

Article

Mobility Disruptions in Accra: Recurrent Flooding, Fragile Infrastructure and Climate Change

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Abstract: This paper analyzes the mobility disruptions experienced by urban residents in relation to heavy precipitation and flooding of roads. The empirical focus is Accra, Ghana, a rapidly growing African city with discernible challenges in its transport system and a longstanding history of recurrent flood hazards, which are likely to be exacerbated by climate change in the future. In a context where there is very little mobility data available from official sources, the paper utilizes data from a large mobility survey ($n = 1053$) conducted through in-person interviews in July–August 2021 in 10 selected neighborhoods in Accra’s sprawling periphery. The survey targeted economically active adults, who are travelling regularly in relation to their income-generating activities. The survey recorded respondents’ experiences with a wide range of mobility disruptions caused by heavy precipitation and water on the roads. The analysis of survey data is supplemented with insights from qualitative interviews with a range of local key informants ($n = 75$). The research illuminates the diversity of mobility disruptions experienced by Accra’s residents during and after heavy precipitation events and the adverse implications for livelihoods and access to markets and services. The results highlight that mobility disruptions related to heavy precipitation are an extremely commonplace experience for residents in Accra’s periphery, across a diverse collection of neighborhoods and across travel patterns and traveler characteristics. While existing research tends to privilege the most dramatic and disastrous flood events and the associated destruction of property, this research, however, draws attention to the somewhat under-researched topic of mobility disruptions to everyday activities and their implications for livelihoods and access to markets and services.

Keywords: sustainable transport; flooding; urban transport; daily mobility; transport infrastructure; African cities



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1. Introduction

Urban transport systems are a major source of greenhouse gas emissions, while also being highly exposed to climate change impacts. Urban transport systems are vulnerable to impacts of extreme weather events [1,2], which are anticipated to become more frequent and intense in the future due to climate change [3]. In African cities, climate change impacts are anticipated to wreak significant havoc on fragile urban transport systems [4,5]. Many African cities are already highly exposed to extreme weather events [6,7], while also challenged by insufficient and over-stretched transport systems [8–10].

Existing research on sustainable transport in cities in the Global South is primarily concerned with mitigating the contribution of urban transport sectors to climate change. A range of studies highlight measures to curb emissions, including compact development [11,12], star-shaped urban form [13], dispersion of housing and industries [14], investments in mass transit systems [15–20] and non-motorized transport modalities [21–23]. The reverse enquiry, how urban transport systems are affected by extreme weather events, likely to be exacerbated

by climate change, has so far received limited attention in the context of the Global South [2]. Notable exceptions include a review paper suggesting that urban transport sectors are particularly vulnerable to the impacts of heavy precipitation events, which may inundate low-lying road segments, undermine the structural integrity of infrastructure and wash away poor quality roads [4]. Studies applying GIS-based modelling illuminate how inundation of road segments may potentially compromise network capacity and increase traffic volumes and congestion in the remainder of the network [5,24,25]. A recent study in Bangalore suggests that a wide range of adaptation measures are needed to make the transport system more resilient to the impacts of heavy precipitation events [26]. A recent qualitative study finds that heavy precipitation and associated inundation of roads constrain mobility of residents in low-income neighborhoods of Manila, Philippines, primarily through increasing congestion and prolonging travel times [27].

This paper contributes to this emerging literature with a study of the mobility disruptions experienced by urban residents in Accra, Ghana, in relation to heavy precipitation events and ensuing flooding of roads. The paper is concerned only with heavy precipitation events and does not consider mobility disruptions caused by other types of extreme weather events, such as storms or heat waves. There is a wealth of research on flood hazards in African cities, but much of it is focused on the most dramatic flood events and the impacts on inundation of houses and destruction of property. Only a few studies have recorded flood impacts on daily mobility and livelihoods. A study in Pikine, Senegal, describes how work places become inaccessible and people stay home to secure their houses and belongings [28]. Similarly, a study of flood-prone areas in Lagos, Nigeria reports widespread inability to work and engage in trading activities during prolonged inundations [29]. A study in Accra reports flood impacts on respondents' economic activities, with almost 90% of households reporting loss of income [30]. While the specific mobility disruptions associated with heavy precipitation events and flooding are not yet well understood, the strong links between mobility and livelihoods are well documented in the context of African cities [31–33]. Several studies highlight that mobility constraints may limit access to work and economic opportunities, restrict access to basic services and prevent development of social networks [34–36]. A range of studies emphasize that mobility constraints can cause social exclusion and trigger downwards social mobility [37–41].

The objective of this paper is to analyze the diversity of mobility disruptions experienced by Accra's residents in relation to heavy precipitation events and how experiences with mobility disruptions vary across a diverse collection of neighborhoods and across travel patterns and traveler characteristics. The paper utilizes data from a large mobility survey ($n = 1053$) conducted in July–August 2021 in 10 different neighborhoods in Accra's sprawling periphery. The survey targeted economically active adults travelling regularly in relation to their livelihood activities and collected detailed information regarding respondents' livelihood activities, daily mobility patterns, assessments of transport infrastructure and experiences with mobility disruptions caused by heavy precipitation events. The survey offers detailed data on mobility in a context where there is very little mobility data available from official sources. The paper draws primarily on the latter part of the survey recording respondents' experiences with mobility disruptions related to heavy precipitation events. To the best of our knowledge, this is the first major mobility survey, which has collected information on the perceived impacts of heavy precipitation events on daily mobility in the context of African cities.

The empirical context of Accra offers a prime example of a rapidly growing African city with widespread urban sprawl, discernible challenges in its transport system and a longstanding history of recurrent flooding. Accra is the capital city and largest urban center in Ghana with an estimated population of 4.7 million people in 2020 [42]. Accra has experienced significant spatial growth over the past decades, with different sources suggesting urban expansion rates of approximately 5–6% per year [43–45]. Expansion is fueled by unregulated acquisition and development of land for residential purposes, primarily by private individuals and households [46–48]. Emerging residential developments

commonly begin in poorly accessible locations, significantly underserved by transport infrastructure [46]. Overall accessibility is challenged by insufficient road infrastructure, limited connectivity and severe congestion, with peripheral areas most challenged in terms of accessibility [49]. Despite this, there is strong functional integration between peripheral and central areas, where key commercial activities and administrative functions are concentrated [32,49]. Flooding is a recurrent hazard in Accra primarily triggered by heavy precipitation events, commonly occurring in the rainy season in May–June, causing flash floods and overflow from the many rivers and streams flowing through the city [50–52]. In recent years, floods have become more frequent and destructive [53]. While often attributed primarily to climate change, a variety of factors contribute to intensifying flood hazards, including unregulated urban expansion, lack of land-use planning, harmful construction practices and encroachment on water bodies [48]. In the future, climate change is anticipated to exacerbate flood hazards as IPCC's climate scenarios for West Africa foresee an increase in the frequency and intensity of heavy precipitation events [54].

2. Materials and Methods

2.1. Methodology

The core data for this paper consists of data from a large mobility survey ($n = 1053$) conducted in July–August 2021 in 10 selected neighborhoods of Accra. The analysis of survey data is supplemented with insights from a preliminary round of qualitative interviews conducted in 2019 with a wide range of local key informants ($n = 75$), including municipal planning officers, officers from the National Disaster Management Organization (NADMO), elected assembly members and representatives from traditional authorities and local residents' associations. Extensive field observations were also collected during fieldwork in 2019, independently and accompanied by relevant local informants to document characteristics of the physical environment in all neighborhoods.

2.2. Survey Design

The survey conducted interviews with a total of 1053 economically active adults residing in 10 different neighborhoods clustered around four locations in Accra's periphery. See Figure 1 for location of Accra and Figure 2 for location of survey neighborhoods within Accra. The survey was administered through in-person interviews by a team of trained enumerators led by researchers from University of Ghana during July–August 2021. The survey deploys the inclusion criteria for main respondents that they should be adult household members over the age of 18, who are economically active and travelling regularly (at least once a week) in relation to their income-generating activities. These inclusion criteria ensure that main respondents are able to provide relevant answers to the survey questionnaire. The survey questionnaire was set up and administered in the SurveyXact online platform. Enumerators conducted the interviews with respondents, while recording their answers directly in the digital questionnaire in SurveyXact on tablets.

The selection and delineation of survey neighborhoods was informed by the preliminary round of qualitative fieldwork in 2019 and sought to ensure maximum variation between neighborhoods as well as a degree of homogeneity within neighborhoods. As is common in Accra's periphery, all 10 survey neighborhoods are developed gradually by private individuals and households, who finance and organized incremental construction of housing for owner-occupation and rental purposes. The selected neighborhoods differ in degree of consolidation, level of accessibility, geo-physical characteristics and socio-economic composition of local populations. See Table 1 for an overview of neighborhood characteristics and socio-economic indicators of the populations. The delineation of neighborhoods is based on administrative boundaries, which have subsequently been adjusted manually to accommodate natural barriers, such as streams and roads, and ensure homogeneity within areas in terms of the timing and characteristics of housing developments.



Figure 1. Location of Accra. Source: Built-up area of Accra for 2017 produced following a method explicated in [43].

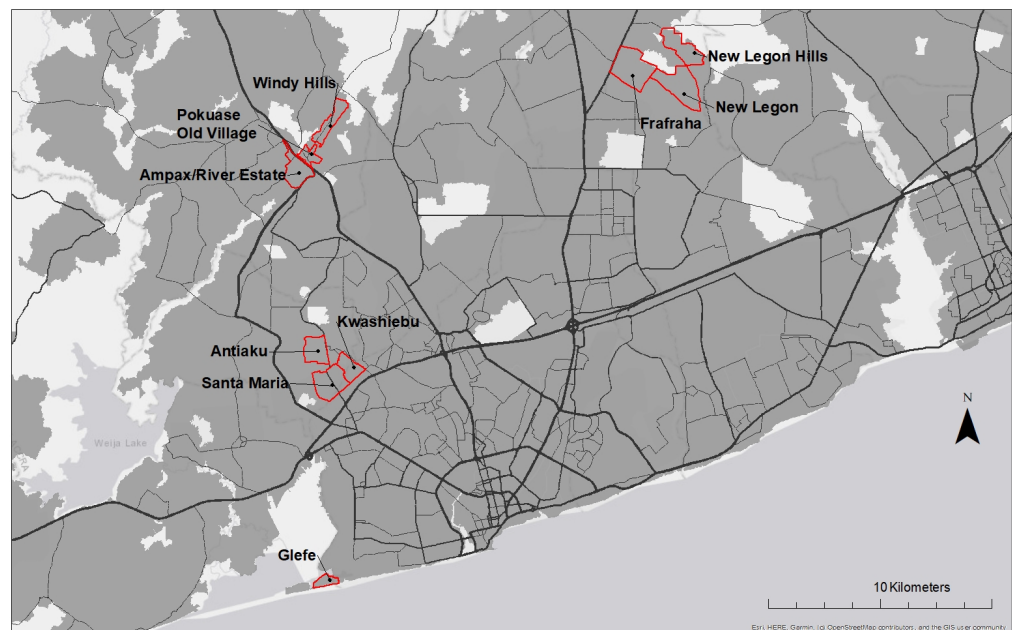


Figure 2. Location of neighborhoods covered by the survey. Source: Built-up area of Accra for 2017 produced following a method explicated in [43]. Road network data from OpenStreetMap.

Table 1. Overview of neighborhood characteristics and socio-economic indicators.

Location	North-Western Consolidated Areas			Western Coastal Area	North-Eastern Peripheral Areas			North-Western Peripheral Areas			
Neighborhood	Santa Maria	Kwashiebu	Antiaku	Glefe	Frafraha	New Legon	New Legon Hills	Ampax/River Estate	Pokuase Old Village	Windy Hills	Total
Neighborhood characteristics											
Geophysical characteristics	Low-lying riverine terrain	Low-lying riverine terrain	Hilly, undulated terrain	Narrow sand strip, along coastal lagoons	Low-lying riverine terrain	Low-lying riverine terrain	Low-lying riverine terrain	Marshy wetland terrain	Low-lying riverine terrain	Hilly, undulated terrain	
Inclusion into the urban extent	1990s	1990s	1990s	1990s	2000s	2000s	2010s	2000s	2000s	2010s	
Stage of consolidation	Consolidated	Consolidated	Consolidated	Consolidated	Recently developed	Recently developed	Newly developing	Recently developed	Consolidated	Newly developing	
Characteristics of main respondents											
Male (%)	40.4	53.9	53.0	48.2	42.2	50.5	50.0	40.6	49.1	54.2	48.1
Female (%)	59.6	46.1	47.0	51.8	57.8	49.5	50.0	59.4	50.9	45.8	51.9
Average age (years)	42.3	39.9	39.1	38.5	38.7	41.0	40.1	39.0	41.4	39.4	39.9
Ave. length of residence in neighborhood (years)	12.7	13.3	13.1	11.5	7.5	6.4	4.9	7.6	16.0	7.4	10.0
Highest level of schooling completed by main respondent											
Primary school/no education received (%)	11.2	16.7	11.2	23.2	11.9	11.9	23.6	19.0	17.1	11.2	15.8
Technical/vocational training (%)	12.1	2.0	5.1	5.4	2.8	6.9	2.8	1.0	7.6	7.5	5.3
Secondary school (%)	44.9	49.0	42.9	63.4	56.0	55.4	54.7	63.0	58.1	52.3	54.1
Tertiary education (%)	31.8	32.4	40.8	8.0	29.4	25.7	17.9	17.0	17.1	29.0	24.7
Vehicle ownership											
Household owns one or more vehicles (%)	38.5	35.3	36.7	12.5	45.9	47.5	37.7	26.0	24.5	37.7	34.1
Dwelling type											
Separate house (%)	45.9	43.1	55.0	14.3	59.6	61.4	57.5	47.5	28.3	57.0	46.7

Table 1. Cont.

Location	North-Western Consolidated Areas			Western Coastal Area	North-Eastern Peripheral Areas			North-Western Peripheral Areas			
Neighborhood	Santa Maria	Kwashiebu	Antiaku	Glefe	Frafraha	New Legon	New Legon Hills	Ampax/River Estate	Pokuase Old Village	Windy Hills	Total
Semi-detached house (%)	7.3	14.7	11.0	3.6	9.2	9.9	6.6	4.0	4.7	9.3	8.0
Apartment (%)	8.3	4.9	3.0	0.9	4.6	4.0	3.8	5.9	0.9	7.5	4.4
Compound house (%)	37.6	35.3	30.0	81.3	15.6	18.8	20.8	39.6	66.0	24.3	37.2
Other (%)	0.9	2.0	1.0	-	11.0	6.0	11.3	3.0	-	1.8	3.0
Dwelling size											
1 bedroom (%)	42.2	51.0	34.0	70.5	34.6	28.3	46.2	36.4	62.3	35.2	44.4
2 bedrooms (%)	22.0	12.0	23.7	17.9	21.5	27.3	18.9	38.4	22.6	26.7	23.0
3–4 bedrooms (%)	25.7	24.0	28.8	8.1	31.8	31.3	30.2	21.2	10.3	29.5	23.9
5 or more bedrooms (%)	10.1	13.0	13.4	3.6	12.0	13.2	4.7	4.0	4.7	8.6	8.7
Tenure form											
Owner-occupier (%)	41.7	42.6	51.0	34.8	43.1	39.6	32.1	51.5	40.6	53.3	42.9
Tenant (%)	46.3	41.6	32.0	51.8	20.2	27.7	21.7	36.6	36.8	21.5	33.7
Living rent-free (%)	6.5	11.9	14.0	11.6	18.3	17.8	18.9	5.0	20.8	16.8	14.2
Caretaker (%)	5.6	4.0	3.0	-	17.4	14.9	26.4	5.9	1.9	8.4	8.8
Dwelling outfitted with the following amenities:											
Piped water (%)	74.3	75.5	62.0	31.3	36.7	47.5	14.2	34.7	20.8	17.8	41.2
Electricity meter (%)	100	95.1	99.0	99.1	93.6	95.0	88.7	95.0	99.1	92.5	95.7
WC/ Improved Pit Latrine (%)	97.2	100	98.0	27.7	79.8	78.2	65.1	87.1	73.6	88.8	79.1
Security gate/ wall	64.2	70.6	55.0	11.6	51.4	45.5	29.2	35.6	17.9	30.8	40.9

The survey questionnaire was designed to collect detailed information regarding main respondents' ($n = 1053$) income-generating activities, daily mobility patterns in relation to both income-generating activities as well as other purposes, their assessments of local transport infrastructure and services in their neighborhood and their self-reported experiences with mobility disruptions during and after heavy precipitation events. The survey collected less detailed information on income-generating activities and daily mobility patterns of other adults in the main respondents' households ($n = 1054$). This paper will draw primarily on the section of the survey recording main respondents' experiences with mobility disruptions. This section was designed specifically to record the impacts of heavy precipitation on mobility and does not consider mobility disruptions caused by other extreme weather events nor other factors which may limit or constrain mobility. The variables in this section of the survey record whether respondents, in their own subjective experience, have experienced a range of different mobility disruptions caused by heavy precipitation and water on the roads. The survey applies a broad conception of mobility disruptions associated with heavy precipitation events, which may range from prolonging travel times, modifying travel patterns to completely hindering mobility. Mobility disruptions may occur during heavy precipitation events or in the following days, where stagnant water may pool in low-lying road segments and rough dirt roads are transformed to slough. The data on mobility disruptions are subjective in nature and reliant on respondents' self-reported experiences, their recollection of past events and their perception of causal relations. Most variables record mobility disruptions experienced within the past year, as this was deemed an appropriate time frame for recollection of past events of this nature. It is not possible to ascertain how respondents' self-reported experiences with mobility disruptions may correlate with actual precipitation patterns.

2.3. Sampling Strategy

The survey was designed to be generalizable at the neighborhood level and deploys a spatial approach to simple random sampling. For each neighborhood a total of 300 random GPS points were generated in ArcGIS 10.8.1 software and consecutively numbered. The team of enumerators successively located each GPS point in field, identified the nearest building and invited the occupants to participate in the survey. The enumerator team worked their way through the list of random GPS points until the target of at least 100 valid responses had been reached for each neighborhood. If two or more buildings appeared equally close to a GPS point, a second round of randomization was conducted by the enumerator in field. If the nearest building was occupied by multiple households, each household was surveyed separately, meaning that in some instances one GPS point would generate multiple valid responses. This may have the effect that tenants are slightly overrepresented in the survey, as rental houses often accommodate multiple households. If no occupants were home on the first visit, enumerators would visit the building a second time a few days later. Data collection was carefully organized to ensure that the team of enumerators collected interviews in all neighborhoods both on normal weekdays and on weekends in order to maximize the response rate. If more than one present household member fit the survey's inclusion criteria, only one participated in the survey, with present household members deciding among themselves who would participate. Across neighborhoods the team of enumerators visited and revisited between 120–200 GPS points to achieve the target of at least 100 valid responses. In total, 1478 GPS points were visited by enumerators to yield valid responses from 1053 main respondents, cf. Table 2. As such, 71% of GPS points yielded valid responses. Approximately 8% of the GPS points pointed to buildings, where none of the occupants fitted the inclusion criteria, and 9% pointed to buildings, where occupants were not willing to participate or not at home on either first or second visits. The remaining 12% of GPS points either pointed to partially completed and unoccupied structures or to non-residential buildings, such as schools or shops.

Table 2. Overview of GPS points and valid responses across neighborhoods.

	Valid Responses	Not at Home/Not Willing to Participate	None of the Occupants Fit Inclusion Criteria	Partially Completed, Unoccupied Structure	Non-Residential Building	Total No. of GPS Points Visited
Santa Maria	109	10	9	6	3	137
Kwashiebu	102	19	9	6	8	144
Antiaku	100	22	5	5	7	139
Glefe	112	4	5	0	0	121
Frafraha	109	20	13	5	1	148
New Legon	101	9	18	3	0	131
New Legon Hills	106	14	14	28	2	164
Ampax/River Estate	101	20	12	25	9	167
Pokuase Old Village	106	5	10	3	12	136
Windy Hills	107	16	18	39	11	191
Total	1053	139	113	120	53	1478

2.4. Profile of Respondents

The vast majority of main respondents (78%) are heads of household or his/her spouse. Some are children of (10%), otherwise related (7%) or unrelated (4%) to the head of household. The sample consist of 48% male and 52% female respondents and the age of respondents range from 18–79, with a mean age of 39.9 years, cf. Table 1. The majority are owner-occupiers (42.9%), while 33.7% are tenants, 8.8% are property caretakers and 14.2% are living rent-free. The majority of respondents have completed secondary school (54.1%), tertiary education (24.7%) or technical/vocational education (5.3%). Some have only completed primary or received no education (15.8%).

The peripheral neighborhoods clustered northeast of central Accra have attracted many middle- and high-income people, despite the poorly accessible, interior locations isolated from main roads. These neighborhoods have a high share of respondents with tertiary education, high vehicle ownership rates and a high share of separate houses and large dwellings with three or more bedrooms.

The peripheral neighborhoods clustered northwest of central Accra are more socio-economically mixed. Low-lying neighborhoods (Ampax/River Estate and Pokuase Old Village) have attracted residents of more modest means, reflected in the lower educational level, smaller dwelling sizes and lower vehicle ownership rates, while the hilly area (Windy Hills) have attracted middle- and high-income people, of similar socioeconomic status as the northeastern periphery.

The consolidated neighborhoods clustered north-west of central Accra have also attracted many middle- and high-income people. These neighborhoods have the highest share of respondents with tertiary education, high vehicle ownership rates and the highest share of respondents with access to piped water, electricity and WC/improved pit latrine.

The consolidated neighborhood Glefe, located on a narrow sand strip along the coast, have attracted many low-income people, reflected in the high share of respondents with low or no education and low vehicle ownership rates. Glefe has the highest share of tenants, shared compound houses and small dwellings with one bedroom, and the lowest share of respondents with access to piped water or WC/improved pit latrine in their dwelling.

3. Results

This section presents results from the survey data analysis concerning the main respondents' self-reported experiences with a wide range of mobility disruptions during and after heavy precipitation events. Mobility disruptions are analyzed according to respondents' neighborhoods, travel patterns and individual characteristics.

3.1. Type and Magnitude of Mobility Disruptions

Overall, the survey results illuminate that mobility disruptions related to heavy precipitation are extremely commonplace in Accra's peripheral neighborhoods. A total of 87% of respondents report that they have experienced some type of mobility disruption

within the past year, while ‘only’ 20% of respondents have experienced inundation of their dwelling. Mobility disruptions range from prolonged travel times, modified travel patterns to inability to travel and damage to neighborhood roads.

Prolonged travel times is the most commonly reported type of mobility disruption, cf. Table 3. Over two-thirds of respondents (68.4%) have experienced being stuck somewhere along the road, while waiting for rainfall to stop or water to recede from the road. Almost half (48.2%) have experienced severe traffic congestion caused by heavy precipitation.

Modified travel patterns is also a frequently reported type of mobility disruption. Approximately 36% have used an alternative mode of transportation and 33% have taken an alternative route to their destination to bypass specific road segments or intersections known to be affected by water. Almost two-thirds of respondents (63.5%) have postponed or avoided a trip in anticipation of rain, while over 20% of respondents with children have rushed home from work to pick up their children from school before the rain begins.

Inability to travel is the most severe type of mobility disruption associated with heavy precipitation. Over half of respondents (55.5%) report having been unable to travel in or out of their neighborhood for one or more days within the past year due to heavy precipitation or water on the roads. Those affected have experienced an average of 4 days of inability to travel. Close to half (46.2%) have experienced that neighborhood roads were too difficult or dangerous to travel, likely due to inundation of roads, surface run-off on the roads or roads transforming to slough. Public transport providers commonly retreat services from peripheral areas if road conditions are too rough. Almost a third of respondents (31.5%) have experienced being unable to access public transport services due to heavy precipitation. Destination areas and travel routes may also be affected by water, as 23.3% of respondents have experienced inability to travel because of roads blocked by water elsewhere in the city.

Damage to roads is a common type of mobility disruption associated with heavy precipitation, which can make roads difficult or even impossible to navigate for some types of vehicles and travelers. Over half of respondents (55.2%) have experienced that heavy precipitation made neighborhood roads unpassable. Interior access roads are mostly rough dirt or gravel roads without roadside drainage, which are highly susceptible to erosion during heavy precipitation events. Over half (54%) of respondents report that neighborhood roads suffered severe erosion due to heavy precipitation. This can also be arduous for vehicles; 7.4% have experienced damage to a private vehicle caused by water or mud on the roads.

3.2. Mobility Disruptions across Neighborhoods

Mobility disruptions are extremely common across all 10 neighborhoods. There are, however, also highly spatialized differences between neighborhoods shaped by settlement consolidation, geophysical characteristics and proximity to main roads. Settlement consolidation, the nature and quality of interior access roads and the proximity to all-weather main roads explain some of the variation in mobility disruptions between neighborhoods.

The significance of proximity to all-weather main roads is illustrated by the peripheral neighborhoods northwest of central Accra, which enjoy a highly accessible location along the Accra-Nsawam highway and easy access to several large all-weather main roads. These neighborhoods have the lowest shares of respondents reporting the most severe type of mobility disruption: Inability to travel in or out of their neighborhoods (41–47%).

Table 3. Mobility disruptions across neighborhoods, travel patterns and traveler characteristics.

Type of Mobility Disruption	Prolonged Travel Time			Modified Travel Patterns			Inability to Travel				Damage to Roads		
Variable *	I Waited Somewhere along the Road for the Rain to Stop or the Water to Recede	I Experienced Severe Traffic Congestion Due to Heavy Rains	I Used an Alternative or Longer Route to My Destination	I Used an Alternative Mean of Transportation than I Normally Would	I Avoided or Postponed Leaving My Home for a Planned Trip	I Rushed to Pick up Children from School before the Rains **	I Was Unable to Travel in or out of My Neighborhood for One or More Days	I Was Unable to Access Public Transport Due to the Rains	It Was Too Difficult or Dangerous to Travel Due to the Rains	I Could Not Travel Because Roads Elsewhere in the City Were Blocked by Water	The Roads around My Home or Leading in/out of My Neighborhood Were Not Passable	Roads in My Neighborhood Suffered Severe Erosion Due to the Rains	My Vehicle Was Damaged by Water or Mud on the Roads
Total	68.4	48.2	32.8	36.0	63.5	21.3	55.5	31.5	46.2	23.3	55.2	54.0	7.4
Neighborhoods	***	***	***	***	***	***	***	***	***	***	***	***	***
Santa Maria	80.7	57.8	41.3	41.3	75.2	19.7	62.0	38.5	63.3	39.4	62.4	59.6	11.0
Kwashiebu	48.0	50.0	30.4	43.1	52.0	25.0	54.5	27.5	33.3	23.5	53.9	38.2	6.9
Antiaku	75.0	53.0	47.0	45.0	59.0	19.3	59.2	34.0	45.0	44.0	49.0	64.0	6.0
Glefe	75.0	57.1	30.4	34.8	64.3	13.3	52.7	29.5	45.5	22.3	45.5	34.8	1.8
Frafraha	62.4	46.8	26.6	36.7	58.7	28.4	56.9	26.6	44.0	13.8	59.6	55.0	8.3
New Legon	68.3	54.5	29.7	34.7	69.3	31.8	60.0	41.6	54.5	26.7	66.3	65.3	14.9
New Legon Hills	78.3	52.8	51.9	49.1	84.0	29.0	80.0	60.4	67.0	30.2	90.6	69.8	12.3
Ampax/River Estate	76.2	35.6	27.7	26.7	58.4	27.1	41.8	21.8	37.6	13.9	49.5	40.6	3.0
Pokuase Old Village	62.3	43.4	30.2	32.1	67.0	9.4	47.1	20.8	40.6	13.2	34.0	46.2	3.8
Windy Hills	57.0	30.8	13.1	16.8	46.7	12.0	41.3	15.0	29.9	6.5	41.1	67.3	6.5
Travel intensity—no. of hours in transit on a normal weekday	***	***					***					***	***
0–1 h	60.1	40.4	29.8	37.2	56.0	20.5	45.3	30.7	44.5	20.2	52.8	45.4	6.0
1–2 h	72.5	46.3	31.7	37.2	59.2	18.9	58.5	31.4	47.4	21.2	53.4	49.6	3.3
2–3 h	69.2	53.6	33.6	32.7	62.6	23.2	60.7	31.3	44.1	26.1	54.0	55.9	10.4
3–4 h	69.3	55.3	36.8	36.0	63.2	25.6	59.3	26.3	47.4	25.4	57.9	70.2	7.0
> 4 h	68.3	57.4	40.6	44.6	55.4	21.5	58.9	40.6	48.5	27.7	65.3	68.3	14.9
Travel frequency—no. of trips in relation to primary livelihood activities													***
Less than once a week	72.5	46.1	27.5	32.4	66.7	17.9	57.4	32.4	50.0	18.6	53.9	55.9	4.9
1–2 times a week	68.6	47.0	28.0	36.0	58.7	21.3	56.0	32.2	42.0	20.1	54.9	49.6	4.2
3–4 times a week	67.1	46.7	32.3	34.1	61.7	19.8	58.8	29.3	48.5	24.0	58.7	52.7	5.4
5–7 times week	68.0	49.9	36.3	37.0	57.3	22.3	54.5	32.0	47.4	25.9	54.8	56.3	10.3
Vehicle ownership	***					***				***	***	***	***

Table 3. Cont.

Type of Mobility Disruption	Prolonged Travel Time			Modified Travel Patterns			Inability to Travel				Damage to Roads		
Variable *	I Waited Somewhere along the Road for the Rain to Stop or the Water to Recede	I Experienced Severe Traffic Congestion Due to Heavy Rains	I Used an Alternative or Longer Route to My Destination	I Used an Alternative Mean of Transportation than I Normally Would	I Avoided or Postponed Leaving My Home for a Planned Trip	I Rushed to Pick up Children from School before the Rains **	I Was Unable to Travel in or out of My Neighborhood for One or More Days	I Was Unable to Access Public Transport Due to the Rains	It Was Too Difficult or Dangerous to Travel Due to the Rains	I Could Not Travel Because Roads Elsewhere in the City Were Blocked by Water	The Roads around My Home or Leading in/out of My Neighborhood Were Not Passable	Roads in My Neighborhood Suffered Severe Erosion Due to the Rains	My Vehicle Was Damaged by Water or Mud on the Roads
Non-vehicle owners	70.6	46.9	31.4	37.5	60.1	18.3	53.5	31.1	45.7	20.5	53.0	50.7	1.9
Vehicle owners	64.2	50.6	34.9	32.7	57.5	26.9	56.6	32.1	46.9	28.5	59.8	60.1	17.9
Gender													***
Male	68.6	50.5	32.7	34.9	56.8	24.0	54.7	30.4	46.9	25.2	55.4	55.0	10.5
Female	68.1	46.2	32.8	37.0	61.4	19.5	56.3	32.6	45.4	21.4	54.9	53.1	4.6
Age				***					***		***		
Below 30	67.6	46.8	34.3	34.7	55.6	19.8	51.0	31.0	42.1	22.2	54.2	52.3	8.3
Between 30–60	69.0	50.3	32.9	38.7	59.3	23.3	56.7	32.0	48.1	24.0	56.7	56.1	7.4
Above 60	57.6	47.0	25.8	22.7	60.6	8.8	56.1	25.8	30.3	25.8	40.9	47.0	4.5
Educational level	***	***					***					***	***
Primary school/no education received	77.0	52.7	26.1	38.2	26.1	24.0	64.6	35.8	49.1	22.4	61.2	49.1	2.4
Technical/vocational training	69.4	44.3	32.7	36.4	28.6	20.8	56.5	31.3	44.6	21.7	54.9	51.4	6.0
Secondary school	69.6	46.4	37.5	35.7	28.6	9.1	48.2	28.6	44.6	26.8	48.2	50.0	8.9
Tertiary education	60.6	54.1	35.1	34.0	27.8	23.4	49.4	30.1	48.3	26.3	53.3	63.7	13.5

* Binary variables indicating the share of main respondents ($n = 1053$), who report that they have personally experienced the specific mobility disruption within the past year, specifically due to heavy precipitation and/or water on the roads. ** Share of main respondents computed only for those with one or more children in their household ($n = 701$). *** Indicates statistically significant differences between groups on the respective indicator of mobility disruption measured with chi-square statistic ($p < 0.05$).

The significance of the nature and quality of interior access roads is illustrated by the high share of respondents in New Legon Hills reporting mobility disruptions; 80% have experienced inability to travel in or out of their neighborhood, 60% have experienced inability to access public transport and 90% report that roads became unpassable. New Legon Hills is a newly developing area, where many houses are still under construction, and neither landowners, nor municipal authorities, have yet invested much in construction or improvement of interior access roads. The adjacent neighborhoods, New Legon and Frafraha, have comparatively lower shares of respondents reporting mobility disruptions. These areas are also characterized by a higher degree of consolidation at present and at least some improvements made on interior access roads.

While consolidation stage is important, a high share of respondents in consolidated neighborhoods have experienced inability to travel in or out of their neighborhood (approximately 50–60%). Santa Maria illustrates the significance of highly localized factors. The main outlet road from Santa Maria is located in low-lying terrain, intersecting with several streams, and regularly exposed to inundation of low-lying road segments close to the nearest main road Accra-Tema Motorway. This causes mobility disruptions for Santa Maria residents and many others, who need to pass through Santa Maria, including residents in Antiaku.

Geophysical characteristics also influence the type of mobility disruptions experienced. Road erosion is for example reported by high shares of respondents in low-lying riverine areas (New Legon, New Legon Hills and Santa Maria) as well as in hilly areas (Windy Hills and Antiaku), where downhill surface runoff volumes and speed can be significant during heavy precipitation.

3.3. Mobility Disruptions across Travel Patterns

Mobility disruptions are extremely common across respondents with different travel patterns. There is a tendency for respondents spending more time in daily transit to be more likely to report prolonged travel times due to severe traffic congestion or waiting somewhere along the roads. Similarly, they are also more likely to report inability to travel in or out of their neighborhoods, road erosion and damage to roads. Likely, their experiences are shaped by more time spent on the roads and longer distances travelled. There are no significant differences in the type and magnitude of mobility disruptions according to travel frequency, except on damage to vehicles.

There is surprisingly little variation between vehicle owners and those relying primarily on public transport. A slightly lower share of vehicle owners compared to non-vehicle owners have experienced waiting somewhere along the road for the rain to stop or water to recede. This may reflect that private vehicles are better able to navigate rough road conditions than the ramshackle minibuses providing public transport in Accra or that vehicle owners are better able to flexibly adjust travel plans and avoid travelling during heavy precipitation. The latter interpretation is supported by the higher share of vehicle owners reporting that they have rushed to pick up children from school before the rains. Vehicle owners are also more likely to report damage to roads than non-vehicle owners. This may reflect that vehicle owners take more notice and attach more significance to road conditions because they are driving themselves. Unsurprisingly, vehicle owners are also more likely to report damage to vehicles.

3.4. Mobility Disruptions across Traveler Characteristics

Mobility disruptions are extremely common across travelers, irrespective of gender, age and educational level. Surprisingly, there are no significant differences in the type and magnitude of mobility disruptions reported by male and female respondents, except for a higher share of male respondents reporting damage to vehicles, which may be explained by the significantly higher share of male vehicle owners ($p < 0.001$).

There are few significant differences on mobility disruptions reported by different age groups. Elderly respondents above 60 years are less likely to report that roads were too

difficult or dangerous to travel. Possibly, the seniors included in the survey are not frail of health, due to the survey targeting economically active people travelling regularly. There is also a tendency for those over 60 years to be less likely to report that neighborhood roads became unpassable. Respondents above 60 years have resided in their neighborhoods for an average of 19 years, compared to 9.8 years for those aged 30–60 and 8 years for those below 30 (F -statistic = 38.332, $p < 0.001$). As such, people over 60 years have a longer time perspective on settlement development and may compare current conditions with (much worse) past conditions.

There is a tendency for respondents with higher education levels to be less affected by mobility disruptions. A smaller share of respondents with secondary or tertiary education experienced inability to travel in or out of their neighborhoods. Those with tertiary education are more likely to report road erosion and damage to vehicles, though this is likely because they are also more likely to own vehicles ($p < 0.001$). Respondents with only primary school or no education are more likely to report prolonged travel times due to congestion and waiting somewhere along the road for the rain to stop. This may reflect differences in travelers' ability to afford alternative means of transportation or the flexibility allowed by different livelihoods activities and jobs to adjust travel patterns to avoid travelling during heavy precipitation events.

3.5. Implications for Livelihoods and Access to Markets and Services

The results suggest that mobility disruptions caused by heavy precipitation have implications for livelihoods and access to markets and services. The survey provides no direct measure of lost workdays, but the high level of livelihood-related mobility among adults suggests that mobility disruptions have adverse impacts on livelihoods and incomes. The vast majority of all adults (83.2%), including both main respondents and other adult household members, travel outside their neighborhoods for income-generating activities at least once a week, with the majority (59.5%) travelling 5–7 times a week. The general prolonging of travel times due to heavy precipitation may encroach on work time, as workers arrive late or leave early to account for delays and congestion. Inability to travel likely means loss of income, especially for the many self-employed and casual workers (52% of all adults), whose incomes are often critically dependent on being able to actually go to work.

Mobility disruptions associated with heavy precipitation restrain access to markets and health and education services, cf. Table 4. Within the past year, 26.1% of main respondents have experienced being unable to procure supplies for a business from bulk goods markets in central Accra, while 26.5% have experienced being unable to purchase food or household necessities due to heavy precipitation. A third of children (33.5%) in the surveyed households attend school outside their neighborhood. A significant share (11.2%) of all adults travel outside their neighborhood at least once a week to pick or drop children at school. Many adults (6.4%) also travel outside their neighborhood for educational purposes at least once a week. Within the past year, 40% of respondents with children in the household report that children have lost one or more school days due to heavy precipitation. This has implications for adult caregivers; approximately 30% indicate that adult household members had to stay home to take care of children. Many adults also travel several times a month to access hospitals and health clinics (15.6%), with 9.7% having experienced being unable to access health services due to heavy precipitation.

Table 4. Implications for access to markets and health and education services.

Indicators *	Inability to Purchase Food or Necessities Outside Neighborhood	Inability to Procure Supplies from Bulk Goods Markets in Central Accra	Inability to Access Health Services Outside Neighborhood (i.e., Hospitals or Health Clinics)	School-Going Children in the Household Missed One or More School Day(s) **	Adult Household Members Had to Stay Home to Watch Children **
Santa Maria	28.4	27.5	12.8	24.2	18.2
Kwashiebu	27.7	25.7	7.9	41.7	36.7
Antiaku	20.4	22.7	9.2	35.1	29.8
Glefe	19.8	22.5	7.2	40.7	34.5
Frafraha	44.8	32.1	13.2	38.0	33.8
New Legon	44.0	37.6	10.9	47.6	33.3
New Legon Hills	43.1	33.7	16.7	69.1	51.5
Ampax/River Estate	11.1	27.0	6.9	46.4	31.9
Pokuase Old Village	13.2	23.6	7.5	27.9	21.0
Windy Hills	12.5	9.3	4.7	21.6	10.8
Total	26.5	26.1	9.7	39.2	30.2

* Binary variables indicating the share of main respondents ($n = 1053$), who report that mobility disruptions caused by heavy precipitation have constrained household members' access to markets and health and education services. ** Share of main respondents computed only for those with one or more children in their household ($n = 701$).

4. Discussion

The results highlight that mobility disruptions caused by heavy precipitation are an extremely commonplace experience for most urbanites in Accra's periphery, across neighborhoods, travel patterns and traveler characteristics. A striking finding, is that the inability to travel into or out of—and the effective insulation—of peripheral neighborhoods is such a widespread occurrence, reported by over half of respondents and across a diverse collection of peripheral neighborhoods. Mobility disruptions caused by heavy precipitation are widely reported by respondents in all neighborhoods covered by the survey, irrespective of stage of consolidation, geophysical characteristics and proximity to main roads. Very likely, mobility disruptions are equally prevalent in many other neighborhoods in Accra's periphery.

While the survey data illuminates the diversity of mobility disruptions experienced by Accra's residents, the subjective nature of the data is a limitation. The results suggest that heavy precipitation events likely reduce overall travel activity, but the nature of the data does not allow for estimation of how much overall travel activity is reduced nor whether overall travel activity is in fact reduced or merely rearranged in time. Further, the nature of the data does not allow for an assessment of the magnitude of heavy precipitation events, which may cause significant mobility disruptions. Insights from key informant interviews suggest that experienced mobility disruptions are not necessarily caused by precipitation events that are particularly "extreme" in magnitude. In fact, "every time it rains" was a common response from key informants when asked how often heavy precipitation events affect roads and mobility patterns of residents in their neighborhood. While this notion is likely not accurate in a strictly empirical sense, it captures well the widespread perception of mobility disruptions as inevitable, inescapable and widely anticipated in relation to heavy precipitation events.

The crude nature of the variables recording mobility disruptions is another limitation of the research. The results suggest that mobility disruptions are rather 'democratic' in nature, in the sense that the experienced disruptions are only to a limited extent differentiated according to individual characteristics of travelers. This is surprising given the vast scientific literature highlighting mobility constraints associated with gender [55–58], age [59,60] and socio-economic status [61–64]. However, this is likely explained by the crude nature of the variables applied in the survey, with most recording whether or not a respondent has experienced a particular disruption within the past year. Very likely, mobility disruptions are experienced differently for salaried employees receiving regular paychecks and self-employed or casual workers, who need to be physically present in a

workplace to earn a daily income. More in-depth research is needed to investigate the issue of gendered or socially differentiated impacts of heavy precipitation events on daily mobility and livelihoods.

An important insight emerging from the research is that mobility disruptions are likely aggravated by the insufficient and even fragile nature of transport infrastructure in peripheral neighborhoods. The nature of the data material does not allow for a systematic assessment of the conditions of local transport infrastructure based on objective criteria. However, across a diverse collection of neighborhoods, local key informants emphasize that heavy precipitation is routinely associated with submersion of road segments and interior access roads transforming to slough. Field observations reveal that roadside drainage is limited or even non-existent in most neighborhoods. Local key informants report that roads commonly channel significant volumes of surface runoff during heavy precipitation events. The severe road erosion reported by respondents across all neighborhoods is both an impact of heavy precipitation as well as a factor, which likely aggravates the impacts of heavy precipitation events on mobility. The fragile nature of interior roads means that even small precipitation events can potentially make certain road segments difficult or dangerous to travel. The ways in which heavy precipitation events impact interior access roads appear to be highly localized and dependent on a variety of factors, such as the nature of the terrain, the conditions of interior access road, the quality of road engineering work, the extent of roadside drainage, lack of maintenance and the extent of housing development close to water bodies [48]. The interconnections between road conditions and impacts of heavy precipitation is an important avenue for further research.

The implication for policy and planning is that significant investments are needed in improvement and flood-proofing of local neighborhood roads in peripheral areas in order to make the transport system more resilient to extreme weather events. This includes measures, such as hardy road surface materials, comprehensive roadside drainage, increasing road heights in low-lying areas and appropriate dimensioning of bridges and culverts where roads intersect with streams. Appropriate measures depend on local circumstances, including geophysical characteristics and the conditions of existing infrastructure, road engineering work and degree of maintenance. According to local informants, undersized and poorly constructed bridges and culverts are a contributing factor causing inundation of road segments. Therefore, it is crucial that investments in transport infrastructure account for pressure and abrasion from heavy precipitation events, which are anticipated to become even more frequent and intense in the future in the West African region [54].

Another relevant insight for transport planners, is that mobility disruptions caused by heavy precipitation are likely worsened by the limited connectivity and general lack of redundancy in the road network. Key informants in many of the neighborhoods highlight that there are few alternative route choices, when important access roads are inundated or otherwise affected by water. The general prolonging of travel times reported by respondents is likely also related to delays and congestion affecting the whole network during heavy precipitation events; as such mobility disruptions cannot be understood separately from deficiencies in the overall transport network.

5. Conclusions

Research on urban transport and climate change in the context of the Global South is much preoccupied with the contribution of urban transport sectors to climate change. The reverse enquiry; how urban transport systems are affected by extreme weather events—likely to be exacerbated by climate change—has so far received limited attention (notable exceptions include [4,5,24–27]). We contribute to this scarce literature with a study of the mobility disruptions experienced by urban residents in relation to heavy precipitation events and ensuing flooding of roads, drawing on a large mobility survey ($n = 1053$) conducted in 2021 with economically active adults residing in 10 selected neighborhoods in the periphery of Accra, Ghana.

The results illuminate the diversity of mobility disruptions associated with heavy precipitation and the adverse implications for livelihoods and access to markets and services. Mobility disruptions caused by heavy precipitation are a very common experience for residents in Accra's periphery, across neighborhoods, travel patterns and traveler characteristics. While existing research tends to privilege the most dramatic and disastrous flood events and the associated destruction of property, this research highlights the more mundane, every day and widely normalized mobility disruptions associated with heavy precipitation. Mobility disruptions are arguably less dramatic and disastrous than those associated with inundation of residential areas, but they affect a much larger share of the urban population, including many urbanites living far away from flood prone locations. Mobility disruptions interfere not only with the daily lives and livelihoods of travelers, there are likely adverse implications for the urban economy, when workers and business owners are regularly stuck at home or on the roadside. There might be adverse implications for the national economy, as a significant share of Ghana's GDP is produced within Accra [53].

It is beyond the scope of this paper to ascertain whether the widespread mobility disruptions experienced by Accra's residents during and after heavy precipitation events may be attributed to climate change. Accra has a long history of recurrent flood hazards and a range of factors contribute to intensify flood hazards, including unregulated urban expansion, lack of land-use planning, harmful construction practices and encroachment on water bodies [48]. However, it is fair to assume that the increasing intensity and frequency of extreme weather events anticipated for the West African region in IPCC projections [54] will aggravate flood hazards in the future and cause widespread disruptions to mobility, if measures are not taken to make Accra's transport system more resilient towards heavy precipitation events. Insights from the research will likely have relevance for many other cities in Africa facing a similar combination of challenges of rapid urban growth, unregulated urban expansion processes, insufficient, fragile infrastructure and recurrent flood hazards, likely to be exacerbated by climate change. Overall, the research highlights the critical role of transport infrastructure in relation to climate change resilience and calls for integration of resilience perspectives in urban transport planning.

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