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Geophysical assessment of flood vulnerability of Accra Metropolitan Area, Ghana

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ABSTRACT

In light of Ghana's exploding population, rapid urbanization, and the imminent threat of climate change, urban flooding is a severe and increasing developmental concern. This study was conducted against the proposition that without anthropogenic factors, geophysical factors drive flooding within Accra Metropolitan Area. This study assessed spatial patterns of flood vulnerability using geophysical variables. The spatial analytical technique of weighted overlays was applied to ascertain the spatial variation of flood vulnerability. Based on geophysical variables, the study finds that only 71% of the metropolis is highly susceptible to flooding. Overlay of geophysical flood vulnerability map with residential neighbourhoods, the results correlated with known vulnerable areas. Three hazard level categories—high, medium, and low—have been established for the flood risk areas. Suburbs with a high or moderate risk of flooding necessitate more sophisticated engineering safeguards. The analysis also found that areas with medium and high incomes are becoming more vulnerable to flooding. The study proposes that efforts at flood control must focus on proper physical planning, stringent development control, elimination of drainage network flaws, and limiting the city's lateral expansion.

1. Introduction

The regularity with which floods occur, their severity, scope, and the cost of destruction are all increasing globally (Moubarak et al., 2021; Omran et al., 2021). Floods are one of the most prevalent natural catastrophes. Numerous lives have been lost due to this global phenomenon, which has also severely harmed the economies of several industrialized and developing countries. Urban flooding is a severe and growing development concern in developing countries against population growth, unchecked urbanization, and the dangers of climate change (Arnous and Omar, 2018; Dube et al., 2022). Urban flooding is becoming more common in Africa, and its causes are changing. Cities have recently seen urban flooding when there has been a lot of prolonged rain or rainy periods. This has resulted in too much surface-flowing water for the drainage networks to manage (Parvin et al., 2016). Physical factors, such as prolonged, heavy rainfall, impermeable rocks, excessively saturated soils, steep slopes, compacted dry soils, etc., because of flooding; these factors are made worse by human factors. These human-induced issues, which include inadequate physical planning and defects in the drainage system, are generally the result of rapid and unplanned development (Amoako and Inkoom, 2018). Increased impervious surfaces caused by the cities' rapid growth and surface paving impede infiltration (Arnold et al., 1996; Addo, 2016). Amoako and Inkoom (2018) point to inadequate city-wide trash management techniques, lax structural expansion management, and substandard housing development procedures as additional crucial explanations.

In Ghana, especially in Accra, urban flooding has emerged as a significant development challenge (Karley, 2009). Substantial flood catastrophes have been documented during the 1950s in the following years: 1955, 1960, 1963, 1973, 1986, 1995, 1999, 2001, 2002, 2010, and 2011 (Rain et al., 2011) and 2015 (International Federation of Red Cross and Red Crescent Societies Ghana, 2016). Accra's extensive property devastation occurred throughout 1955, when the first significant flood occurrence was recorded (Amoako and Frimpong-Boamah, 2015). According to Asumadu-Sarkodie et al. (2015), between 1955 and 1997, flooding caused assets worth over $30 million to be demolished, 100 people to die, and 10,000 to become homeless during or right after the flooding. Flooding-related hazards, as well as vulnerabilities, keep getting exacerbated. For instance, in 2015, 200 individuals perished, 187 homes were demolished entirely or in part, and 46,370 people were damaged by flooding (International Federation of Red Cross and Red Crescent Societies Ghana, 2016). Property lost in this tragedy is

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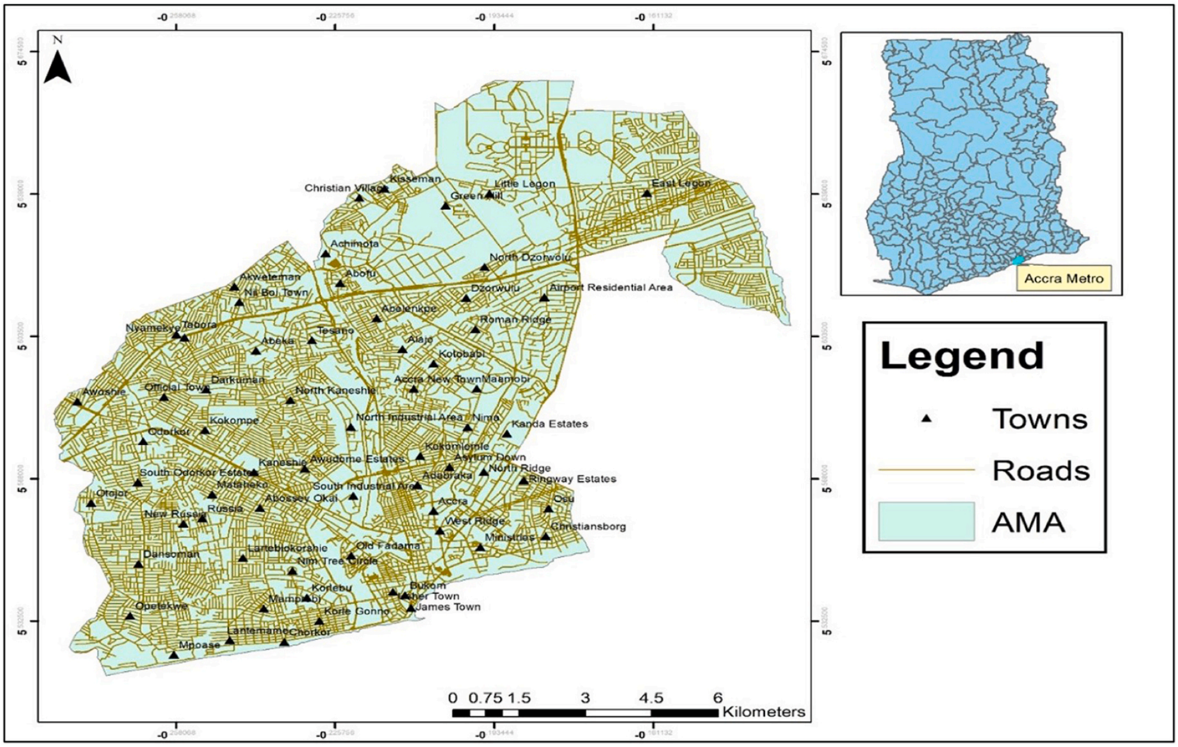

Fig. 1. Map of Accra Metropolitan area.

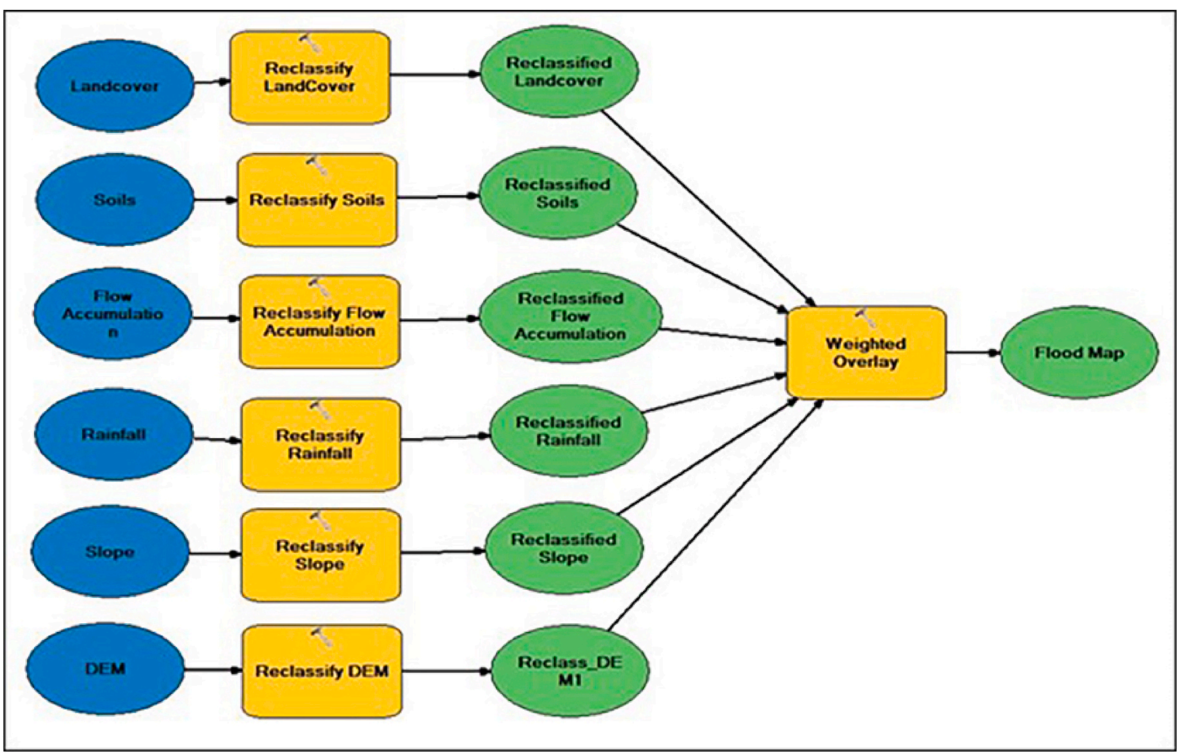

Fig. 2. Workflow for mapping flood hazard.

projected to have cost $55 million (Dogbevi, 2017). Flooding in Accra has become a perennial occurrence. In the effort of the Government of Ghana to proactively manage it, GH¢197 million (approx. $38 million) was allocated for control of perennial flooding in Accra in 2019, indicating the magnitude of the menace at hand (Appiah-Adjei, 2019).

Many drivers have been identified to have contributed to the flooding events experienced in Accra. Amoako and Frimpong-Boamah (2015) recognized a potential contribution of climate change and unpredictability to Accra's flooding. These have been connected to alterations in rainfall and temperature patterns, as well as coastal flooding and erosion. Accra's natural drainage is altered due to increasing and unregulated development, climate change, and excessive precipitation,

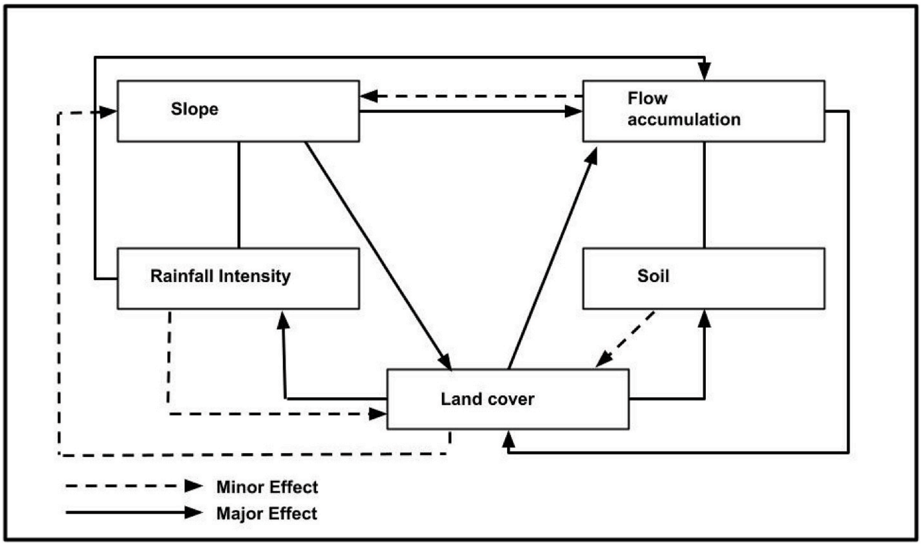

Fig. 3. Schematic diagram of the interaction between the physical causative factors of flooding.
Source: Authors construct adapted from Ozkan and Tarhan (2016).

Table 1
Rates of physical causative factors.

	Interactions between factors	Rates	Outcome
Flow Accumulation	1 major +1 minor	(1x1) + (1x0.5) =	1.5
Slope	3 major + 0 minor	(3x1) + (0x0.5) =	3.0
Land cover	3 major +1 minor	(3x1) + (1x0.5) =	3.5
Rainfall Intensity	1 major + 1 minor	(1x1) + (0x0.5) =	1.5
Soil	1 major + 1 minor	(1x1) + (1x0.5) =	1.5

which increases the amount of peak runoff velocity and puts the city at risk of flooding (Acodjoe and Afuduo, 2015). Mitigation of Accra's floods has primarily been a battle for succeeding administrations. Almost every administration has developed one plan or another to eliminate overflows from the city landscape permanently. However, strategies to address these floods have been criticized for being reactive and ad-hoc, often implemented after a severe flood. Examples of such efforts include the GH¢197 million allocated for controlling perennial floods in Accra, implemented in 2019 (Appiah-Adjei, 2019), the National Flood Contingency Plan development, and the district flood disaster management plans by various Districts Assemblies. The main activities involved in these projects include widening drainage channels, demolishing buildings cited on waterways and drains and waste management. The recent attempt is the implementation of the Greater Accra Resilient and Integrated Development project (GARID), which is stated as the first among a series of projects designed to build the resilience of

Table 2
Classification and weighting of factors.

Factor	Domain	Descriptive Level	Proposed weight (a)	Rate (b)	Weighted rate (a*b)	Total weight	%
Flow Accumulation (m)	0 - 5123513725	Very Low	2	1.5	3	28.5	11
	5123513726-1344922353	Low	3		4.5		
	1344922354-259377884	Moderate	6		9		
	2593778825-40828	High	8		12		
Soil (%)	Pinthosols	Very High	10	1.5	15	22.5	9
	Luvisols	Low	4		6		
	Acrisols	Very Low	1		1.5		
Landcover	Built up	Moderate	6	3.5	21	42	16
	Bareland	Low	3		10.5		
	Water	Very Low	2		7		
	Vegetation	Very Low	1		3.5		
Rainfall Intensity (mm)	150 – 187	Very Low	2	1.5	3	45	18
	187- 207	Low	4		6		
	207 – 228	Moderate	6		9		
	228 – 248	High	8		12		
	248 - 274	Very High	10		15		
Slope (%)	0-32.28448044	Low	10	3	30	33	13
	32.28448045 - 66.3914718	Very High	1		3		
DEM	0-33	Very HIgh	10	3.5	35	84	33
	33-67	High	8		28		
	67-270	Moderate	6		21		
Total					**255**	**255**	**100**

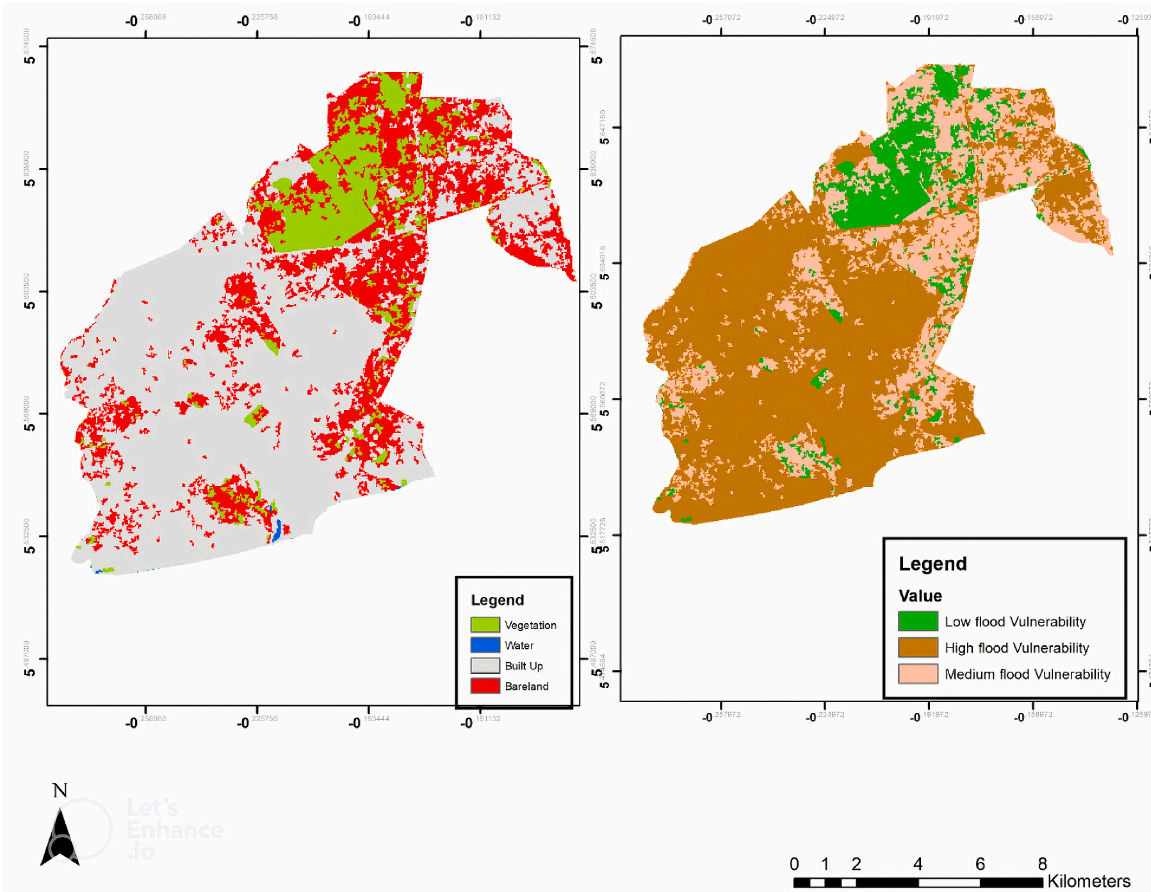

Fig. 4. Landcover vulnerability map of Accra Metropolitan Area.

Accra. The initial phase is five (5) years covering 2020 to 2025 (GARID Secretariet, 2020). After flood events, the government's reactive response to flood involves compensating those whose homes were impacted. The recent proactive action undertaken annually is the desilting of selected drains within the city, which unfortunately tend to be filled again by uncollected desilted silt and litter of solid waste on the streets by the onset of the next rains.

As such, there is a need for holistic planning and implementation of comprehensive flood risk management plans to mitigate and prepare for flood disasters based on an accurate understanding of the geophysical characteristics and the type of plans that suit that geophysical environment. Many research works on floods in AMA have focused on and concluded that anthropogenic factors are the primary determinants. They have cited indiscriminate littering, poor drainage system, narrow drains, building on waterways and poor flood management practices (Appiah-Adjei, 2019; Gyau-Boakye, 1997; Amoako and Boamah, 2015; Rain et al., 2011; M Braimah et al., 2014). This study holds a counter view that without human presence, the geophysical characteristics would facilitate flooding in the study area and that inadequate attention has been paid to the geophysical characteristics of AMA and its catchment area. The paper's novelty is to adequately examine the impact of each geophysical signal on the vulnerability in the research area. This study used a deductive approach. Indicator approaches are typically structured around a multi-criteria analysis structure that explicitly assesses numerous conflicting components in decision-making. The extent to which vulnerability assessments inform flood adaptation policies is mainly unknown. The study uses an approximate indicator-based technique to build a flood vulnerability indicator map for AMA with relevant and specific flood vulnerability indicators. The study therefore aimed to assess the spatial differences in flood vulnerability and susceptibility of the Accra Metropolitan Area based on geophysical variables using GIS spatial analytical techniques. This is one of the most critical and valuable steps for comprehensive and effective flood risk management. To reduce flood-related damage and vulnerability, the city government and the general population will be helped by creating a flood risk map. By enforcing measures like zoning restrictions and building requirements, etc., land usage within the most susceptible zones can be managed, ultimately reducing the extent of flood damage. Additionally, this work will add up and extend previous research findings on anthropogenic causes of flooding and flood risk mapping in Ghana by (Karley, 2009; Rain et al., 2011; Amoako and Frimpong-Boamah, 2015; Gyau-Boakye, 1997; Nyarko, 2002) and (Asumadu-Sarkodie et al., 2015) by critically assessing the flood vulnerability based on the geophysical setting of the city.

2. Materials and methods

2.1. Study area

The survey was conducted in the Accra Metropolitan Area (AMA), Ghana's official and regional capitals (Ghana Statistical Service, 2012). According to the 2010 population and housing census, AMA had an estimated 1,665,086 people, or 42% of the entire region's population (Ghana Statistical Service, 2014) and with a 2021 population of 284, 124 with 134,045 males and 150,079 females. Ga West Municipal, Ga South Municipal, the Gulf of Guinea, and La Dadekotopon Municipal are Accra's northern, western, southern, and eastern neighbours, respectively. Accra is sometimes referred to as the AMA. According to GSS (Ghana Statistical Service, 2012), it has around 139.67 km2 (53.93 sq mi) land area. The research area's spatial dimension was calculated

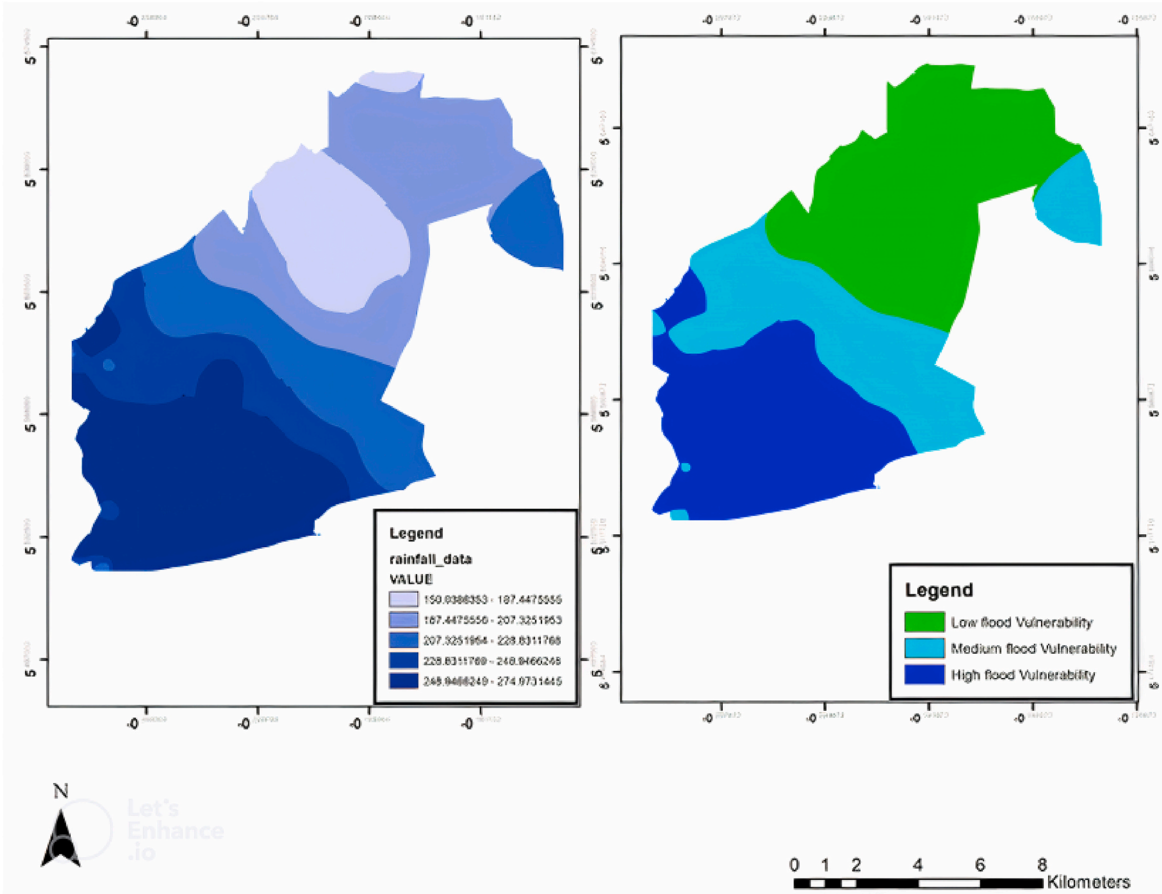

Fig. 5. Rainfall vulnerability map of Accra Metropolitan Area.

using the borders in place before the 2018 reconfiguration.

The general terrain of the AMA is between 20 and 70 m above mean sea level, with infrequent isolated hills and plains (Nyarko, 2002; Kortatsi and Jørgensen, 2001). The city has a water table between 4.80 and 70 m below the earth's surface, with an average gradient of roughly 11% (Nyarko, 2002). Three broad vegetation zones, comprising shrubs, grassland and coastal lands, are found in AMA. However, human-induced and climatic factors have altered the original vegetation cover (Owusu, 2018). Soil types in AMA include lateritic sandy clay soil, residual clays and gravels, alluvial and marine mottled clay and drift materials from wind erosion. Alluvial, impervious black cotton soils are common in low-elevation, poor-drained locations (Ministry of Local Government and Rural Development, 2012). The map of the Accra Metropolitan Area is depicted in Fig. 1.

2.2. Methods

A comprehensive literature review was conducted to ensure adequate knowledge about the causes of flooding in AMA and how vulnerable urban people are to flooding. To accurately classify an area within AMA as flood-prone, factors such as rainfall intensity, soil, flow accumulation, slope and land cover were identified as the geophysical drivers of flooding in AMA. Using similar methodologies, Arnous et al. (2022) and Arnous and Mansour (2022) investigated the impact of topography, lithology, and geological structures on the coastal zone of Ras Ghareb City, Gulf of Suez, basin system in Egypt. The investigations of Dekongmen et al. (2021) mainly concentrated on the drainage density, slope patterns, and elevation patterns of the Accra Metropolis. A flood susceptibility (vulnerability) map was made using GIS software after these factors' relative contributions to flooding were weighted.

The land cover data was generated from the Landsat 8 OLI image classification acquired on April 15, 2018, from the United States Geological Survey (USGS) website. The classification was made for four classes; water, bare land, built-up, and vegetation. Bare land and vegetation were further reclassified into areas of low flood possibility and built-up areas into high flood possibility and water.

Soil data covering AMA was sub-setted from global soil data acquired from International Soil Reference and Information (2019). The data was developed as vector data and then converted to raster using ArcMap's "feature to raster" tool. The resulting layer of the soil data was reclassified to group different soil types into high, moderate and low vulnerability to flooding based on their permeability levels. ArcGIS 10.7 software was used to model flow accumulation from the digital elevation model data ASTGTM2_N05W001 obtained from USGS. According to Tarboton et al. (1991) and Jenson and Domingue (1988), the flow accumulation tool calculates the cumulative flow as the total weight of all cells flowing into each downslope cell in the output raster.

Additionally, a system is built to display the flow in each grid cell. Filling sinks in the DEM data was the first step in creating a new dataset. This method lessened the inaccuracies in the data that was obtained. The output was then reclassified as high flood vulnerability, medium flood vulnerability and low vulnerability. The slope tool in ArcGIS was used to generate the slope map from the DEM data. According to climateps.com, the average elevation of AMA is about 68 m. This was used as the parameter for delineating the areas with high and low vulnerability during reclassification.

Rainfall data was transformed into an uninterrupted surface overlay using a computation tool for the inverse distance weighting (IDW) technique. Results from the IDW analysis were then reclassified to change and group values into new values for straightforward

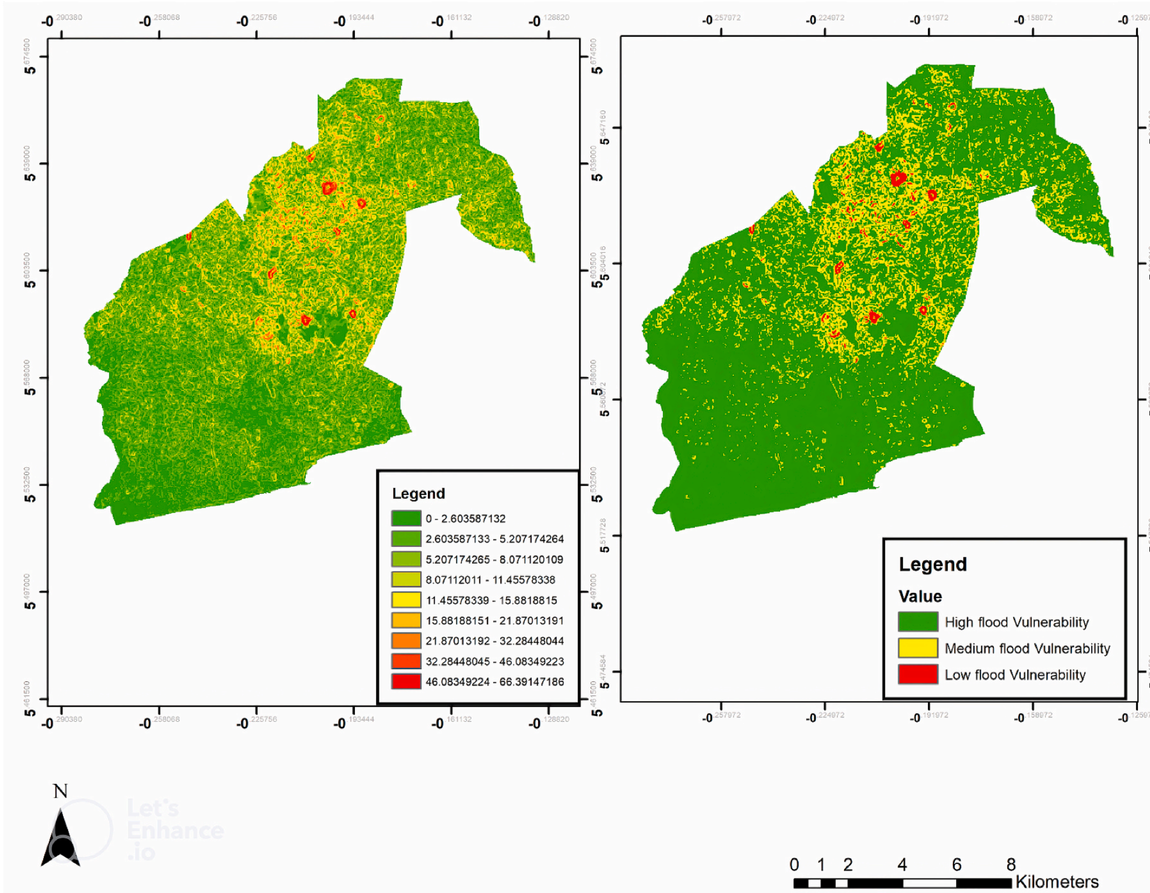

Fig. 6. Slope map of Accra Metropolitan Area.

interpretation. Rainfall values were reclassified to represent high, medium and low vulnerability to flooding. Fig. 2 illustrates the steps in executing the geoprocessing function in the model builder tool.

2.3. Weighted overlay

Ozkan and Tarhan's (2016) model was used to rate the flood risk among the various hazard metrics. The flood susceptibility map was produced using five geophysical causal variables. The technique shown in Fig. 3, which depicts how all the elements communicate, was used to calculate the value. One causative component strongly impacts the aspect the arrow points to, as seen by the solid lines connecting the two elements. The dashed line joining two causative factors shows a slight (secondary) impact on the component the arrow points at. For instance, flow build-up has a secondary effect on the slope, even though it essentially affects land usage. One (1) point was given to the considerable influence, and one-half point (0.5) was given to the modest effect to compare the two items. As shown in Table 1, a factor rate is determined as the total effects on other parties.

Since each element affects flood threats differently, the weighted approach was used, and weights were assigned to each factor. Factor weights were calculated using the Ozkan and Tarhan (2016) methodology.

Table 1 above displays the ratios that were calculated for the various elements. All data layers were integrated and categorized into the chosen classes in ArcMap. By multiplying the estimated ratio and its estimated weight to acquire the total weight of each element, the weight and proportions of each factor were combined to facilitate an in-depth examination of prospective flood threats. Different descriptive levels and weights ranging between 0 (very low) and 10 (very high) were used. These scores were based on expert judgement, as indicated in Table 2.

Table 2 displays the weighted average percentage of each factor. The ratio of elements is calculated for rainfall intensity (18%), flow accumulation (11%), soil (9%), land cover (16%), and slope (13%), corresponding to their effects on the likelihood of flooding. Thematic maps showing the thematic modelling variables' results are presented and discussed in the next section.

3. Results

This section presents the investigation findings of the spatial differentiation of the six (6) geophysical determinants of flood risk. The indicators are land cover, rainfall, slope, soil, flow accumulation and elevation (Digital Elevation Model).

i. Land cover

Flood vulnerability based on land cover types shows high to low exposure (Fig. 4).

The places within the city that have been recognized as having a greater risk of flooding are those that are more densely populated and have more extensive sections of impervious surfaces. As a result, rainwater penetration is impeded, and runoff emerges. These include Accra Central, Dansoman and Darkuman, Circle and Avenor areas Areas with medium and low flood vulnerability have vegetation cover, and the soil has higher absorptive capacity than built-up areas. These include Achimota and Legon areas.

ii. Rainfall pattern

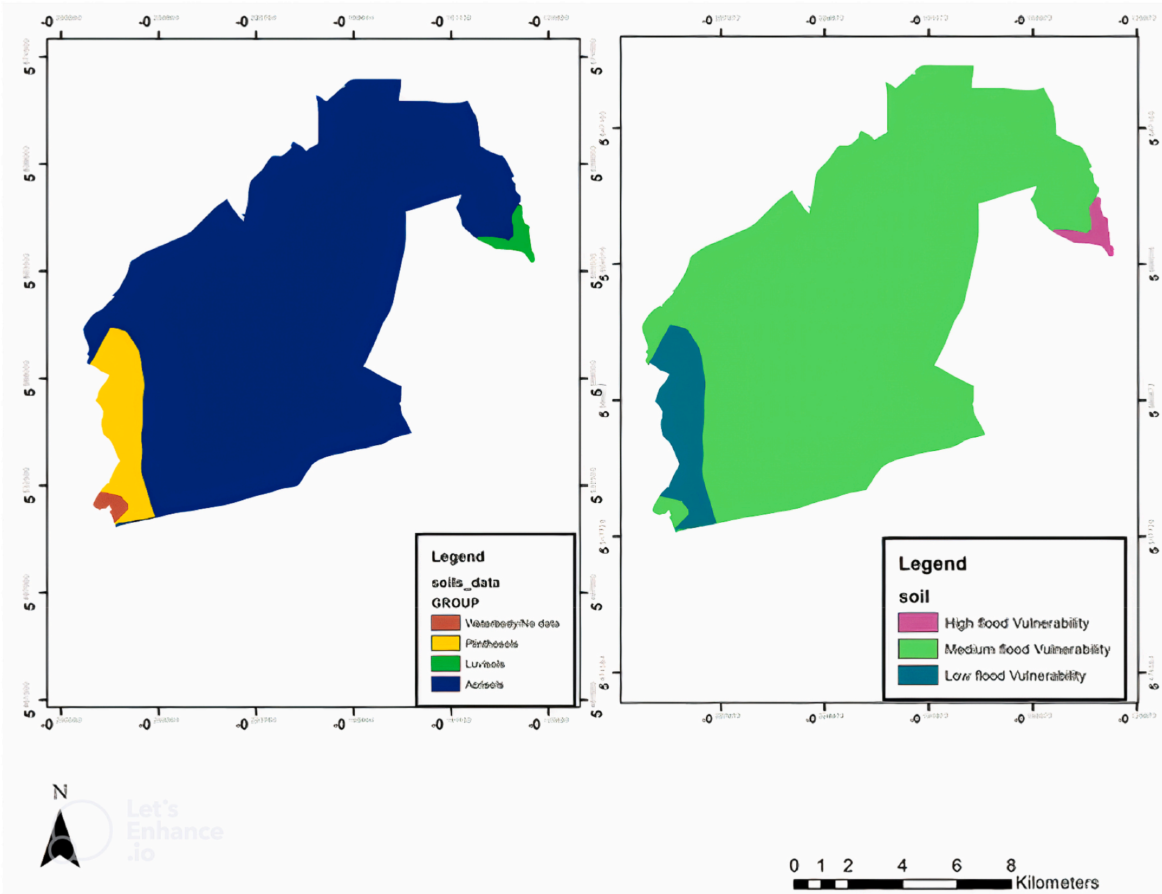

Fig. 7. Soil vulnerability map of Accra Metropolitan Area.

Rainfall-induced flooding is high in built-up areas, particularly in slums and low to middle-income communities with poor physical planning and drainage facilities. These areas include Alajo, Asylum Down, Adabraka, Korle Gonno, Mamprobi and Labadi. Areas showing medium and low flood vulnerability are well-planned residential areas with adequate drainage facilities, though sometimes poorly drained or obstructed. Flooding generally happens when there is more rain than the drainage system can handle. The study areas within this category are Tesano, Abeka, Akweteman, Abelenkpe, Dzorwulu, Roman Ridge, North Kaneshie and Ringway Estate. Low-accumulation communities include Legon, Achimota, Green Hill, East Legon, North Dzorwolu and Airport Residential Area. Where drainage channels are absent or blocked, annual local flooding results from heavy rainfall that typically occurs during brief storms. Rainfall based flood vulnerability map is shown in Fig. 5. These conditions are common in the study area as it has always been observed during the rainfall seasons.

iii. Slope in the area

Fig. 6 presents slope induced flood vulnerability map. The slope of the land is a principal variable that affects the movement of water.

Running water travels swiftly on steep slopes, lowering the water collected into the soil underneath. AMA is a gently sloping area (Nyarko, 2002), and water does not flow quickly, thus making the area highly susceptible to flooding, as indicated in Fig. 6. Few isolated knolls and hills like Legon Hills are less vulnerable. The low flood-prone areas (Fig. 6) were also observed within the contour ranges of 46–66 m. This shows that the surface runoffs from the steep slope areas flow toward the gentle slope zones, which serve as high convergence zones of the runoffs leading to the occurring floods.

iv. The soil in the area

Soil permeability is crucial when determining how well the soil will absorb water (Fig. 7). Higher penetration soils, like sandy soil, are less likely to flood since water can easily infiltrate them with little resistance. Soils in AMA are predominantly acrisols, clay-rich soils with low permeability, thereby increasing the area's vulnerability to flooding. Areas with Luvisol soils have high flood vulnerability because of their higher clay content and high base saturation. Over 90% of the study area has medium soil-based flood vulnerability except for some small areas of East Legon, which have high soil-based flood vulnerability as the site is waterlogged. The vertical strip of the western boundary has plinthosols soil that makes the area less vulnerable.

v. Flow accumulation

Water usually flows and accumulates at lower elevation areas. This makes the metropolis a low flood-vulnerability area interspersed with medium to high flood-vulnerability areas (Fig. 8).

The high-risk regions bordering water bodies like Densu, Sakumo Lagoon, and the Odaw-Korle-Chemu watershed, which runs through the city's centre with multiple tributaries, are where the medium and high flood susceptibility areas are located. Poor drainage systems, such as those with inadequate, disconnected, and improperly channelled sewers, also contribute to a high-flow build-up.

vi. Elevation of the area

Lower flood vulnerability areas have higher elevations than the high flood risk areas associated with low hills (Fig. 9). Moreover, high-risk

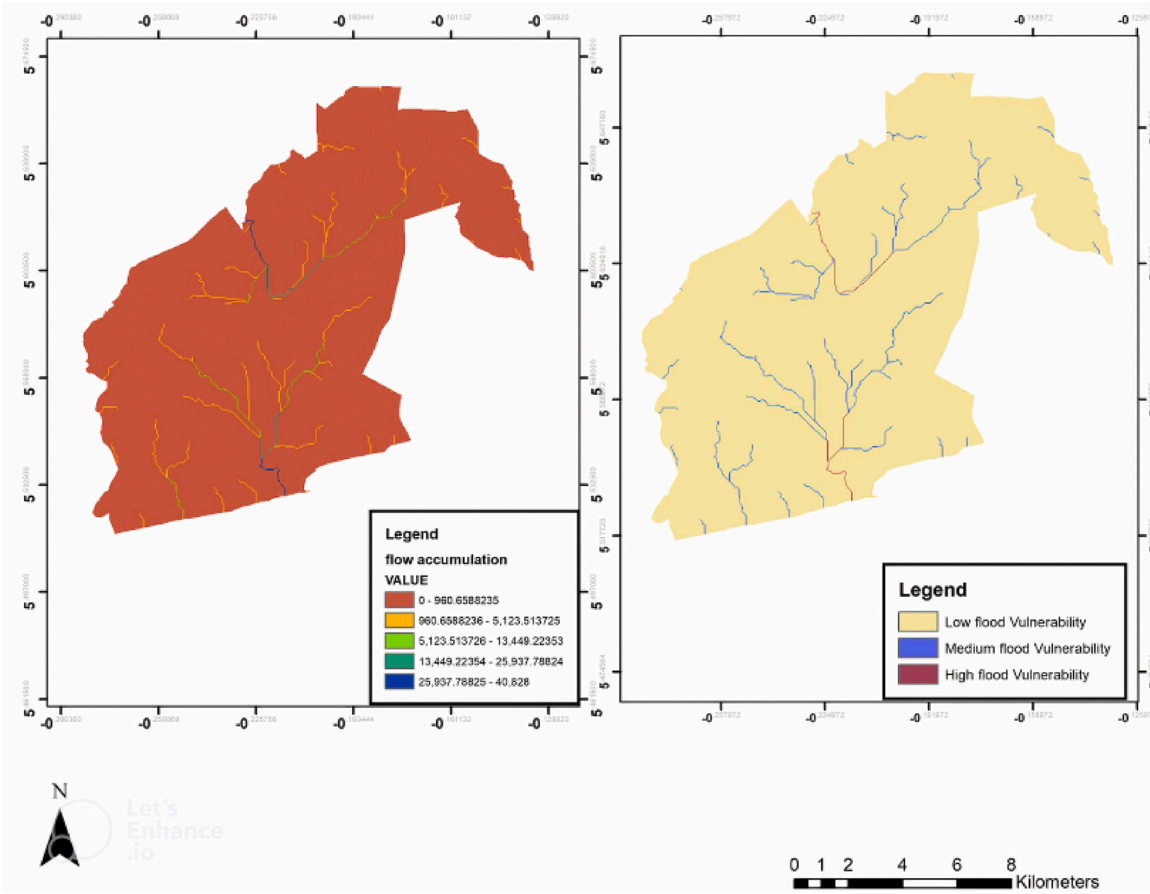

Fig. 8. Flow accumulation vulnerability map of Accra Metropolitan Area.

zones in AMA are bordering lagoons and rivers, built-up areas with impervious surfaces, and bare lands with clay soils. These locations in the CBD and old residential areas include Accra Central, Adabraka, Korle Gonno, Mamprobi, Dansoman and Darkuman. Others include Accra Newtown, Maamobi and Nima.

Anthropogenic factors have contributed to low elevation levels in AMA, making the area highly susceptible to floods.

These six (6) characteristics that are specifically connected to the flood that might happen in AMA are combined to create a synthesis map of flood risk zones. The final flood hazard map illustrating flood susceptibility zones is created and displayed in Fig. 10 due to integrating annotated maps with the weighting technique thematically.

Maps of flood susceptibility have been crucial for managing, communicating, and controlling floods. In the past few years, Accra's frequent floods have emerged as one of Ghana's issues during the rainy season, particularly in June and July. The six (6) bio-physical markers lead us to conclude that it is impossible to avert floods in AMA, but it is possible to lessen their severity and related effects. With this flood susceptibility map, it is possible to take preventative action to reduce the likelihood of future flooding and its adverse consequences. The flood susceptibility map indicates that despite specific differences, practically every area of Accra is susceptible to flooding. About 71% (94841.3 km) of the entire surface of AMA lies among the high to medium flood possibility classifications, which are divided into high, medium, and low. The flood vulnerability map was overlaid with the AMA neighbourhoods (Community) layer, and all the towns where floods have occurred fell inside the areas with a high likelihood of flooding, as indicated in Fig. 11. Mpoase, Chorkor, Korle Gono, Bukom, Ussher Town, Old Fadama, Abbosey Okai, Mataheko, New Russia, Opetekwe etc., fall within the high and medium flood vulnerability categories. These are slum areas, some of which are located along the Odaw River and must be targeted for flood management and prevention interventions. Areas with low flood vulnerability tended to be the first- and second-class residential areas (medium-high class) in Accra: Airport Residential Area, Dzorwulu, Roman Ridge, Abelempke, East Legon and Greenhill.

These neighbourhoods have well-planned drainage systems, and tarred roads and generally clean, but care must be taken to efficiently manage their drainage networks to sustain their minimal vulnerability to flooding. Identifying the susceptibility to flooding is the first step to developing an effective response strategy.

4. Discussion

The final map shows that close to 50% of AMA is a high flood vulnerability (susceptibility) area based on the weighted combined effect of six geophysical indicators. About 25% of the site is classified as moderate risk, and the remaining 25% is low. These six factors have their strengths and weaknesses in promoting or reducing floods, and their combined effect could be seen as powerful real-life experiences. Although this study is based on modelling, all the identified high flood-risk areas flood annually. AMA's southern region lies near the ocean. In their study of Accra Metropolis, Dekongmen et al. (2021) discovered comparable findings concerning the area's height. It is not exceptionally high, a coastal plain with poor soil drainage, inadequate land cover, and excessive water accumulation. In essence, these are what cause floods in the studied region. Due to swift reaction times and high peak discharges, heavy rains can induce flash floods. Flooding happens when there is nowhere for surface water to flow due to low elevation. Accra is a low-lying metropolis with an average height of less than 70 m above sea level. Therefore, the city's more notable areas are vulnerable to flooding anytime it rains without a sufficient drainage framework.

This study considers anthropogenic modification of these

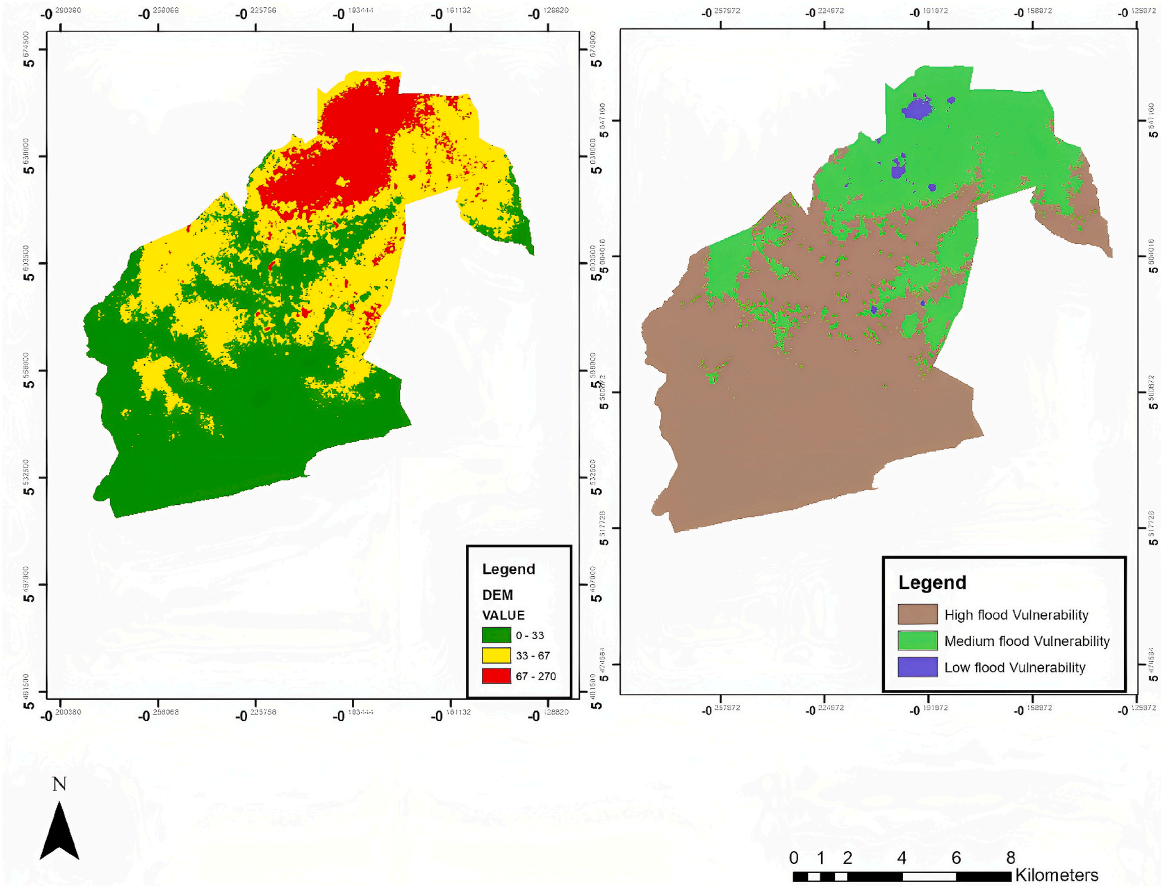

Fig. 9. Elevation map of Accra Metropolitan Area.

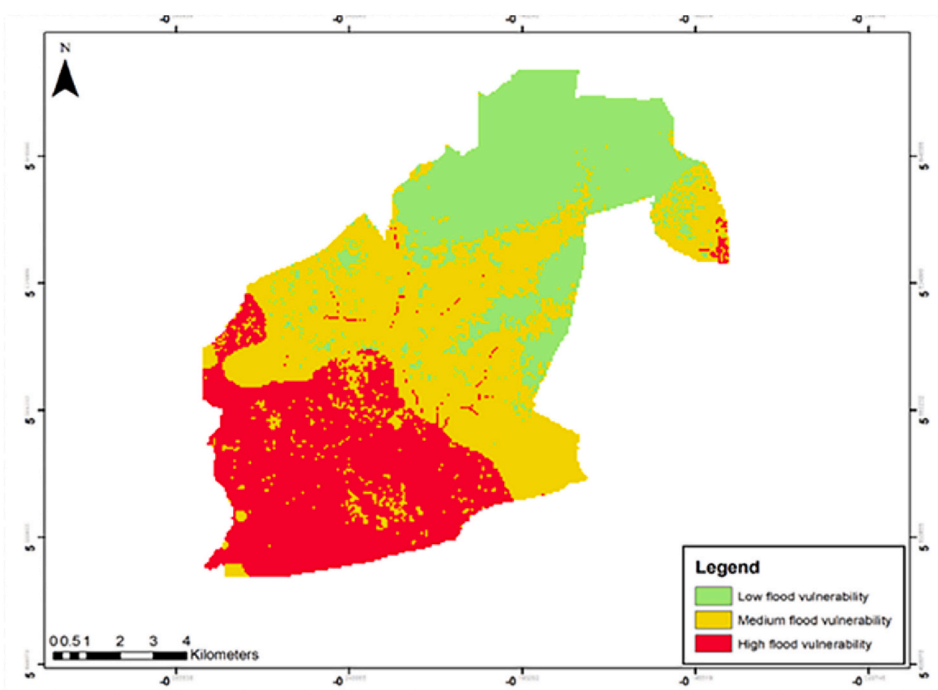

Fig. 10. Synthesis map of flood vulnerability of Accra Metropolitan Area.

geophysical deficiencies as a possible positive input to reduce the flood vulnerability of the area. For instance, introducing proper physical planning and city engineering, a sound drainage system, including widening existing storm drains and a sound waste management system, may help improve runoff and provide flood controls. However, the anthropogenic modification of the geophysical environment

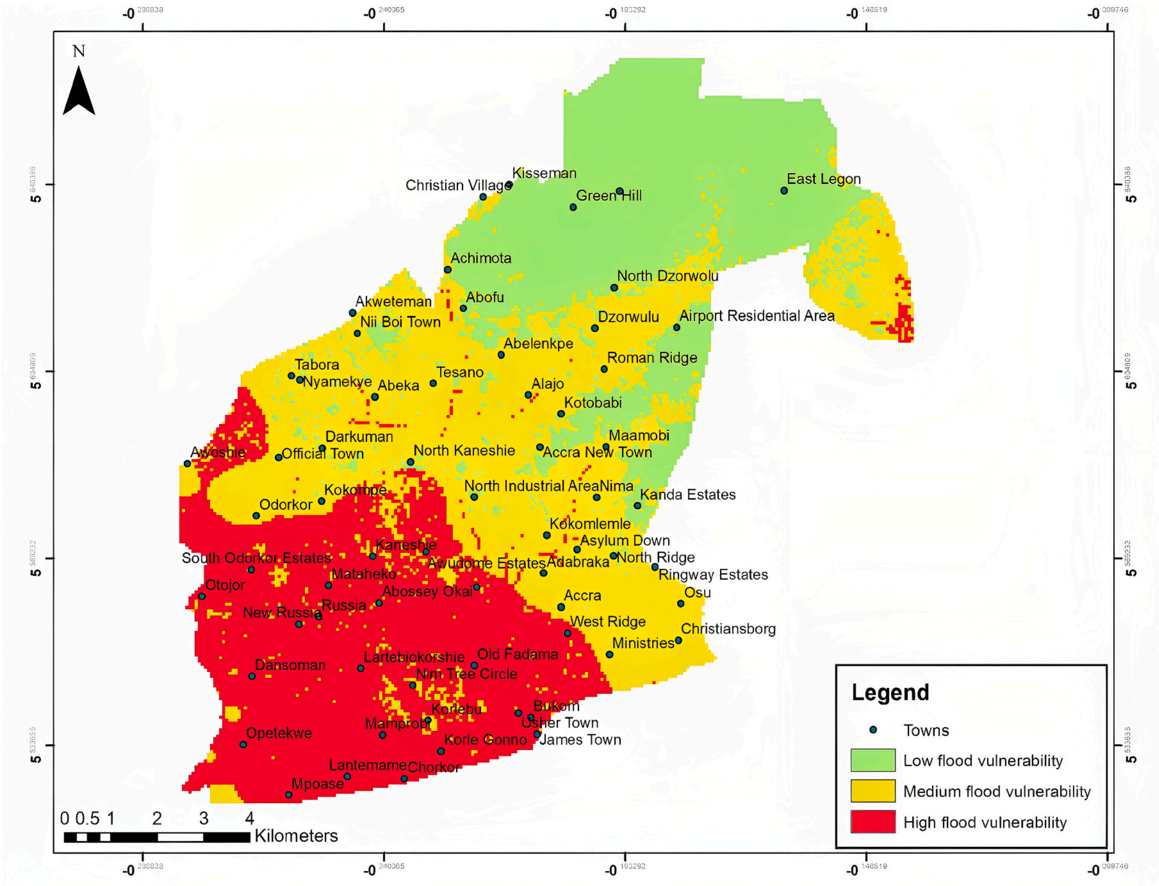

Fig. 11. Flood possibility map overlaid with towns in Accra Metropolitan Area.

Fig. 12. Dredging of the odaw river.
Source: Graphic online

implemented in AMA has somewhat exacerbated and escalated the already precarious situations created by the geophysical environment. For instance, inadequate infrastructure development, faults, and drainage network flow have all triggered floods in the city (Aryeetey-Attoh, 2001; Rain et al., 2011). Several low-lying areas in Accra experience major periodic flooding due to culverts that are too small for the job and significant drains that have become clogged with silt from years of abandonment and poor upkeep. In Accra, gullies and erosion can be seen on the road surfaces and in the soil between buildings with untarred roadways. Flood water cannot enter accessible drains as a result. As a result of erosion, some urbanized areas near the catchment provide a lot of sediments, which causes problems related to reduced capacity. Additional drains lead to the Korle Lagoon due to erosion; several urbanized areas near the catchment deliver a lot of sediments. Other drainage ditches frequently release significant quantities of silt into the Korle Lagoon, situated along the coast south of AMA. This worsens the lagoon's dire situation (Asumadu-Sarkodie et al., 2015).

Similarly, due to their positioning in the city and inadequate flow, Accra's Odaw River and Korle Lagoon, intended to be essential outlets for runoff and stormwater overflow to the sea, are now considered significant flood risks. The Odaw River and its tributaries, Nima, Onyasia, Dakobi, and Ado, drain most of AMA's built areas. The river basin has the most significant population density in AMA, with almost 60% of those who live in the Greater Accra Region nearby. Approximately 30% of the population is under threat due to continuing flooding, according to the Ministry of Works and Housing (2019). Avenor, Glefe, James Town, Kotobabi, and other neighbouring informal settlements such as Alajo, Kokomlemle, Mpoase, Kpehe, and others are also plagued by the perennial flooding. The annual flow of the Korle Lagoon and Odaw River has been decreased due to silt and solid waste build-up, and numerous governments have attempted in vain to dredge the two water bodies and return them to their prior condition. According to Arkorful (2008), Accra will nonetheless flood when it rains unless the Korle Lagoon is constructed to allow the Odaw River to empty into it. Between February and May 2019, one million cubic meters of waste materials were distilled from the Odaw River and Korle Lagoon (Myjoyonline.com, 2019). Until this recent stride, management of the surface water bodies remained a challenge, thus exacerbating the already dire situation (Fig. 12).

Again, poor municipal engineering, illiteracy, and flagrant contempt for building codes have led to numerous Accra houses being erected in the city's green belt zones, depleting vegetation and increasing areas' susceptibility to erosion and floods (Waterworld, 2010; Acodjoe and Afuduo, 2015). Inappropriate disposal and collection of solid waste in

Accra negatively correlate with flooding within the city. Existing waste management systems cannot successfully collect the volume of solid waste generated from silt and rubbish. Residents of communities in Accra's peri-urban areas frequently deposit substantial trash into waterways, drains, ditches, and other drainage structures. This practice decreases their potential for flow and makes them more likely to overflow during rainstorms and trigger floods (Amoako and Inkoom, 2018). From the study, it can be ascertained that geophysical and anthropogenic conditions of the city have worsened flood vulnerability. Factors such as rainfall and rapid and unplanned urbanization create further havoc for the city. Similar to this, poor oversight of the city's water resources and population growth render more essential areas of Accra particularly vulnerable to flooding (Douglas et al., 2008).

5. Conclusions

This study has demonstrated that geophysical conditions of AMA predispose over 70% of the area to annual flooding. The soils, the slope and elevation, rainfall, flow accumulation and land cover have all worked together to promote permanent flood city. It is, therefore, not surprising that AMA is usually inundated with floods, even at the expense of little rainfall. Yet, modern technological innovations coupled with anthropogenic modification of these geophysical conditions could reduce floods. Unfortunately, over the years, AMA (City of Accra) has not succeeded in this direction. Instead, anthropogenic modifications of the geophysical conditions have worsened the flooding. There is, therefore, the need for re-engineering of the city. The physical planning, city drains and storm management systems, land use and land cover and building design all need a second look. There is a need for decongestion of the city and good open space management with the understanding of learning to live with nature in the city. These efforts ought to target the modification and improvement of adverse conditions created by the geophysical condition of the town.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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