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Enhancing resilience of transportation infrastructure in the city of Accra

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Abstract

The city of Accra, Ghana, is experiencing rapid urbanization and increased transportation demands, posing significant challenges to its transportation infrastructure. This study explores strategies for enhancing the resilience of Accra's transportation system, focusing on mitigating the impacts of climate change, population growth, and urban congestion. By assessing the vulnerabilities of existing transportation networks, the research identifies key weaknesses in the infrastructure, including inadequate drainage systems, traffic congestion, and limited connectivity. The study proposes a multi-faceted approach that incorporates sustainable urban planning, smart transportation technologies, and climate-adaptive infrastructure. Recommendations include the integration of green infrastructure, improved public transit systems, and the adoption of resilient road networks that can withstand extreme weather events. The findings aim to guide policymakers, urban planners, and engineers in building a more resilient and sustainable transportation infrastructure for Accra, ensuring its capacity to support economic growth while minimizing disruptions caused by climate change and urban stresses.

Keywords: Urbanization; Transportation Infrastructure; Resilience; Climate Change; Sustainable Urban Planning; Public Transit Systems

1. Introduction

Climate change poses a serious threat to people living in cities, towns, and rural areas, exposing them to different weather events that can damage their buildings, disrupt services, and put their health and safety at risk. The way we currently design and plan our communities may not be enough to deal with these challenges, making us more susceptible to the consequences of climatic change. We need creative ideas to make our cities and towns stronger and help everyone deal with extreme weather events. Engineers have a big role to play in making our buildings and infrastructure better able to handle these challenges. The decisions we make about how to design our roads, parks, and other public spaces, as well as how government agencies plan for emergencies, can all make a big difference in how well our communities can handle and recover from disasters caused by climate change.This paper explains applying a variety of strategies, and methods to improve transportation infrastructure in response to potentialCoastal Flooding.

1.1. Background

Regarding this paper, the chosen city for this project is the Accralocated on the southern coast part at the Gulf of Guinea in Ghana(Ghana Population Census and Housing,2021).The city covers an area of about 20.4km^2 of the country and had a population of 284,124 inhabitants as of 2021(Ghana Population Census and Housing,2021).The city is experiencing swift expansion, with its population increasing by an annual rate of 4.3% from 1984 to 2000, and around 4% from 2000 to 2010 (Ghana Statistical Service ,2002). Spanning roughly 300 square kilometers in size (Grant and Yankson, 2005), the city is situated between longitudes 0° 1′ West and 0° 15′ East and latitudes 5° 30′ North and 5° 50′ North (Nyarko in 2000).

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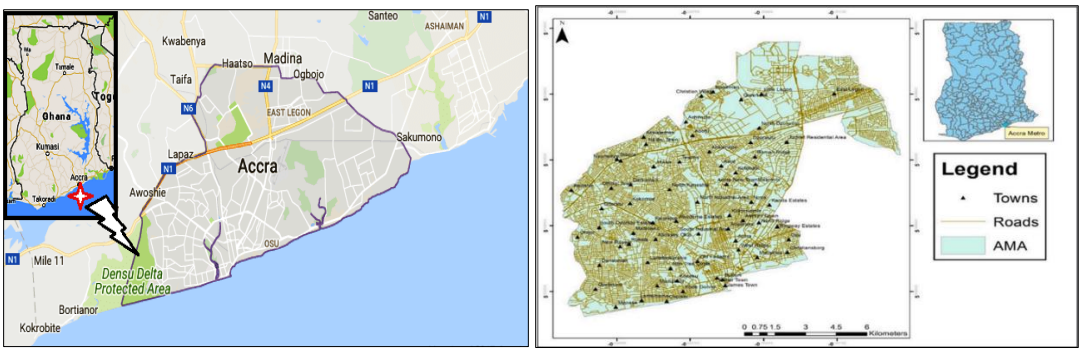


source: (Georgette Baaba Atakrah, 2023)

Figure 1 Map of Accra city

Accra's climate is characterized as a marginally hot semi-arid one, closely bordering on a tropical dry climate, with an average annual rainfall of around 730 mm, mainly occurring during Ghana's two distinct rainy seasons.(Ghana Population Census and Housing,2021). There is always a variation in temperature occurs throughout the year (Ghana Population Census and Housing,2021). Average temperatures per month vary, with August seeing an average of 25.9 degrees Celsius and March experiencing a higher average of 29.6 degrees Celsius.

The chart below shows the climate data for Accra in Ghana from the year 1991 – 2020(Ghana Population Census and Housing,2021).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	36.6 (97.9)	37.1 (98.8)	36.5 (97.7)	38.7 (101.7)	35.0 (95.0)	33.5 (92.3)	32.3 (90.1)	32.8 (91.0)	33.9 (93.0)	34.5 (94.1)	38.0 (100.4)	36.0 (96.8)	38.7 (101.7)
Mean daily maximum °C (°F)	32.6 (90.7)	33.0 (91.4)	33.0 (91.4)	32.7 (90.9)	31.8 (89.2)	29.8 (85.6)	28.6 (83.5)	28.4 (83.1)	29.6 (85.3)	31.1 (88.0)	32.1 (89.8)	32.4 (90.3)	31.3 (88.3)
Daily mean °C (°F)	28.5 (83.3)	29.2 (84.6)	29.2 (84.6)	29.0 (84.2)	28.3 (82.9)	26.8 (80.2)	25.9 (78.6)	25.6 (78.1)	26.5 (79.7)	27.5 (81.5)	28.3 (82.9)	28.6 (83.5)	27.8 (82.0)
Mean daily minimum °C (°F)	24.5 (76.1)	25.4 (77.7)	25.4 (77.7)	25.3 (77.5)	24.7 (76.5)	23.8 (74.8)	23.3 (73.9)	22.9 (73.2)	23.4 (74.1)	23.8 (74.8)	24.6 (76.3)	24.7 (76.5)	24.3 (75.7)
Record low °C (°F)	15.0 (59.0)	16.7 (62.1)	18.9 (66.0)	19.4 (66.9)	18.6 (65.5)	17.8 (64.0)	17.8 (64.0)	17.2 (63.0)	18.3 (64.9)	19.4 (66.9)	17.8 (64.0)	16.7 (62.1)	15.0 (59.0)
Average precipitation mm (inches)	11.8 (0.46)	25.5 (1.00)	61.1 (2.41)	87.8 (3.46)	151.4 (5.96)	189.6 (7.46)	63.0 (2.48)	21.0 (0.83)	42.9 (1.69)	80.0 (3.15)	37.2 (1.46)	27.2 (1.07)	798.5 (31.44)
Average precipitation days (≥ 1.0 mm)	0.8	1.6	4.1	4.7	8.3	10.2	5.4	3.6	5.4	5.7	2.8	1.5	54.1
Average relative humidity (%)	77	78	79	80	81	85	84	83	81	82	80	80	81
Mean monthly sunshine hours	185.9	189.7	211.9	221.2	219.4	157.9	150.8	146.8	173.0	237.6	244.9	222.7	2,361.8

(source: NOAA. Gov,2023)

Figure 2 Climate data for Accra in Ghana

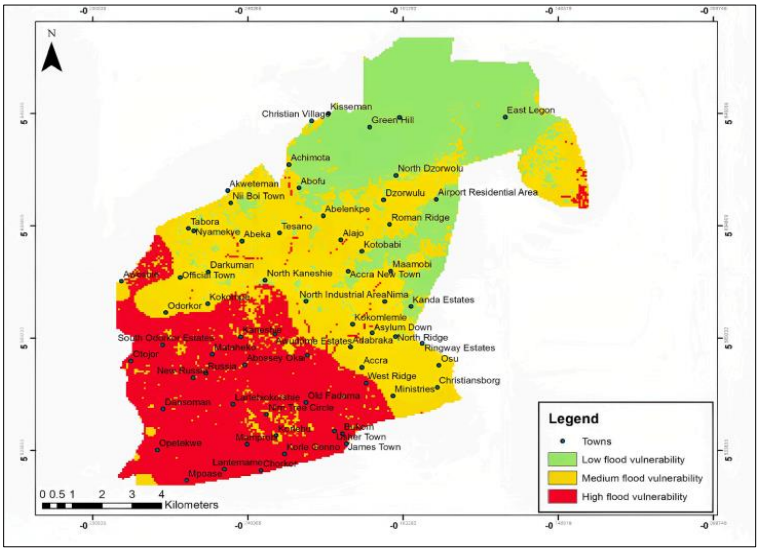
1.2. History of Flooding

Coastal flooding in Accra is nothing new. Some of the flooding events that have been documented are in the following years: 1995,1960,1973,1999,2001,2010,2011,2015,2019,2023(Georgette Baaba Atakrah, 2023). Figure 3 shows one of the flood events that occurred in Accra.

source: George Agboklu, 2015

Figure 3 Flood event in Accra

In 2015, the flooding event resulted in the loss of 500 lives, a complete destruction of 187 homes, and affected 46,370 individuals, (Appiah-Adjei and Asumadu-Sarkodie in 2020). In a proactive response to manage recurrent flooding, the Ghanaian government designated approximately GH¢197 million, equivalent to around $38 million, in 2019 for flood mitigation measures in Accra (Appiah-Adjei,2019). Figure 4 below explains some of the possible flood prone towns in Accra city basedon the past historical data on the events.



source: (Georgette Baaba Atakrah, 2023)

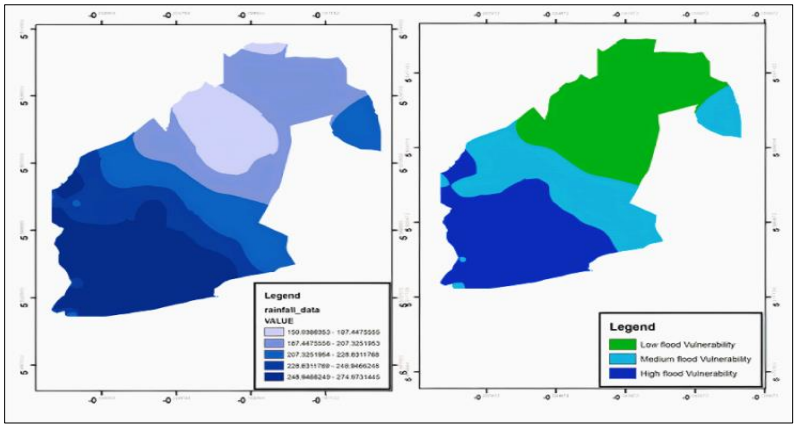
Figure 4 Possible flood prone zones in Accra

1.3. Some Contributors of Coastal flooding in Accra

Many factors have contributed to coastal flooding in the Accra city(landcover, paper).Below are some of the main contributors to flooding in the city of Accra.

1.3.1. Rainfall

Higher rainfall intensity means that more rain is falling in a shorter amount of time, which can lead to an increase in a large volume of water accumulating on the ground surface (Dekongmen,Domfeh, 2021). When the ground becomes saturated and cannot absorb water quickly enough, excess water runs off flows into the nearby rivers, streams, and drainage systems. This rapid runoff can overwhelm drainage infrastructure and cause water levels to rise rapidly, leading to flooding in low-lying areas (Dekongmen,Domfeh, 2021).High rainfall intensity can overwhelm urban drainage systems designed to handle typical rainfall events. Inadequate infrastructure capacity, such as undersized stormwater pipes or insufficient drainage networks, can lead to flooding in urban areas (Dekongmen,Domfeh, 2021). Figure5 below shows the vulnerability map of intense rainfall pattern for the city of Accra.

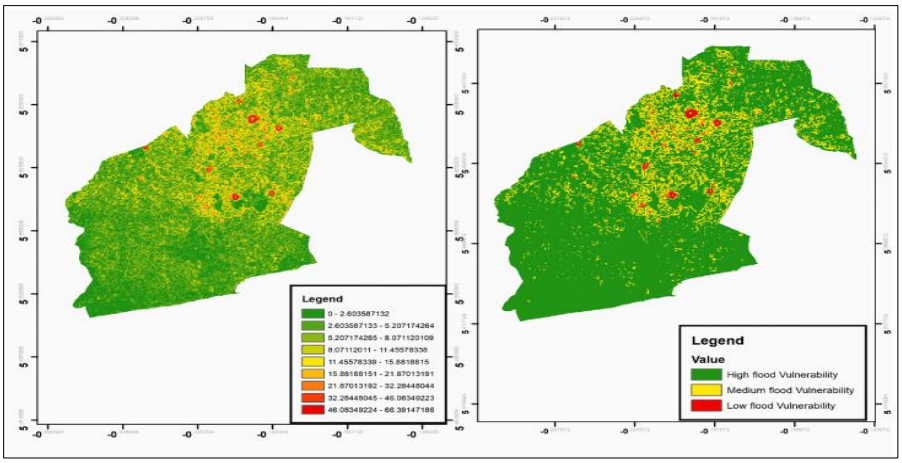


source: Adams, A. G. (2008

Figure 5 vulnerability map of intense rainfall.)

1.3.2. Slope map of Accra city

The slope of Accra is one of the major contributors to flooding. In areas of the city with steep slopes, rainfall can quickly accumulate leading to rapid increases in the volume of water of river and streams (Boadi, Kuitunen, 2002).As water flows downhill of the sloppy areas, it can pick up sediment and transport it towards coastal regions, where it may contribute to sedimentation in river and streams channels(Boadi, Kuitunen, 2002). This sedimentation can alter the natural flow patterns of rivers and exacerbate flooding during high tide or storm events(Boadi, Kuitunen, 2002). Figure 6 explains the slope vulnerability map of the city of Accra.

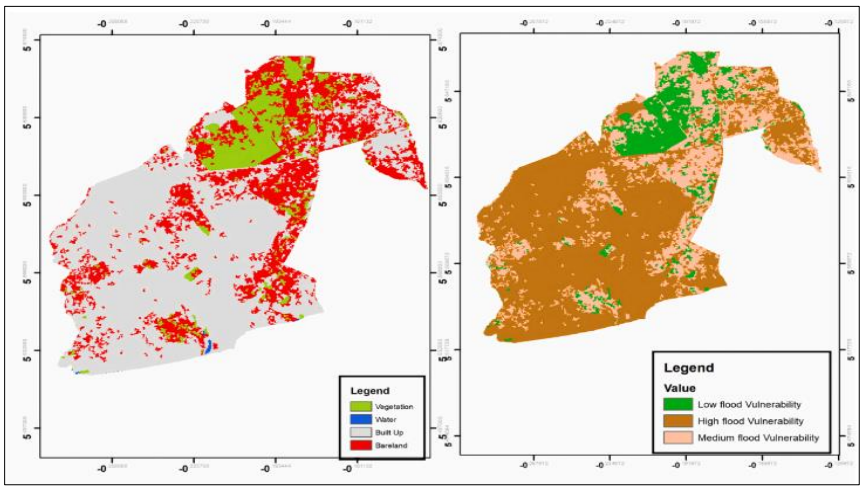


Source: (Amoako, 2015)

Figure 6 vulnerability map of slope in Accra

1.3.3. Vegetation and Landcover

Vegetation, including forests, wetlands, and mangroves, plays a role in flooding but has a low contribution to flooding in the city. Most of the vegetation in Accra acts as defense against storm surges, waves, and erosion, helping to reduce the impacts of flooding on coastal communities. The figure7 below shows the landcover vulnerability in Accra city area ranging from low to high.



. Source: (Charles Yaw Okyere, 2013)

Figure 7 Vulnerability Map of landcover

1.4. Some existing Practices and Planning in the city of Accra that leads to flooding.

In Accra, the capital city of Ghana, the engineering practices and urban planning reflect its dynamic growth and diverse challenges. As a major urban center, the city has seen a mix of traditional and modern engineering efforts to accommodate its expanding population and to foster sustainable development. This overview explores the existing strategies and infrastructures in place, their short comings, and approaches and how they contributeto coastal flooding in Accra.

1.4.1. Land Delivery and Building Permit Issuance

In Accra, the capital city of Ghana, urban development has largely proceeded without integrated land management, leading to anurban sprawl and significant land delivery issues (Andreasen,2016). Most of Accra's land is informally managed by traditional authorities with little government help, resulting in poor layouts and a lack of coordination between traditional landowners and government land agencies (Oteng- Ababio,2023). These practices have contributed to a chaotic environment characterized by rapid, unplanned expansion, corruption, and multiple sales of the same parcels of land, causing extensive legal disputes and delaying development (Kofie,2023). Poor record-keeping by state agencies worsts these problems, as seen in the Accra Metropolitan Assembly (AMA), where land records are disorganized and building permits are mostly unverified (Yiran,2023). This lack of structure and accountability has caused unregulated construction, often in areas prone to flooding, contributing to the city's vulnerability to environmental hazards.

1.4.2. Unplanned Growth and Disorganization.

Accra's rapid expansion has been marked by disorganized and haphazard growth, frequently exploited by influential individuals for their personal advantage. This development pattern has neglected essential services such as proper drainage, which is sorely lacking in many parts of the city Bogaert K (2011).During the rainy season, the city's inadequate drainage systems are overwhelmed by heavy downpours, causing rainwater to accumulate rapidly in residential areas and on streets(Ayambire,2021).This inadequate water management infrastructure results in significant waterlogging from even moderate rainfall, which disrupts daily life, damages property, and poses severe health risks (Mensah H,2021).Compounding these challenges is the city's topography and the prevalence of impermeable surfaces like concrete, which inhibit natural soil absorption of water(Teye JK,2014). These factors underscore the urgent need for comprehensive urban planning in Accra that integrates robust infrastructure to manage stormwater effectively, prevent flooding, and foster sustainable and equitable development across all its diverse neighborhoods.

[source:https://link.springer.com/article/10.1007/]

Figure 8 Slums in Accra city (Agbogbloshie)

1.4.3. Informal Land Management

In Accra, the management of land is largely informal and is predominantly overseen by traditional authorities, which often leads to disorganized urban layouts and contributes to widespread corruption (Asiedu,2009). This chaotic system of land management is frequently plagued by legal disputes, a common issue arising from the same plot of land being sold to multiple buyers. This practice not only fosters a breeding ground for corruption but also results in complex legal battles over land ownership (Afenah,2012). The lack of trust in the formal land registration and management systems has given rise to the phenomenon of "Land Guards." These unauthorized private security groups are hired by landowners to protect their claims because they do not believe the formal systems will adequately safeguard their interests (Adewale BA,2020). The emergence of these guards is a direct response to the perceived inadequacies and failures of official land management policies and practices.

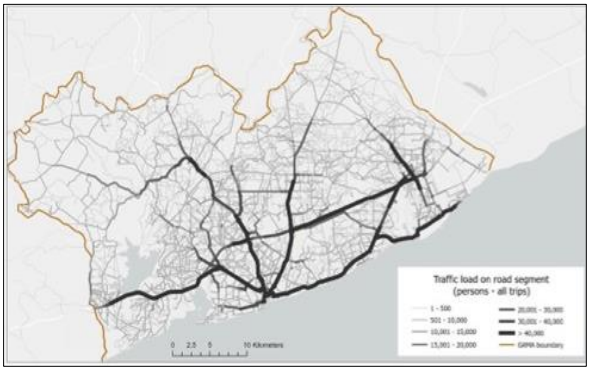
2. Vulnerability of Road Infrastructure

Ghana has a large and varied network of roads, with the main ones being regional, national, and interregional trunk roads. The Ministry of Roads and Highways, set up in 1974, oversees these trunk roads, which stretch for 13,367 km and make up a third of the country's total road distance of 40,186 km(Ghana Mobility and Accessibility Project,2016) .The central responsibilities of the Ministry of Roads and Highways(Medium Term Expenditure Framework, 2023) are:

- Crafting, monitoring, evaluating, and coordinating policies related to road infrastructure.
- Developing and upkeeping road infrastructure.
- Enhancing road safety and environmental standards.
- Securing funds for road maintenance.
- Providing training for professionals such as engineers and contractors.

The Department of Feeder Roads looks after the smaller feeder roads, while theUrban Roads Department of takes care of road networks in cities (Ghana Mobility and Accessibility Project,2016). In Accra, the capital, there's a mix of 2,826 km of local and highway roads. It is crucial to spot the busy roads that could flood; to keep traffic moving smoothly and make sure the road system can handle problems like floods. Knowing where these risky spots are helps the ministry figure out where to make roads stronger and safer. The Accra Transport Master Plan, covers 12 districts within the Accra Metropolitan Assembly, prioritizes analyzing the city's road network capacity for handling increased traffic, especially during disasters that elevate vehicle usage to ensure continued mobility (Ghana Mobility and Accessibility Project, 2016).

Figures 9 and 10 highlight the traffic conditions in Accra during floods. Figure 9 shows that when floods hit, traffic jams often happen on roads outside the central city. When floods happen, they can cover the roads that people use a lot. Because these roads are underwater, there is more traffic on them as everyone still tries to use them. This causes a lot of traffic jams. Drivers must then look for other ways to go, which can be tough if they donot know the area well or if there arenot many other routes available. It is important to have a backup plan with different roads to use when the usual ones are flooded to keep everyone moving and safe.On the other hand, Figure 10 looks at the routes going into the city center. Here, keeping roads clear is important, especially during floods, because these areas have important services. When flooding occurs, traffic can get heavy as people are forced onto fewer roads that are still open, causing delays and making it hard for emergency services to get through.Managing traffic both into and away from central Accra during floods is essential.The Ministry of Roads and Highway and Planners need to watch these patterns to help with emergency planning and to keep traffic flowing.It is also important to make sure that people can get around the city, whether they are heading towards the center for essential services or moving away from it to avoid the floods.



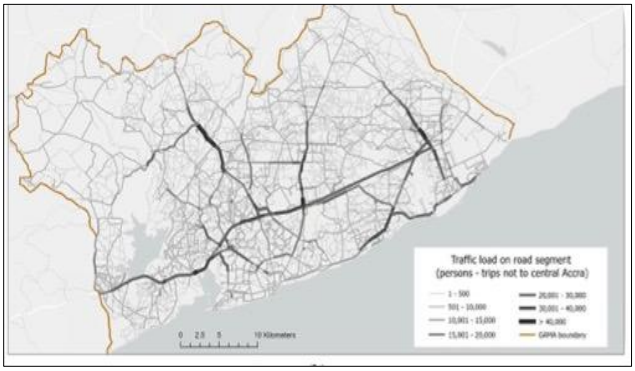


Figure 9 Trips to central Accra (Allotey,2023) **Figure 10** Trips not to central Accra (Allotey,2023)

3. Mitigation Measures in Transportation

Since Accra is the capital and the busiest city in Ghana, it is important to have plans in place for when disasters like floods happen. This way, people and businesses can keep going even when there's a flood. Having different roads to take during these times means that drivers and the public can still reach their destinations safely and without being late. This helps everyone stay productive, which is good for the economy of the country.Flood mapping tools like those by FEMA are not available for Africa, which hinders official flood forecasting. To fill this gap, a flood map tool wasused that uses

historical flood data (flood elevation) to predict flood zones was used. This helps identify which areas and roads might be affected by future floods.

Figure 11 illustrates Accra's road network, highlighting popular drop-off points where people usually stop for their daily activities.

Figure 11 Major Road network in Accra

Based on the most severe flood recorded in 2023(Yaw Twumasi,2023), which reached a maximum height of 46.39 inches, Figure 10 identifies the areas of Accra that are most vulnerable to flooding and shows how these floods intersect with the road network.To anticipate future flooding scenarios, projections using higher estimated water levels 50.4 inches were made shown in figure 13. The areas shaded in bright colors represent the projected spread of the floodwaters and indicate the potential impact on the roads. These visuals serve to highlight the extent of flooding and its potential disruption to the city's transportation infrastructure.

Figure 12 Routes for 46.45in flood height

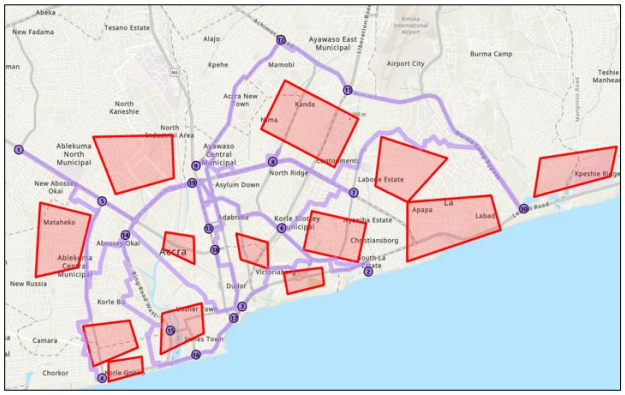


Figure 13 Routes for 50.45in flood height

The network tool in ArcGIS Pro helps find the quickest paths on city roads. It uses a smart method called Dijkstra's algorithm to do this. When floods happen, this tool shows different roads people can take to avoid the water and still get to where they need to go quickly. This is helpful for minibuses, which many people rely on, especially those who don't have much money. They can use these other roads suggested by the tool, so people arenot late and can travel smoothly. The picture we have shown these alternate routes for when there's a flood.

4. Results

The analysis of Accra's transportation infrastructure revealed several critical insights regarding its vulnerability to coastal flooding:

Historical Flood Events: Documented flood events in Accra (e.g., 1960, 1973, 1995, 2015, 2019, 2023) have caused significant damage, with the 2015 event resulting in the loss of 500 lives, destruction of 187 homes, and affecting 46,370 individuals. These events highlight the city's susceptibility to extreme weather conditions.

4.1. Contributing Factors

- Rainfall Intensity: High-intensity rainfall overwhelms the city's drainage systems, leading to rapid water accumulation in low-lying areas.
- Slope Vulnerability: Steep slopes exacerbate runoff, increasing river and stream volumes and contributing to sedimentation that alters natural flow patterns.
- Land Use and Urban Planning: Informal land management, lack of coordinated building permits, and unplanned urban sprawl have led to construction in flood-prone zones, worsening the situation.

4.2. Transportation Network Analysis

- Flood mapping tools were used to predict flood zones based on historical data. For example, the 2023 flood reached a maximum height of 46.39 inches, impacting key road networks.
- Simulated flood scenarios at higher water levels (50.4 inches) identified critical areas where road closures could disrupt traffic significantly.
- ArcGIS Pro's network analysis tool, utilizing Dijkstra’s algorithm, successfully identified alternative routes to maintain connectivity during flood events, ensuring smoother traffic flow and reducing delays.

4.3. Mitigation Strategies

- Improved drainage systems and elevated roads in vulnerable areas are recommended to prevent waterlogging.
- Implementation of stricter land-use regulations and better coordination between traditional authorities and government agencies can reduce unregulated construction in flood-prone zones.
- Adoption of advanced flood forecasting tools and emergency response plans will enhance preparedness and minimize disruptions during floods.

These results emphasize the importance of integrating technology and sustainable urban planning to build a resilient transportation network capable of withstanding future flood events in Accra.

Table 1 Accra Transportation Flood Resilience Analysis

Category	Details
Historical Flood Events	Floods in 1960, 1973, 1995, 2015, 2019, 2023. The 2015 flood resulted in 500 deaths, destruction of 187 homes, and affected 46,370 individuals.
Contributing Factors - Rainfall Intensity	High-intensity rainfall overwhelms drainage systems, leading to rapid water accumulation in low-lying areas.
Contributing Factors - Slope Vulnerability	Steep slopes increase runoff, raising river and stream volumes and contributing to sedimentation.
Contributing Factors - Land Use and Urban Planning	Informal land management, lack of coordinated building permits, and urban sprawl lead to construction in flood-prone zones.
Transportation Network Analysis - Flood Mapping	Flood mapping tools predicted zones based on historical data. The 2023 flood reached a height of 46.39 inches, impacting key road networks.
Transportation Network Analysis - Simulated Flood Scenarios	Simulated floods at 50.4 inches identified critical areas where road closures could severely disrupt traffic.
Transportation Network Analysis - Alternative Route Identification	ArcGIS Pro's network analysis tool, using Dijkstra’s algorithm, identified alternative routes to maintain connectivity during floods.
Mitigation Strategies - Drainage and Road Improvements	Recommendations include improved drainage systems and elevated roads in vulnerable areas to prevent waterlogging.
Mitigation Strategies - Land Use Regulations	Stricter land-use regulations and better coordination between authorities can reduce unregulated construction in flood-prone zones.

Mitigation Strategies - Advanced Flood Forecasting	Advanced flood forecasting tools and emergency response plans will enhance preparedness and minimize disruptions.

5. Conclusion

Accra's vulnerability to flooding, compounded by climate change and rapid urbanization, underscores an urgent need for resilient infrastructure planning. The city's historical flood events and current road network susceptibility highlight the critical need for comprehensive flood mitigation strategies. Effective management of transportation, particularly during flood events, is essential for ensuring the city remains functional and safe. The deployment of tools like ArcGIS Pro's network analysis, which utilizes Dijkstra's algorithm, exemplifies the integration of technology in disaster management. It aids in identifying alternative routes that can mitigate the impact of floods on the most used roads, ensuring the mobility of minibuses and other crucial forms of transport, particularly for those in economically vulnerable positions. The considerations made for Accra's transportation network and urban planning must account for the dynamic and complex challenges posed by flooding. Strategies that encompass improved drainage, elevated roads, and enhanced land management practices are necessary to bolster Accra's defenses against flooding. Continuous monitoring, coupled with a proactive and adaptive approach to urban development and disaster response, will be vital in safeguarding the economic productivity and wellbeing of Accra's inhabitants. Accra faces significant challenges from coastal flooding, but with effort towards improving land use, drainage, and transportation infrastructure, while embracing innovative technological tools, the city can enhance its resilience against such disasters, securing a safer and more productive future for all residents.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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