devising and implementing effective flood mitigation measures and formulating resilient land use plans. By doing so, this study aims to protect communities and critical infrastructure from the adverse impacts of flooding within the Okoko River Basin. This holistic approach to flood risk assessment and management underscores the importance of considering terrain elevation as a foundational element in disaster preparedness and community resilience efforts.

The digitization and subsequent analysis of buildings, roads, and drainage systems within the study area, as presented in Figure 5, have provided valuable insights into the potential impacts of flooding on the built environment. This analysis complements the broader understanding of flood vulnerability, as depicted in Figure 6. The results of this analysis revealed a significant concern: within the study area, a considerable number of houses, specifically 8204 out of the total 16,829 houses examined, are projected to remain continually vulnerable to flooding events. This statistic underscores the pressing need for proactive flood risk mitigation measures and preparedness efforts to safeguard these residential structures and their occupants. Furthermore, the analysis extends its focus to the vulnerability of major and minor roads, shedding light on the potential disruptions they may face in the absence of adequate mitigation strategies. These transportation arteries play pivotal roles in the connectivity and accessibility of the study area, making them critical components of the local infrastructure. The identification of their susceptibility to the adverse impacts of flooding emphasizes the importance of implementing measures that can protect both the roads themselves and the communities they serve. Additionally, the study highlights that a significant proportion of buildings within the study area, totaling 48.7% of the entire inventory, have been identified as susceptible to flood disasters. This finding serves as a stark reminder of the critical importance of devising and implementing resilient infrastructure, flood management strategies, and land use planning initiatives. Such measures are essential to mitigate the risks posed by flooding events and to enhance the overall resilience of the built environment.

The findings of this research have unveiled a notable pattern of vulnerability

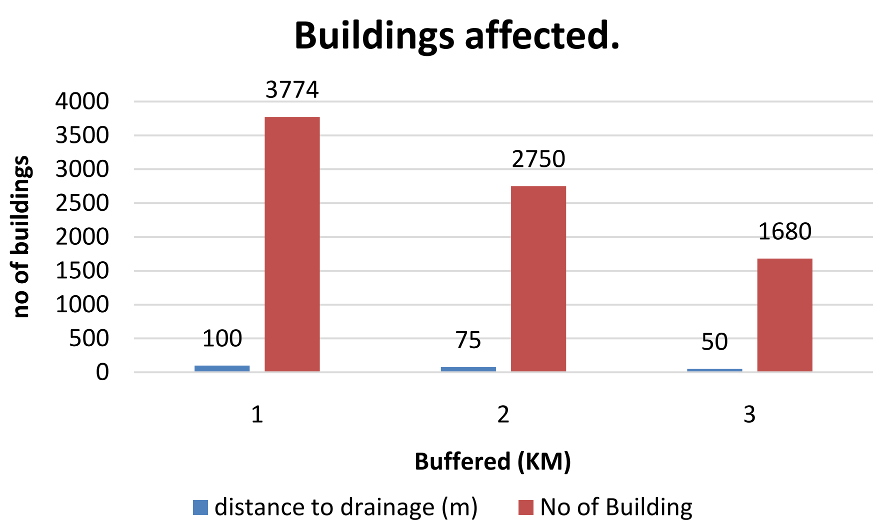

Figure 6. Analysis of residential buildings affected.

Table 2. Analyis of vulnerability.

Classes of Flood	Area (Km^2)	(%)
Highly vulnerable	2.08	11.65
Vulnerable	12.1	67.79
Slightly vulnerable	3.58	20.06
Less vulnerable	0.1	**0.5**

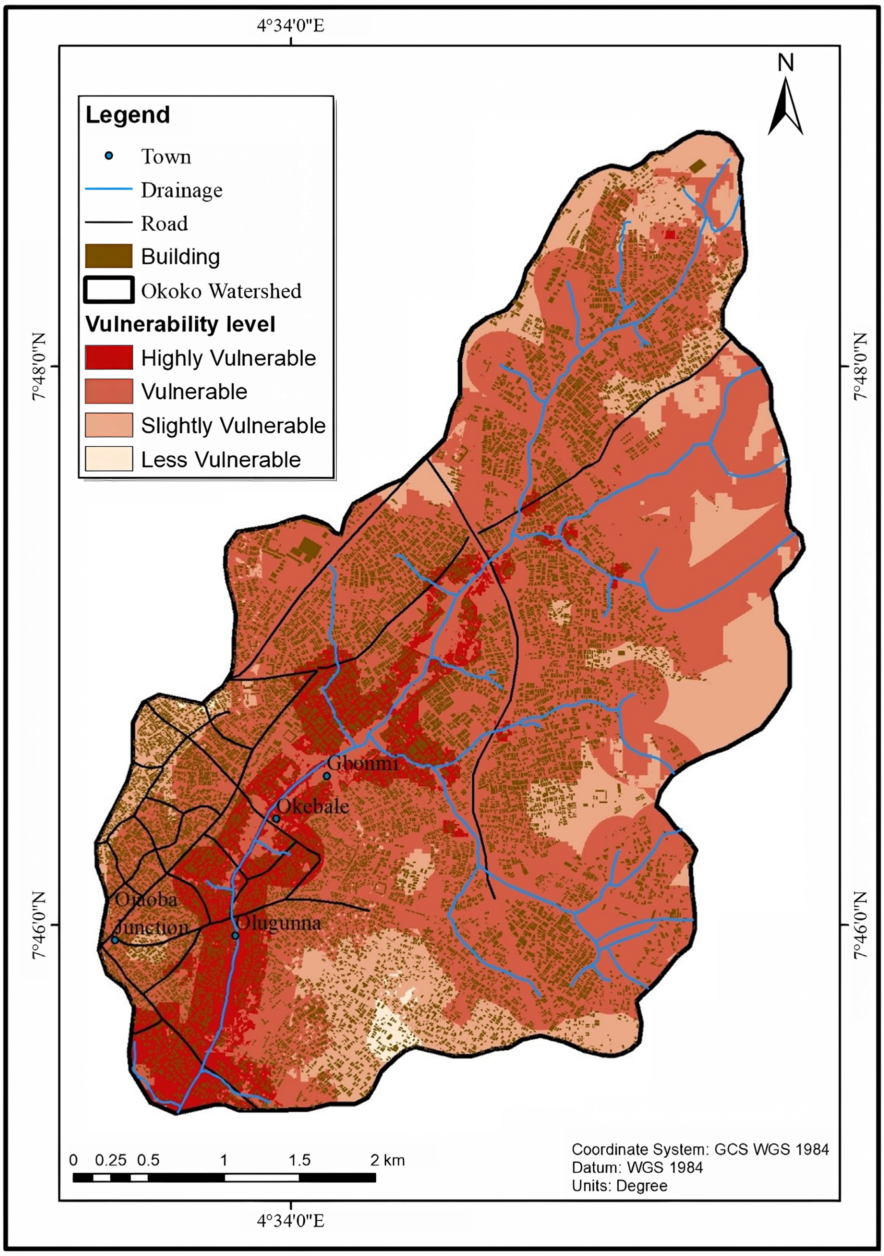

Figure 7. Flood risk map of the study area.

within the study area. A substantial portion of the land cover, comprising approximately 79.4% of the total area, has been identified as highly vulnerable, encompassing an extent of 14.2 square kilometers. In contrast, areas characterized as less vulnerable constitute 20.56% of the study area, equivalent to 3.68 square kilometers, as detailed in **Table 2**. To ascertain the accuracy of these vulnerability assessments, a validation process was initiated. The coordinates of significant locations known for their recurrent susceptibility to flooding were meticulously recorded. Subsequently, these coordinates were superimposed onto the flood risk map, as visualized in **Figure 7**. This superimposition facilitated a rigorous validation procedure, enabling the alignment of observed flood-prone areas with the predicted vulnerable zones indicated by the flood risk map.

The alignment of real-world occurrences of recurrent flooding with the mapped vulnerability zones not only serves as a validation of the model's predictive capabilities but also reinforces the credibility of the identified vulnerable sites. Furthermore, this validation process enhances the overall robustness of the research outcomes and strengthens their applicability in real-world flood management and mitigation strategies.

4. Conclusions

In conclusion, the utilization of these novels, spatially-detailed datasets has enabled the identification of 14.2 km^2 of highly vulnerable areas within the basin. This study represents a significant advancement in the comprehension of localized flood vulnerability, introducing an original fine-scale analysis that had not been undertaken previously in the Okoko basin. The development of flood risk maps and the quantification of vulnerable infrastructure serve as crucial foundational elements for enhancing urban planning and flood management strategies based on our research findings. While it is evident that some residents have already been forced to vacate their homes due to the recurrent flooding, certain communities, such as Olugunna and Okebale, remain particularly susceptible to the impacts of pluvial floods. This underscores the urgent need for targeted interventions and resilient measures to mitigate the adverse effects of flooding on these vulnerable populations this research underscores the critical need for proactive management and planning measures to ensure the long-term sustainability of the community under study. The integration of remote sensing and GIS technologies has demonstrated its robustness, reliability, and effectiveness, particularly in the delineation of flood-prone zones. The findings presented here offer stakeholders access to more informed and precise data, enabling the design of efficient and cost-effective flood mitigation strategies for the identified vulnerable communities.

Consequently, it is strongly recommended that comprehensive and enforceable regulations and policies be put in place to manage and mitigate flooding activities. Prioritizing re-orientation and environmental education/awareness campaigns for the community regarding the inherent dangers of building and settling in flood-prone areas is imperative.

In light of these considerations, the study proposes that the Osun State government takes decisive action to relocate inhabitants residing in highly vulnerable areas to safer regions. Additionally, areas identified as prone to flooding should be repurposed for agricultural use. It is equally important to ensure rigorous monitoring of development activities in the Oja-Oba junction.

Furthermore, it is suggested that future research endeavors delve into the characteristics of properties that may necessitate evacuations of building contents within flood-prone zones. These newfound insights can serve as valuable resources for authorities tasked with developing targeted flood mitigation strategies specific to this vulnerable watershed.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Amoateng, P., Finlayson, C.M., Howard, J. and Wilson, B. (2018) A Multi-Faceted Analysis of Annual Flood Incidences in Kumasi, Ghana. *International Journal of Disaster Risk Reduction*, **27**, 105-117. https://doi.org/10.1016/j.ijdrr.2017.09.044

[2] FEMA: Federal Emergency Management Agency (2016) National Flood Insurance Program Terminology Index. https://www.fema.gov/national-flood-insurance-program/definitions#F

[3] Akintoye, O., Eyong, A., Effiong, D., Agada, P. and Digha, O. (2016) Socio-Economic Implications of Recurrent Flooding on Women Development in Southern Ijaw Local Government Area, Bayelsa State, Niger Delta Area of Nigeria. *Journal of Geoscience and Environment Protection*, **4**, 33-46. https://doi.org/10.4236/gep.2016.48004

[4] Maddox, I. (2014) The Risks of Hazard: Three Common Types of Floods Explained. http://www.intermap.com/risks-of-hazard-blog/three-common-types-of-flood-explained

[5] Kousky, C. (2016) Impacts of Natural Disasters on Children. *The Future of Children*, **26**, 73-92. https://doi.org/10.1353/foc.2016.0004

[6] Tella, A., *et al.* (2023) Spatial Prediction of Flood in Kuala Lumpur City of Malaysia Using Logistic Regression. *The International Archives of Photogrammetry*, *Remote Sensing and Spatial Information Sciences*, **48**, 363-369. https://doi.org/10.5194/isprs-archives-XLVIII-4-W6-2022-363-2023

[7] Ghosh, A., Sen, A. and Frietsch, M. (2023) "What Is a 'Very Severe Cyclone' Please"? Uncovering Knowledge and Communication Gaps in Climate Resilience Realities. *International Journal of Disaster Risk Reduction*, **86**, Article ID: 103499. https://doi.org/10.1016/j.ijdrr.2022.103499

[8] Mhd Noor, M.T., *et al.* (2022) Facing Flood Disaster: A Cluster Randomized Trial Assessing Communities' Knowledge, Skills and Preparedness Utilizing a Health Model Intervention. *PLOS ONE*, **17**, e0271258. https://doi.org/10.1371/journal.pone.0271258

[9] Saravanan, L., *et al.* (2022) A Novel Approach for a Smart Early Flood Detection and Awareness System Using IoT. 2022 8*th International Conference on Smart Structures and Systems* (*ICSSS*), Chennai, 21-22 April 2022, 1-4. https://doi.org/10.1109/ICSSS54381.2022.9782286

[10] Essien, E.E., *et al.* (2018) Mapping and Analysis of Flood Risk Zones in Uyo Urban Nigeria Using Satellite Imagery. *Journal of Environment and Earth Science*, **8**, 23-29.

[11] Oladejo, S.O. and Ojo, B.T. (2018) A Study of Contributory Factors to Flood Hazards in Ifelodun Local Government Area, Osun State, Nigeria. *Environmental Technology & Science Journal*, **9**, 21-31.

[12] Feldmeyer, D., *et al.* (2020) Regional Climate Resilience Index: A Novel Multimethod Comparative Approach for Indicator Development, Empirical Validation and Implementation. *Ecological Indicators*, **119**, Article ID: 106861. https://doi.org/10.1016/j.ecolind.2020.106861

[13] Alkema, D. (2004) RS and GIS Applications in Flood Forecasting. *Proceedings of the National Workshop on Flood Disaster Management*: *Space Inputs*, Hyderabad, 3-4 June 2004, 57-59.

[14] Moges, E. and Bhat, H.S. (2017) Assessment of Flood Hazard, Vulnerability and Risk in the Gambella Region of Ethiopia. *International Journal of River Basin Management*, **15**, 447-463.

[15] Satterthwaite, D., Huq, S., Reid, H., Pelling, M. and Lankao, P.R. (2009) Adapting to Climate Change in Urban Areas: The Possibilities and Constraints in Low- and Middle-Income Nations 1. Adapting Cities to Climate Change. https://www.taylorfrancis.com/chapters/edit/10.4324/9781849770361-2/adapting-climate-change-urban-areas-possibilities-constraints-low-middle-income-nations1-david-satterthwaite-saleemul-huq-hannah-reid-mark-pelling-patricia-romero-lankao

[16] Gelleh, I.D., Adelakun, I.O. and Okeke U.H. (2016) Flood Vulnerability Assessment in Lagos City Using Multi-Criteria Analysis. *Greener Journal of Environmental Management and Public Safety*, **5**, 24-32. https://doi.org/10.15580/GJEMPS.2016.2.011316005

[17] Guo, J., Luan, Y., Li, Z., Liu, X., Li, C. and Chang, X. (2021) Mozambique Flood (2019) Caused by Tropical Cyclone Idai Monitored from Sentinel-1 and Sentinel-2 Images. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, **14**, 8761-8772. https://doi.org/10.1109/JSTARS.2021.3107279

[18] 2012 Flood Disaster Cost Nigeria N2.6tn—NEMA. https://www.thenigerianvoice.com/movie/114732/2012-flood-disaster-cost-nigeria-n26tn-nema.html

[19] IRIN Africa (2012) Nigeria: Worst Flooding in Decades. https://reliefweb.int/report/nigeria/worst-flooding-decades

[20] Nigerian Tribune (2016) Osogbo Flood: Tears, Pain That Won't Go Away. http://tribuneonlineng.com/osogbo-flood-tears-pain-wont-go-away

[21] Daily Trust (2016) Flood Destroys Properties, Displaces Residents In Osogbo. https://dailytrust.com/flood-destroys-properties-displaces-residents-in-osogbo

[22] 2012 Nigeria Floods. https://en.m.wikipedia.org/wiki/2012_Nigeria_floods

[23] Alimi, S.A., *et al.* (2022) Flood Vulnerable Zones Mapping Using Geospatial Techniques: Case Study of Osogbo Metropolis, Nigeria. *The Egyptian Journal of Remote Sensing and Space Science*, **25**, 841-850. https://doi.org/10.1016/j.ejrs.2022.08.003

[24] Adeaga, T. (2008) Problems of Translating Two Nigerian Novels into German. *Acta Scientiarum. Language and Culture*, **30**, 63-70. https://doi.org/10.4025/actascilangcult.v30i1.4057

[25] Olajuyigbe, A.E., Rotowa, O.O. and Durojaye, E. (2012) An Assessment of Flood Hazard in Nigeria: The Case of Mile 12, Lagos. *Mediterranean Journal of Social*

Sciences, **3**, 367-375.

[26] Koks, E.E., Jongman, B., Husby, T.G. and Botzen, W.J. (2015) Combining Hazard, Exposure and Social Vulnerability to Provide Lessons for Flood Risk Management. *Environmental Science & Policy*, **47**, 42-52. https://doi.org/10.1016/j.envsci.2014.10.013

[27] Vojinovic, Z., Seyoum, S.D., Salum, M.H., Price, R.K., Fikri, A.K. and Abebe, Y.A. (2016) Modelling Floods in the Debre Tabor Catchment, Lake Tana Basin, Ethiopia. *Hydrological Sciences Journal*, **61**, 927-942.

[28] Meesuk, V., Vojinovic, Z., Mynett, A.E. and Abdullah, A.F. (2015) Urban Flood Modelling Combining Top-View LiDAR Data with Ground-View SfM Observations. *Advances in Water Resources*, **75**, 105-117. https://doi.org/10.1016/j.advwatres.2014.11.008

[29] Rahmati, O., Falah, F., Naghibi, S.A., Biggs, T., Soltani, M., Deo, R.C., Bui, D.T., *et al.* (2019) Land Subsidence Modelling Using Tree-Based Machine Learning Algorithms. *Science of the Total Environment*, **672**, 239-252. https://doi.org/10.1016/j.scitotenv.2019.03.496

[30] Khattak, H.A., Shah, M.A., Khan, S., Ali, I. and Imran, M. (2019) Perception Layer Security in Internet of Things. *Future Generation Computer Systems*, **100**, 144-164. https://doi.org/10.1016/j.future.2019.04.038

[31] Lisotta, R. (2011) In Over Our Heads: The Inefficiencies of the National Flood Insurance Program and the Institution of Federal Tax Incentives. *Loyola Maritime Law Journal*, **10**, 511.

[32] Kumar, P., Debele, S.E., Sahani, J., Aragão, L., Barisani, F., Basu, B., Zieher, T., *et al.* (2020) Towards an Operationalisation of Nature-Based Solutions for Natural Hazards. *Science of the Total Environment*, **731**, Article ID: 138855. https://doi.org/10.1016/j.scitotenv.2020.138855

[33] Olajire, A.A. and Imeokparia, F.E. (2001) Water Quality Assessment of Osun River: Studies on Inorganic Nutrients. *Environmental Monitoring and Assessment*, **69**, 17-28. https://doi.org/10.1023/A:1010796410829

[34] National Population Commission (2006) Nigerian Population Census Report.

[35] Adejuwon, J.O., Jeje, L.K. and Ogunkoya, O.O. (1983) Hydrological Response Patterns of Some Third Order Streams on the Basement Complex of Southwestern Nigeria. *Hydrological Sciences Journal*, **28**, 377-389. https://doi.org/10.1080/02626668309491977

[36] Orimoogunje, O.O.I., Oyinloye, R.O. and Soumah, M. (2009) Geospatial Mapping of Wetlands Potential in Ilesa, Southwestern Nigeria. FIG Working Sheet 2009. https://fig.net/pub/fig2009/papers/ts04b/ts04b_orimoogunje_etal_3412.pdf

[37] Akinwumiju, A.S. (2017) Morphometric and Landuse Analysis: Implications on Flood Hazards in Ilesa and Osogbo Metropolis, Osun State Nigeria. *Ethiopian Journal of Environmental Studies and Management*, **10**, 229-240. https://doi.org/10.4314/ejesm.v10i2.9

[38] Farr, T.G., *et al.* (2007) The Shuttle Radar Topography Mission. *Reviews of Geophysics*, **45**. https://doi.org/10.1029/2005RG000183

[39] Etuonovbe, A.K. (2011) The Devastating Effect of Flooding in Nigeria. FIG Working Week 2011: Bridging the Gap between Cultures, Marrakech. https://scholar.google.com/scholar?cluster=7076278958407148392&hl=en&as_sdt=2005&sciodt=0,5

[40] Sarkar, D., *et al.* (2020) Morphometric Analysis Using SRTM-DEM and GIS of Na-

gar River Basin, Indo-Bangladesh Barind Tract. *Journal of the Indian Society of Remote Sensing*, **48**, 597-614. https://doi.org/10.1007/s12524-020-01106-7

[41] Musa, S.D., Wei, C. and Mustapha, A. (2015) Determination of Potential Flood Risk Zones in Abuja Metropolis Using GIS Techniques. *American Journal of Geographic Information System*, **4**, 1-7.