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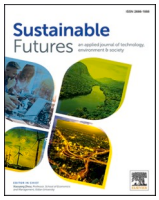

Assessing local community perspectives on climate change and variability: Implications for unpaved secondary roads in Sierra Leone

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ABSTRACT

Climate change presents significant challenges to infrastructure and livelihoods, particularly in highly climate-sensitive regions such as Sierra Leone. Although Sierra Leone is widely recognized as vulnerable, limited research has examined local community perceptions of climate variability and its effects on infrastructure. This study explored community perspectives on climate change and its impacts on unpaved roads in Sierra Leone. It examined how communities perceive and experience climate change, how these changes affect unpaved roads that connect livelihood hubs, and which local anthropogenic activities exacerbate these effects. Using a cross-sectional design, data were collected from 430 participants across four districts in Sierra Leone through questionnaires, group discussions, and informant interviews. This mixed-methods approach enabled triangulation of findings and facilitated comprehensive documentation of community experiences, although the cross-sectional nature limited temporal analysis and causal inference. Communities reported increasingly frequent and intense weather events, including heavy rainfall, rising temperatures, windstorms, and droughts, as significantly affecting daily life. Climate change and variability were reported to degrade unpaved roads, cause erosion, washouts, and potholes, and disrupt access to markets, healthcare, schools, etc.,. In addition, local activities such as inadequate drainage management, deforestation, and inappropriate land use were perceived to intensify soil erosion and sedimentation. These findings provide new insight into community perceptions of climate-related impacts on unpaved roads in Sierra Leone and support climate-resilient infrastructure planning and adaptation through community engagement and policy interventions aligned with SDGs 9 and 13, promoting sustainable and inclusive development.

1. Introduction

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) identifies greenhouse gas emissions from human activity as the primary driver of unprecedented changes in the global climate (Intergovernmental Panel on Climate Change [IPCC], 2014). This phenomenon, termed climate change, has emerged over recent decades as a significant threat to human survival on the surface of the Earth [1]. Climate change, accompanied by extreme weather events, profoundly affects every socioeconomic sector essential for human well-being [2]. Increasing temperatures; erratic rainfall patterns marked by extreme events such as floods and droughts; rising frequency of severe windstorms; sea-level rise; and other related phenomena impact life-supporting sectors, including agriculture, water resources, infrastructure, and natural resources [2]. Schweikert et al. [3] emphasized that in low-income rural areas, roads are vital for economic activity, agriculture, and access to critical services such as healthcare and education. Due to their sparse distribution, each road is indispensable yet highly vulnerable to extreme weather, which accelerates deterioration, raises maintenance costs, and shortens lifespan [3]. Increased temperatures, intensified rainfall, and extreme conditions such as floods or storms exacerbate pavement degradation, cause erosion, and damage road foundations [4].

Like other developing countries, Sierra Leone is confronting significant impacts from climate change. In 2017, it ranked as the third most vulnerable country to climate change after Bangladesh and Guinea-

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Bissau (African Development Bank [5], 2018). Scientific literature reports notable climate variability accompanied by extremes in Sierra Leone. For example, the USAID (2017) report indicates that the average annual temperature has increased by +0.8 °C since 1960. Solomon et al. [6] examined the current and future climatic conditions of the country from 1975 to 2018 using six environmental indices (maximum and minimum temperature, precipitation, relative humidity, wind speed, and solar radiation). Their findings revealed significant climate changes over the study period, attributed to socioeconomic and anthropogenic factors such as population growth, deforestation, and unsustainable agricultural practices resulting in vegetation loss. Similarly, the United Nations [7] report ranks Sierra Leone among the top ten most sensitive countries globally to climate change effects (International Monetary Fund [IMF], 2024). Yila *et al.* [8] reported that the valuable ecosystems of the country are projected to suffer substantial impacts from climate change, including increased extreme weather events such as high winds, storm surges, and flash floods accompanied by landslides. Furthermore, projections indicate that by 2060, mean temperature will increase by 1–2.5 °C, and single rainfall events will become considerably more intense and frequent toward mid- and late-century [9–11]. These trends raise serious concerns due to their potential adverse effects on socioeconomic sectors, including transportation infrastructure (United Nations Development Programme [12], 2021).

Understanding the experiences and indigenous knowledge (IK) of local communities about climate variability can substantially inform climate change policy [13]. Researchers assert that such knowledge enables decision-makers to identify effective adaptation and mitigation strategies to improve resilience [14]. For instance, a study in Moyamba district, Sierra Leone, combined farmers' perceptions with climatic data analysis to reveal significant changes in rainfall and temperature, underscoring the need for policy measures supporting climate-resilient agriculture and capacity building for farmers and extension workers [8]. In the Bobiri forest reserve, Ghana, local community insights alongside satellite imagery and climate data showed alignment between perceived rainfall and temperature changes and observed land cover transformation, informing policies for sustainable forest management and alternative livelihoods [15]. A systematic review highlighted the crucial role of IK in climate adaptation, as indigenous communities employ their knowledge to predict, prepare for, and respond to extreme climatic conditions, underscoring the importance of integrating IK with scientific research for effective policy formulation and sustainable development [16].

The Government of Sierra Leone (GoSL), aiming to enhance resilience in socioeconomic sectors for sustainable development, has developed several policy documents addressing climate change and adaptation, including the National Adaptation Plan and Nationally Determined Contributions (NDC). Although some research has informed these policies, studies emphasizing the value of information, particularly the application of IK to address community challenges, remain limited [17]. Incorporating local perspectives and knowledge on climate change is essential for guiding mitigation and adaptation efforts, especially in data-constrained countries like Sierra Leone where long-term instrumental meteorological records are insufficient for comprehensive trend analysis [18,19].

The perspectives of local individuals, who directly experience the impacts of climate variability, are critical to bridging gaps between general perceptions and quantitative climate trends documented by physical scientists [18]. Such information is difficult to obtain from general circulation models (GCMs) or regional climate models (RCMs), which primarily measure global or regional climate patterns [20]. The authors have assessed historical and projected changes in climatic variables and their implications for unpaved roads in Sierra Leone, analyzing three decades of instrumental meteorological data from four regions. Findings demonstrate significant climate change and variability with associated impacts on socioeconomic sectors, particularly road infrastructure, where unpaved roads exhibit inherent vulnerability to climate effects.

Despite increasing evidence of Sierra Leone road infrastructure vulnerability to climate change impacts—such as rising temperatures, erratic rainfall, and extreme weather events—localized community insights and perceptions remain insufficiently integrated into climate adaptation planning. This lack of integration limits the development of effective, context-specific resilience strategies for road infrastructure, particularly unpaved roads across the country. This study addresses this gap by investigating local perceptions of climate change and variability and their impacts on unpaved roads across the four regions of Sierra Leone. These perceptions can be incorporated with instrumental meteorological data to inform policy interventions and resilience strategies for unpaved roads. The study objectives are as follows: (i) to explore how communities have experienced and perceived climate change and variability in local contexts over recent decades; (ii) to examine the impacts of climate change and variability on unpaved roads that connect livelihood hubs in these communities; and (iii) to evaluate the perceived role of human activities in exacerbating the effects of climate change and variability on unpaved roads in local communities of Sierra Leone.

1.1. Overview of the road network in Sierra Leone

The road subsector is one of the priority areas identified by the government of Sierra Leone under its economic diversification program aimed at poverty reduction. Roads serve as the primary mode of transport for goods, people, and services. According to a World Bank report, Sierra Leone has a total road network of approximately 11,300 km, of which only around 17.6 % are paved, mainly consisting of primary roads [21]. Data from the Sierra Leone Roads Agency indicate that approximately 4044 km constitute the maintainable core road network (CRN), which includes both primary and secondary roads as defined in the Sierra Leone National Roads Agency classification. Of this CRN, only about 40 % is paved, with the remaining 60 % unpaved. Among the unpaved roads, more than 96 % are secondary roads (Class B), which receive limited investment from donor partners despite their critical role in the country's socioeconomic development. In addition, there are 4152 km of feeder roads that primarily serve remote communities, all of which are unpaved. The urban and township road network spans 3104 km, of which only 2.67 % (80 km) are paved. These secondary roads typically function as feeders to Class A roads, connecting district headquarters towns, economic hubs and supporting long-distance travel with relatively high traffic volumes, although lower than those of Class A roads. Table 1 provides a summary of the classified road network in Sierra Leone.

As shown in Table 1, unpaved secondary roads constituting the core road network in Sierra Leone total 1904 km, of which only 54.4 km are paved, while 1849.46 km remain unpaved. An internal assessment by the Sierra Leone Roads Authority (SLRA) indicates the distribution of these roads as follows: 31.06 % in the Northern Province, 24.61 % in the Southern Province, 35.88 % in the Eastern Province, and 8.46 % in the Western Area. These roads often degrade into impassable, muddy, or eroded tracks due to climate change impacts, severe monsoon rains, and economic challenges [22]. Such factors cause recurring geohazards, including floods, landslides, and erosion, which severely restrict access to essential services and exacerbate local hardships [8]. Researchers attribute the increased impacts of climate change and variability in Sierra Leone to anthropogenic activities, such as deforestation from logging, unsustainable agriculture, mining, and fossil fuel (charcoal) extraction [10]. These activities frequently cause flooding and inundation of road infrastructure, occasionally resulting in washouts of road components and sections becoming impassable (IPCC, 2018). Keller et al. [23] and Steenbergen et al. [24] highlight that these challenges drive up road maintenance costs and place severe strain on infrastructure not designed to withstand such extremes.

Road agency reports in Sierra Leone emphasize inconsistent maintenance due to funding delays and increased heavy vehicle usage

Table 1
Classification of the road network in Sierra Leone.

An overview of Nartional Road Network			
Category	**Total (km)**	**Paved (km)**	**Unpaved (km)**
Primary (Class A) Roads	2,140	1,698.4	441.6
Secondary (Class B) Road	1,904	54.54	1,849.46
Urban/City Roads	3,104	236.8	2,867.2
Feeder (Class F) Roads/Tertiary Roads	4,152	0	4,152
Total	**11,300**	**1,989.74**	**9,310.26**

Source: Author's construct (2024).

Source: Author's construct (2024).

without axle load control, exacerbating climate change and variability impacts on the socioeconomic well-being of the country. These conditions underscore the importance of research, especially in areas where local populations have directly experienced climate change effects in their communities. According to World Bank [11], the climate in Sierra Leone is projected to continue changing, along with increasing extremes, with negative consequences for social structures and substantial impacts on the road infrastructure, particularly unpaved roads, which are highly vulnerable to climate variables [25,26].

The escalating impacts of climate change and variability, driven by anthropogenic activities, have led to unplanned flooding, road washouts, increased dust during the dry season, potholes, rutting, and other severe maintenance challenges, especially for unpaved roads. Infrastructure struggles to withstand these extremes, compounded by inconsistent maintenance and funding delays. The lack of research on indigenous perspectives of climate change highlights the urgent need for studies to understand how directly affected local communities perceive and adapt to environmental changes, ultimately informing more sustainable infrastructure solutions.

IPCC reports identify developing countries, particularly in sub-Saharan Africa, as among the most vulnerable to climate change impacts due to limited adaptive capacity and fragile infrastructure [9]. In Sierra Leone, where unpaved roads dominate the transport infrastructure and provide critical access to markets, healthcare, and education, projected increases in extreme weather events such as intense rainfall, rising temperatures, and windstorms pose significant threats [11]. These climate stressors accelerate unpaved road deterioration, disrupt connectivity, and hinder socioeconomic development, emphasizing the urgency of integrating climate resilience into rural road infrastructure planning and policy [25].

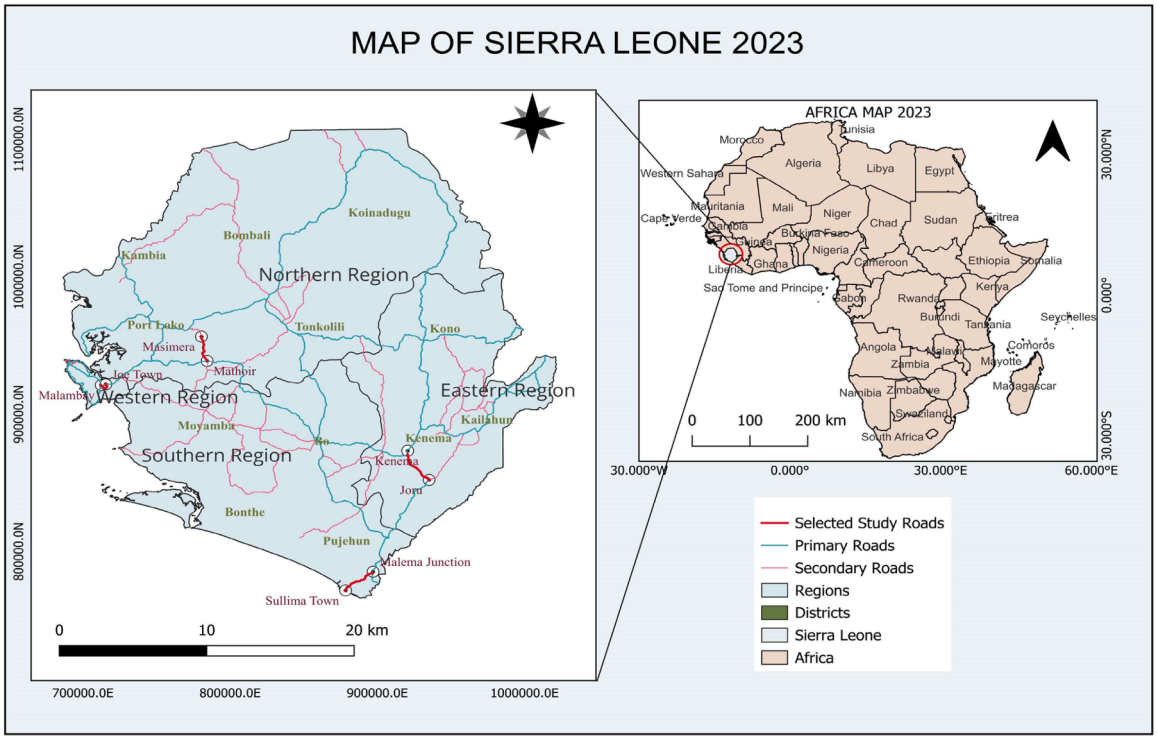

Fig. 1. Map of Sierra Leone and its geographical boundaries.

2. Materials and methods

2.1. Description of the study area

This study focuses on Sierra Leone, located along the west coast of Africa, characterized by a monsoon-type tropical climate. It shares borders with Guinea to the north and east, Liberia to the south, and the Atlantic Ocean to the west (Fig. 1). Sierra Leone comprises four primary geographic zones: interior plains, plateau and mountain regions, coastal marshes, and the Sierra Leone Peninsula. The country's topography varies significantly by region. The coastal marsh region extends approximately 320 km along the Atlantic Ocean (Comité Permanent Inter-états de Lutte contre la Sécheresse dans le Sahel [[27]S], 2016). This low-lying plain, 8 to 40 km wide, is prone to regular flooding and is predominantly composed of sand and clay soils (Comité Permanent Inter-états de Lutte contre la Sécheresse dans le Sahel [[27]S], 2016). The Sierra Leone Peninsula, which includes the capital city, Freetown, features a forested mountain range that runs 40 km parallel to the coast. The Peninsula Mountains rise sharply from coastal wetlands, reaching up to 880 m at their highest point, Picket Hill. Inland from the coast, the interior plains feature the Bolilands in the north—seasonal marshes that flood during the rainy season and dry out during the dry season. The southern lowlands are characterized by gently rolling, forested terrain interspersed with occasional hills exceeding 300 m in elevation (Comité Permanent Inter-états de Lutte contre la Sécheresse dans le Sahel [[27]S], 2016). Fig. 1 below shows the study area of this research.

The climate of Sierra Leone is tropical, with alternating wet and dry seasons, and is generally warm and humid. The rainy season typically begins in May and ends in September, though it can extend beyond five months. During this period, average temperatures range between 22 and 25 °C. The dry season lasts from October to April, with average temperatures between 25 and 27 °C. The climate is more extreme in the north. The Peninsula Mountains receive more than 5000 mm of precipitation annually, while the northeast receives approximately 2000 mm, indicating higher rainfall along the coast compared to the interior. Both seasons can contribute to severe weather-related disasters, increasingly driven by extreme weather events in recent years (Comité Permanent Inter-états de Lutte contre la Sécheresse dans le Sahel [[27]S], 2016).

Sierra Leone is divided into four regions—Eastern, Northern, Southern, and Western—each with distinct socioeconomic characteristics, particularly in relation to road infrastructure, which significantly affects access to social services and economic development [21]. The Eastern Region (including Kailahun, Kenema, and Kono) is rich in diamonds and agriculture. However, poor road conditions, especially during the rainy season, limit access to markets, education, and healthcare, thereby increasing costs and constraining economic growth. Improving roads could enhance trade and livelihoods. The Northern Region (including Bombali, Kambia, Koinadugu, and Tonkolili) is primarily agricultural—producing rice, cassava, and groundnuts—and also hosts iron ore mining. While major highways are relatively well-developed, rural roads are often unpaved and rapidly deteriorate, hindering access to remote areas. Road improvements could bolster agricultural productivity, reduce transport costs, and support mining and regional trade. The Southern Region (including Bo, Bonthe, Moyamba, and Pujehun) is agriculturally rich, particularly in cocoa, coffee, and oil palm. Fishing is also prominent in Bonthe. Although Bo has comparatively better road connectivity, other districts experience poor, unpaved roads—especially during the rainy season—limiting access to services, raising transport costs, and constraining economic opportunities. The Western Region, which includes Freetown, is the most urbanized and economically developed, with well-maintained urban roads. However, rapid urbanization has led to congestion and infrastructure deterioration. Rural areas continue to face significant road access challenges. Improving rural roads in this region could support tourism, agriculture, and fishing, thereby contributing to economic growth.

2.2. Research philosophy, design, sampling procedure, and data collection

The study examined climate change and variability and their potential impacts on road transport infrastructure, with particular reference to unpaved roads in the selected communities. It aimed to identify prevalent climate factors, assess community perceptions of climate change and variability, determine contributing factors, explore the implications for unpaved roads, and evaluate adaptive features to inform mitigation strategies.

2.2.1. Research design

A cross-sectional research design was employed to obtain information from communities in the study areas at a single point in time, offering a snapshot of their perceptions during data collection [14,28,]. This approach provides detailed insights into specific phenomena and enables decision-makers to formulate informed strategies based on current conditions. It is widely used in studies of climate change and extreme weather events. For instance, Obsi et al. [29] applied a cross-sectional design to examine determinants and barriers to climate adaptation in farming communities in southwestern Ethiopia. They found that access to extension services and climate information influenced adaptation decisions, whereas limited irrigation, high input costs, and infertile soils were key barriers. Mendelsohn and Massetti [30] highlighted the utility of cross-sectional analysis in assessing climate impacts on agriculture, noting its effectiveness in evaluating productivity outcomes. This study adopted a cross-sectional design, combining a household survey with structured questionnaires and interviews. Both quantitative and qualitative data were collected to assess local perspectives on climate change and its implications for unpaved secondary roads in Sierra Leone. Self-reports in cross-sectional studies are prone to biases that may affect data reliability [31]. These include recall bias, social desirability bias, and response tendencies such as acquiescence or central tendency bias [32]. Additionally, inaccuracies in self-perception and contextual factors such as mood or setting can distort responses [32]. To address these limitations, this study employed neutrally worded questions, guaranteed respondent anonymity, conducted pilot testing to identify ambiguous items, and triangulated self-reported data with observational or objective measures where feasible.

2.2.2. Sampling procedure

A multi-stage sampling approach was used to enhance data coverage. Purposeful sampling was employed to select respondents based on their relevance and knowledge, ensuring data richness but introducing limitations in representativeness and the potential for selection bias. To address this, broader multi-stage methods were integrated to include diverse stakeholders across locations. Clear inclusion criteria and triangulation of sources were applied to strengthen the credibility of findings. In the first phase, four study districts Port Loko, Pujehun, Kenema, and Western Rural were selected out of fourteen, based on prior research and climate variability analyses [14]. Each district represents one of Sierra Leone's geographic regions and was selected for its high climate variability coefficients and significant trends in Mann-Kendall tests, indicating heightened sensitivity to change. This approach focused on worst-case scenarios to enhance policy relevance and ensure representation from high-priority regions.

The second phase involved selecting communities within each district. Due to spatial, logistical, and financial constraints, two communities were purposefully chosen per district: Koya and Masimera (Port Loko), Barrie and Soro Gbema (Pujehun), Dama and Gaura (Kenema), and Koya Rural and Waterloo Rural (Western Rural). The questionnaire focused on six themes in addition to socio-demographic characteristics: perceptions of climate variability, contributing factors, perceived impacts on unpaved roads, adaptive capacities of unpaved roads, and barriers to adaptation in Sierra Leone. Focus group discussions (FGD)

and key informant interviews (KII) explored three main themes: (i) perceptions of climate change and variability, (ii) environmental impacts with emphasis on unpaved roads, and (iii) the role of human activities in exacerbating these impacts. Using the Cochran formula for finite populations [33],

$$n = N/1 + N(\alpha^2) \quad (1)$$

to derive the sample size, where 'n' = sample size, 'N' = total population for all the communities calculated to be 538,206 and 'α' = the precision level, which was set at 5 %, we had $n = 399.7 \approx 400$. From this total sample size, we aggregated them based on the population size of each district (2 communities). This gives the Northern Region (Port Loko district) a sample size of $n = 94$, the Southern Region (Pujehun district) a sample size of $n = 59$, the Eastern Region (Kenema district) a sample size of $n = 36$, and the Western Region (western Rural district) a sample size of $n = 211$. The survey questions were designed for household heads in each community and key stakeholders such as local council staff who had stayed in those districts for a long time, other stakeholders including agriculturists, environmentalists, and non-governmental organization personnel with adequate knowledge of the terrain and climatic variability within the locality were considered for interviews and discussions.

2.2.2.1. Questionnaire interviews. The questionnaire targeted 400 respondents from the most vulnerable district in each region. As part of a community participatory approach, intermittent FGD were conducted across the four regions of the country. The research engaged household heads, farmers, rural community members, local traders, road managers, women, youth, community leaders, NGOs, government officials, climate change experts, and agricultural extension workers to capture perceptions of climate variability, its impacts on unpaved roads, and local adaptation strategies in Sierra Leone. This approach aligns with similar perception studies on climate change and variability, including Baffour-Ata et al. [15] and Baffour-Ata et al. [34]. The information generated through these efforts is critical for informing policy development and supporting decision-making processes [35]. A comprehensive key informant interview approach was adopted to gather insights from individuals with contextual knowledge of shifting climatic conditions and the extent of variability observed over recent decades. These interviews provided region-specific insights on climatic trends and offered further understanding of the effects on unpaved secondary roads and anticipated future impacts. The findings can inform policy considerations relevant to the road sector, local communities, and institutional stakeholders [36].

2.2.2.2. Focus group discussions (FGD) and key informant interview (KII). The sampling strategy involved organizing eight focus groups—two per region—comprising six participants per group, selected to reflect diversity in gender, age, education, occupation, and income. Participants included farmers, traditional leaders, youth groups, local councils, NGOs, and community-based organizations. Each focus group discussion, lasting approximately 1 h, explored local experiences of climate change and variability, as well as perceived impacts on unpaved roads. Balanced gender representation was maintained to ensure inclusive perspectives. Respondents who demonstrated a strong understanding of climatic changes during the FGD and questionnaire phase such as increased rainfall, severe storms, droughts, and human-induced pressures on road infrastructure were selected for 45-minute KII. Five individuals per community, including decision-makers and community representatives, participated in these interviews. All discussions were recorded, transcribed, and anonymized using pseudonyms.

2.2.3. Data collection

This study employed multiple data collection methods to obtain information from the four geographic regions of Sierra Leone. These included structured questionnaires, interview schedules, and FGDs [37]. Qualitative data were collected through interviews, desk-based research, and FGDs, each comprising six to eight participants selected using a combination of stratified random sampling and purposive sampling techniques [37]. A structured questionnaire was used to address six core themes: socio-demographic characteristics, perceptions of climate variability and extremes, perceived contributing factors, impacts on unpaved roads, adaptation measures, and barriers to coping strategies. The questionnaire offered a practical, standardized, and cost-effective instrument for climate change perception studies, supporting consistent and reliable data collection while enabling thematic analysis to synthesize key insights from participant narratives [38]. FGDs were conducted following ethics approval from the Committee on Human Research Publication and Ethics at KNUST, Kumasi, Ghana, and written informed consent was obtained from all participants. Each group consisted of six to eight participants, including at least one woman. Discussions were organized among individuals with similar backgrounds, facilitated by an experienced moderator, and recorded with participant consent to ensure accuracy. These sessions provided in-depth insights into participant perspectives [39].

To improve efficiency and data integrity, the study utilized the KoBoToolbox data collection platform, an open-source software, in combination with Android-based devices [40]. KoBoToolbox includes a flexible form builder that supports questionnaire creation, validation, and reuse, enabling both online and offline data collection through the KoBoCollect mobile app or Enketo web interface [40]. The platform's integrated features for data management, analysis, and visualization—such as summary reports, mapping, and export functions—further streamlined field activities and facilitated the generation of accessible outputs [41]. These tools were selected for their capacity to capture detailed local insights and maintain data quality under the logistical constraints of remote field environments. For this study, KoBoCollect v1.23.3k was used for mobile data collection, while the online KoBoToolbox form designer was used to develop the survey instruments. Data collected by field teams were uploaded in real time to the central server by the study team based outside the field location.

3. Data analysis of the questionnaire

Data from the survey were analyzed using both quantitative and qualitative methods. Quantitative data were processed using the Statistical Package for the Social Sciences (SPSS), version 26. Frequency distribution tables and descriptive statistics, including frequencies and percentages, were generated for all quantitative variables [34]. To assess the reliability of the data collection instrument, internal consistency was evaluated using Cronbach's alpha, with a threshold of ≥ 0.70 indicating acceptable reliability [42]. Validity was examined through content validation by expert review and construct validity using exploratory factor analysis. Qualitative data from FGD and KII were analyzed thematically using both inductive and deductive approaches in an iterative process. Initial codes were grouped into preliminary themes aligned with six key areas of inquiry. These themes were refined through discussion during multiple research team sessions [43]. As understanding of the data developed, re-coding was conducted, and further refinement occurred through in-depth questioning in subsequent data collection rounds [43]. To enhance transparency and rigor, facilitators and analysts maintained audit logs and reflexive memos throughout the analysis [44]. Findings were reviewed in several group discussions involving members of the study team.

4. Results and discussion

Table 2 presents the socio-demographic characteristics of respondents across the four regions of Sierra Leone.

The results of the socio-demographic survey indicate that respondents were distributed across the four geographic regions of Sierra

Table 2
Socio-demographic characteristics of respondents.

Variables	Northern Region (Total = 105)	Southern Region (Total = 64)	Eastern Region (Total = 50)	Western Region (Total = 211)
Sex				
Male	59 (56.2)	35 (54.7)	28 (56)	129 (61.1)
Female	46 (43.8)	29 (45.3)	18 (36)	82 (38.9)
Age (years)				
20–30	18 (17.1)	8 (12.5)	5 (10)	9 (4.3)
31–40	18 (17.1)	11 (17.2)	15 (30)	46 (21.8)
41–50	27 (25.7)	15 (23.4)	11 (22)	71 (33.6)
51–60	23 (21.9)	16 (25)	10 (20)	57 (27)
>61	19 (18.1)	14 (21.9)	5 (10)	28 (13.3)
Marital status				
Single	9 (8.6)	5 (7.8)	3 (6)	21 (10)
Married	84 (80)	48 (75)	33 (66)	135 (64)
Divorce/separated	3 (2.9)	3 (4.7)	1 (2)	28 (13.3)
Widowed	9 (8.6)	8 (12.5)	9 (18)	27 (12.8)
Education level				
Non-formal education	53 (50.5)	30 (46.9)	17 (34)	31 (14.7)
Basic education	29 (27.6)	18 (28.1)	19 (38)	58 (27.5)
Secondary/technical	16 (15.2)	13 (20.3)	8 (16)	61 (28.9)
Tertiary/university	7 (6.7)	3 (4.7)	2 (4)	61 (28.9)
Occupation				
Farmer	63 (60)	30 (46.9)	28 (56)	5 (2.4)
Driver	1 (1)	5 (7.8)	3 (6)	26 (12.3)
Trader	25 (23.8)	12 (18.8)	7 (14)	69 (32.7)
Teacher	8 (7.6)	1 (1.6)	1 (2)	20 (9.5)
NGO Staff	0 (0)	0 (0)	1 (2)	21 (10)
Local council staff	0 (0)	0 (0)	0 (0)	24 (11.4)
Other	8 (7.6)	16 (25)	6 (12)	46 (21.8)
Years in community				
<10	11 (10.5)	4 (6.3)	5 (10)	31 (14.7)
10–20	8 (7.6)	11 (17.2)	9 (18)	49 (23.2)
21–30	24 (22.9)	18 (28.1)	11 (22)	65 (30.8)
31–40	22 (21)	14 (21.9)	7 (14)	42 (19.9)
>41	40 (38.1)	17 (26.6)	14 (28)	24 (11.4)
Income level				
Less than NLe 6000	91 (86.7)	45 (70.3)	37 (74)	75 (35.5)
NLe 6100–NLe 10,000	13 (12.4)	16 (25)	9 (18)	57 (27)
NLe 10,100–NLe 20,000	1 (1)	2 (3.1)	0 (0)	56 (26.5)
NLe 20,100–NLe 30,000	0 (0)	1 (1.6)	0 (0)	15 (7.1)
Above NLe 31,000	0 (0)	0 (0)	0 (0)	8 (3.8)
Predominant economic activities				
Agricultural activity	103 (98.1)	48 (75)	48 (96)	156 (73.9)
Mining activity	101 (96.2)	51 (85)	44 (88)	185 (87.7)
Timber logging	10 (9.5)	52 (81.3)	48 (96)	79 (37.4)
Fossil fuel extraction	86 (81.9)	50 (78.1)	39 (78)	71 (33.6)
Industrial manufacturing	2 (1.9)	14 (21.9)	21 (42)	198 (93.8)
Construction activities	3 (2.9)	1 (1.6)	48 (96)	171 (81)
Fishing	28 (26.7)	48 (75)	19 (38)	115 (54.5)

Note: *Numbers in parentheses are percentages, and numbers without parentheses are frequencies.*
Source: Field Data (2024).

Leone. Across all regions, a higher proportion of respondents were male, with the Western Region exhibiting the highest male representation at 61.1 %. Age distribution varied, although the majority of respondents fell within the 41–60-year age group. This demographic pattern may reflect increased environmental awareness or a heightened interest in the subject matter among individuals in this age bracket. Most respondents across the regions were married, suggesting that considerations such as economic stability, long-term planning, familial responsibilities, and intergenerational concerns may influence perceptions of climate change.

Educational attainment varied widely, with a substantial proportion of participants reporting no formal education. Farming was the predominant occupation, particularly in the Northern and Eastern Regions. Length of residency also varied, with many respondents having resided in their communities for extended periods. This combination of formal and non-formal education, traditional ecological knowledge, and prolonged exposure to local climate conditions may have enhanced the respondents' awareness of climate trends over time. Continuous interaction with the environment—such as learning from elders and direct experiences appears to have supported pattern recognition and informed responses to extreme weather events. The dominance of farming as a livelihood further amplifies this awareness, as climate variability directly affects agricultural productivity and resilience.

Income levels were predominantly low, with many respondents reporting monthly earnings below NLe 6000.00 (equivalent to approximately US$2272.27 at the time of the survey). This reflects limited financial capacity, with many communities depending on climate-sensitive sectors such as agriculture, fishing, and outdoor labor. These groups rely heavily on accessible transportation routes, particularly unpaved roads, to reach markets. Consequently, climate variability—including erratic rainfall and extreme weather—poses significant threats to income stability, food security, and livelihood sustainability. The main economic activities reported included agriculture, mining, timber logging, fossil fuel extraction, and fishing—particularly along coastal areas. Industrial manufacturing was limited overall but was more prominent in the Western Region. Construction activity was generally low, with somewhat higher engagement in the Eastern and Western Regions. These varied economic pursuits, while essential to local livelihoods, also contribute to environmental degradation through unsustainable agricultural practices, deforestation,

soil erosion, and ecosystem disruption. The socio-demographic findings provide a comprehensive foundation for understanding climate change perceptions and highlight the urgent need for sustainable practices and context-specific adaptation strategies. Table summarizes respondents' perceptions of climate change and variability across the four regions.

Table 3 above presents the predominant climate variables identified by older participants (aged ≥40) across the four regions of Sierra Leone. Rainfall was widely observed across all regions, with near-universal acknowledgement in the Western (99.5 %) and Southern (98.4 %) Regions. Heatwaves were most commonly reported in the Eastern (90 %) and Southern (85.9 %) Regions. Windstorms were frequently noted in the Southern (98.4 %), Eastern (90 %), and Northern (72.4 %) Regions. Relative humidity was more prominently recognized in the Southern (79.7 %) and Eastern (74 %) Regions compared to the Western Region (52.1 %). Participants consistently reported that these climate variables have increasingly deviated from historical norms, with events lasting longer or occurring more frequently in recent decades. Extreme weather events—including heavy rainfall leading to floods, intense windstorms, and severe droughts—were reported throughout all regions, with the Northern and Southern Regions experiencing the most significant impacts. These findings underscore the increasing intensity and variability of climatic conditions and their adverse effects on local communities and unpaved road infrastructure [45]. The results align with reports from the World Bank [11] and the United Nations International Children's Emergency Fund [46], which document Sierra Leone's exposure to numerous minor to medium-scale natural disasters annually, such as flooding, windstorms, landslides, and wildfires over recent decades. Specifically, intense windstorms, extreme temperatures, frequent landslides, and drought conditions have been highlighted as significant challenges [11]. These observations highlight the diversity and severity of climate-related events experienced in the study areas. The prominence of rainfall, temperature, wind, and relative humidity as dominant climate variables is consistent with the findings of Solomon et al. [6], who reported similar patterns across the Mano River Union region—which includes Sierra Leone, Liberia, Côte d'Ivoire, and Guinea.

Table 4 summarizes respondents' perceptions of activities they believe contribute to the impacts of climate change and variability in Sierra Leone.

The analyzed data reveal that agricultural practices are widely perceived as a significant contributing factor to climate change, particularly in the Northern (84.8 %) and Eastern (88 %) regions. Mining is also regarded as a major contributor, especially in the Western (91.9 %) and Northern (64.7 %) regions. Fossil fuel extraction, primarily charcoal production, is associated with weather changes in the Eastern (78 %) and Northern (74.3 %) regions. Conversely, industrial manufacturing is perceived to have minimal impact across all regions. The burning of coal and other fossil fuels, along with deforestation, are recognized as primary drivers of climate change, as highlighted by Shivanna [47]. Construction activities are notably prominent in the Eastern (92 %) and Western (80.1 %) regions, whereas timber logging is more prevalent in the Southern (65.6 %) and Northern (58.1 %) regions but remains rare in the Western region (6.2 %), according to participant responses. Waste management is a key concern predominantly in the Western region (57.8 %). While most participants were able to identify human activities that exacerbate climate change and variability, a considerable proportion struggled to link these impacts to anthropogenic causes, instead attributing them to natural occurrences—particularly in the Eastern (92 %) and Western (80.6 %) regions. These perception patterns highlight not only regional differences but also knowledge gaps regarding the drivers of climate change, indicating a need for targeted interventions such as widespread educational programs. The findings align with the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change [9], which confirms that these activities significantly contribute to climate change and environmental degradation globally. Table 5 below presents the perceived effects of climate change and variability on unpaved roads in Sierra Leone.

Table 3
Perception of climate change and variability in Sierra Leone.

Variables	Northern Region ($N = 105$)	Southern Region ($N = 64$)	Eastern Region ($N = 50$)	Western Region ($N = 211$)
Which climate variables have been observed as significant in the locality over the past few decades?				
Rainfall variations	68 (64.8)	63 (98.4)	44 (88)	210 (99.5)
Temperature fluctuations (e.g., heat waves)	89 (84.9)	55 (85.9)	45 (90)	150 (71.1)
Windstorms	76 (72.4)	63 (98.43)	45 (90)	197 (93.4)
Changes in relative humidity	71 (67.6)	51 (79.7)	37 (74)	110 (52.1)
Drought conditions	55 (52.4)	54 (84.4)	32 (64)	133 (63)
Occurrence of landslides/ mudslides	6 (5.7)	9 (14.1)	1 (2)	2 (0.9)
Incidence of wildfires	2 (1.9)	9 (14.1)	1 (2)	4 (1.9)
Sea-level rise	11 (10.5)	40 (62.5)	6 (12)	104 (49.3)
Which climate variables have been observed to persist for extended durations in the locality over the past few decades?				
Prolonged rainfall events	47 (44.8)	61(95.3)	33(66)	190 (90)
Extended periods of high temperatures (e.g., heat waves)	72 (68.6)	63 (98.4)	44 (88)	167 (79.1)
Persistent humidity conditions	47 (44.8)	43 (67.2)	17 (34)	24 (11.4)
Extended windstorm events	77 (73.3)	63 (98.4)	39 (78)	140 (66.4)
Prolonged drought conditions	53 (50.5)	52 (81.3)	34 (68)	116 (55)
Extended wildfire events	8 (7.6)	5 (7.8)	1 (2)	211 (100)
Persistent landslides/ mudslides	1 (1)	5 (7.8)	1 (2)	1 (0.5)
Sustained sea-level rise	11 (10.5)	30 (46.9)	1 (2)	75 (35.5)
Which climate variables have been observed to occur for shorter durations than usual in the locality over the past few decades?				
Shortened rainfall events	56 (53.3)	3 (4.7)	21 (42)	18 (8.5)
Brief high-temperature events (e.g., heat waves)	27 (25.7)	4 (6.3)	3 (6)	71 (33.6)
Short-term humidity conditions	57 (54.3)	13 (20.3)	29 (58)	189 (89.6)
Brief windstorm events	24 (22.9)	7 (10.9)	9 (18)	80 (37.9)
Shortened drought conditions	31 (29.5)	7 (10.9)	4 (8)	109 (51.7)
Limited-duration wildfire events	36 (34.3)	18 (28.1)	11 (22)	164 (77.7)
Brief landslide/mudslide occurrences	24 (22.9)	18 (28.1)	9 (18)	172 (81.5)
Short-term fluctuations in sea-level rise	23 (21.9)	9 (14.1)	9 (18)	147 (69.7)
Which climate variables have been observed to align with typical patterns in the locality over the past few decades?				
Rainfall patterns	39 (37.1)	11 (17.2)	2 (4)	134 (63.5)
Temperature trends (e.g., heat waves)	52 (49.5)	8 (12.5)	2 (4)	193 (91.5)
Dewiness (relative humidity) levels	71 (67.6)	22 (34.4)	9 (18)	142 (67.3)

(*continued on next page*)

Table 3 (*continued*)

Variables	Northern Region ($N = 105$)	Southern Region ($N = 64$)	Eastern Region ($N = 50$)	Western Region ($N = 211$)
Windstorm occurrences	61 (58.1)	21 (32.8)	7 (14)	196 (92.9)
Drought conditions	69 (65.7)	28 (43.8)	12 (24)	184 (87.2)
Wildfire incidents	27 (25.7)	9 (14.1)	1 (2)	29 (13.7)
Landslide/mudslide events	24 (22.9)	5 (7.8)	1 (2)	26 (12.3)
Sea-level fluctuations	34 (32.4)	17 (26.6)	1 (2)	181 (85.8)
Which climate variables have been observed to occur frequently in the locality over the past few decades?				
Rainfall occurrences	51 (48.6)	56 (87.5)	46 (92)	206 (97.6)
Temperature variations	77 (73.3)	55 (85.9)	46 (92)	122 (57.8)
High windspeed events	81 (77.1)	61 (95.3)	43 (86)	180 (85.3)
Changes in dewiness (relative humidity)	54 (51.4)	53 (82.8)	23 (46)	10 (4.7)
Drought conditions	31 (29.5)	54 (84.4)	32 (64)	162 (76.8)
Wildfire occurrences	2 (1.9)	6 (9.4)	46 (92)	211 (100)
Landslides/mudslides	2 (1.9)	7 (10.9)	46 (92)	1 (0.5)
Sea-level rise incidents	5 (4.8)	30 (46.9)	46 (92)	44 (20.9)
Which climate variables have been observed to exhibit extreme characteristics with increased disaster events in the locality over the past few decades?				
Heavy rainfall leading to flooding and debris flow	54 (51.4)	43 (67.2)	36 (72)	98 (46.4)
High temperatures accompanied by excessive heat waves	51 (48.6)	51 (79.7)	30 (60)	160 (75.8)
Intense windstorms with significant impacts	94 (89.5)	63 (98.4)	42 (84)	194 (91.9)
Increased landslides triggered by torrential rains	8 (7.6)	8 (12.5)	1 (2)	14 (6.6)
Severe weather-related dust emissions	89 (84.8)	63 (96.9)	45 (90)	203 (96.2)
Prolonged and extreme drought conditions	54 (51.4)	52 (81.3)	34 (68)	197 (93.4)
Escalation of wildfire events	2 (1.9)	4 (6.3)	3 (6)	5 (2.4)
Intensified hailstone occurrences	21 (20)	15 (23.4)	29 (58)	131 (62.1)

Note: *Numbers in parentheses are percentages, and numbers without parentheses are frequencies.*
Source: Field data (2024).

Table 5, revealed that the most commonly observed impacts of climate change and variability on unpaved roads across all regions of Sierra Leone include washouts (99.5 %), road surface erosion (97.6 %), pothole formation (97.6 %), and excessive dust emissions (98.6 %). Although these findings align with the broad observations of Hugo *et al.* [4] regarding climate change impacts on infrastructure, our high percentages across all regions highlight the pervasive vulnerability of the unpaved road network in Sierra Leone to these common climatic stressors. This suggests a systemic lack of resilient road construction and maintenance practices nationwide, making even minor climate variations impactful. Regional variations were noted, with traffic disruptions being particularly high in the Southern (87.5 %) and Eastern (90 %) Regions and lower in the Northern Region (37.1 %). Blocked culverts and resulting waterlogging were more prevalent in the Southern (92.2 %) and Eastern (90 %) Regions, whereas the Western Region

Table 4
Perceived contributing factors to climate variability and extremes in Sierra Leone.

Variables	Northern Region ($N = 105$)	Southern Region ($N = 64$)	Eastern Region ($N = 50$)	Western Region ($N = 211$)
Which activities do you perceive to have worsened the impact of extreme weather events observed in your locality in recent decades? (Select all that apply)				
Agricultural practices	89 (84.8)	41 (64.1)	44 (88)	164 (77.7)
Mining activities	68 (64.7)	38 (59.4)	35 (70)	194 (91.9)
Fossil fuel extraction (e.g., charcoal production)	78 (74.3)	37 (57.8)	39 (78)	107 (50.7)
Industrial manufacturing activities	10 (9.5)	1 (1.6)	5 (10)	19 (9)
Construction activities	29 (27.6)	31 (48.8)	46 (92)	169 (80.1)
Timber logging	61 (58.1)	42 (65.6)	17 (34)	13 (6.2)
Waste management practices	24 (22.9)	4 (6.3)	1 (2)	122 (57.8)
Natural occurrences	27 (25.7)	4 (6.3)	46 (92)	170 (80.6)

Source: Field data (2024).

experienced significantly fewer issues (37.4 %). Vegetation encroachment, though less frequently cited, was more prominent in the Southern (86.7 %) and Western (95.3 %) Regions. These regional disparities likely reflect variations in local topography, drainage systems (or lack thereof), and vegetation management practices. The higher incidence of traffic disruptions and waterlogging in the Southern and Eastern Regions could be linked to potentially higher average rainfall or more intense precipitation events in these areas, exacerbating existing infrastructure weaknesses. Conversely, the lower reports in the Northern and Western Regions require further investigation to understand potential protective factors or differing reporting biases.

The above result is consistent with the study conducted by Schweikert et al., [48], which indicates that climate change has significant impacts on road infrastructure—such as washouts, erosion, potholes, traffic disruptions, and drainage issues—while highlighting the importance of proactive adaptation strategies to mitigate these effects and associated costs. However, our regional data provide a more nuanced understanding of where these broad impacts are most acutely felt within Sierra Leone, emphasizing the need for geographically targeted interventions rather than a one-size-fits-all approach to adaptation.

The survey analysis in Table 5 highlighted increased transportation costs (94.8 %) and disruption of economic activities (93.8 %) as the most significant socioeconomic impacts of unpaved road deterioration due to climate change and variability. Limited access to basic amenities (57.8 %) and reduced school attendance (55.5 %) were also notable consequences. These high percentages emphasize the profound interconnectedness between the condition of unpaved roads and the daily lives and livelihoods of communities in Sierra Leone. The disruption of economic activities, driven by impassable roads, likely hinders agricultural trade, market access, and overall economic growth in these regions. These socioeconomic impact findings align with global research on climate change impacts on infrastructure [49]. However, our study provides empirical evidence of these global trends within the specific context of rural Sierra Leone, highlighting the tangible human cost of climate-induced infrastructure damage. Regional differences were evident, with the Southern and Eastern Regions experiencing higher disruptions in school attendance and access to amenities, whereas respondents in the Northern and Western Regions showed limited

Table 5
Perceived effects of climate change and variability on unpaved roads in Sierra Leone.

Variables	Northern Region ($N = 105$)	Southern Region ($N = 64$)	Eastern Region ($N = 50$)	Western Region ($N = 211$)
What impacts of extreme weather events on unpaved roads and their components have been observed in your locality over the past decades?				
Washouts of road components	97 (92.4)	60 (93.8)	45 (90)	210 (99.5)
Road surface erosion	95 (90.5)	63 (98.4)	45 (90)	206 (97.6)
Formation of potholes	98 (93.3)	61 (95.3)	45 (90)	206 (97.6)
Traffic disruptions	39 (37.1)	56 (87.5)	45 (90)	182 (86.3)
Excessive dust emissions	94 (89.5)	60 (93.8)	44 (88)	208 (98.6)
Blocked culverts and ditches causing waterlogging	77 (73.3)	59 (92.2)	45 (90)	79 (37.4)
Obstruction or encroachment from roadside vegetation growth	91 (86.7)	61 (95.3)	45 (90)	146 (69.2)
Do not know	75 (71.4)	56 (87.5)	43 (86)	89 (42.2)
What socioeconomic impacts of extreme weather events on unpaved roads have been observed in your locality in the past few decades?				
Restricted access to basic amenities	64 (61)	60 (93.8)	45 (90)	122 (57.8)
Disruption of economic activities	57 (54.3)	60 (93.8)	41 (82)	198 (93.8)
Increased transportation costs	101 (96.2)	63 (98.4)	45 (90)	200 (94.8)
Reduced school attendance	61 (58.1)	60 (93.8)	39 (78)	117 (55.5)
Limited delivery of NGO aid	52 (49.5)	52 (81.3)	42 (84)	125 (59.2)
Do not know	56 (53.3)	37 (57.8)	21 (42)	44 (20.9)
What changes in weather patterns and extreme climate conditions do you anticipate in your locality in the coming decades?				
Increased frequency of extreme rainfall	52 (49.5)	58 (90.6)	27 (54)	203 (96.2)
Higher occurrence of extreme temperatures	63 (60)	58 (90.6)	43 (86)	129 (61.1)
Increased intensity of extreme wind speeds	73 (69.5)	60 (93.8)	40 (80)	197 (93.4)
Greater extremes in relative humidity	43 (41)	44 (68.8)	24 (48)	38 (18)
Increased frequency of wildfires	8 (7.6)	12 (18.8)	4 (8)	4 (1.9)
More frequent landslides or mudslides	7 (6.7)	9 (14.1)	2 (4)	8 (3.8)
Heightened intensity of Harmattan wind event	52 (49.5)	54 (84.4)	27 (54)	201 (95.3)
Do not know	23 (21.9)	48 (75)	31 (62)	73 (34.6 %)

Note: *Numbers in parentheses are percentages, whereas numbers without parentheses are frequencies.*
Source: Field data (2024).

The analysis, as shown in which confirms that these activities significantly contribute to climate change and environmental degradation globally. Table 5 below presents the perceived effects of climate change and variability on unpaved roads in Sierra Leone.

awareness of the socioeconomic effects, often responding with "Don't know."

The higher vulnerability in the Southern and Eastern Regions could be attributed to a greater reliance on these compromised road networks for essential services or potentially longer distances to alternative options. The "Don't know" responses in the Northern and Western Regions may indicate a lower awareness of the indirect socioeconomic consequences, possibly due to different livelihood patterns or a less direct perceived link between road conditions and daily life. This warrants further qualitative investigation to understand the nuances of these perceptions. Furthermore, the data analysis in which confirms that these activities significantly contribute to climate change and environmental degradation globally. Table 5 below presents the perceived effects of climate change and variability on unpaved roads in Sierra Leone.

Table 5 reveals that respondents across the four regions of Sierra Leone anticipate a significant increase in the frequency, duration, and intensity of extreme weather events in the coming decades. A substantial majority (96.2 %) expect more frequent extreme rainfall, 61.1 % foresee higher temperatures, and 93.4 % predict stronger wind speeds. These strong anticipations highlight a high level of awareness within local communities regarding the changing climate patterns and their potential to worsen existing road infrastructure challenges. These perceived anticipations of increasing climate change and variability impacts are inconsistent with other research, including studies by Jurgilevich et al. [50] and Lennard et al. [51]. The discrepancy between local perceptions and these studies warrants further scrutiny. It could indicate that the global or regional models used in those studies do not accurately capture the localized climate changes experienced in Sierra Leone or that local communities are particularly sensitive to even subtle shifts in weather patterns due to their direct reliance on the environment and vulnerable infrastructure. In contrast, concerns regarding less common events such as wildfires (1.9 %), landslides (3.8 %), and changes in relative humidity (18 %) are relatively minor. However, there is an expectation of increased harmattan wind intensity, particularly in the Western Region (95.3 %).

The low concern for wildfires and landslides might reflect the specific environmental context of the study regions, whereas the high anticipation of increased harmattan winds in the Western Region indicates a localized understanding of this specific climate phenomenon and its potential impacts—possibly related to dust storms and reduced visibility affecting transportation. These findings, while agreeing that there will be an increase in the frequency and intensity of extreme events due to climate change, highlight regional differences in perceptions of climate change impacts on local communities. This underscores the importance of incorporating local knowledge into climate change adaptation planning, as these perceptions can provide valuable insights into the specific threats and vulnerabilities faced at the community level.

From this analysis, the researchers can infer that climate change and variability are already having significant and regionally varied impacts on unpaved roads in Sierra Leone, with widespread issues such as washouts, erosion, potholes, and dust emissions observed across the country. These are not merely isolated incidents but systemic failures in road resilience. These impacts contribute to increased transportation costs, economic disruptions, and limited access to basic services, particularly in the Southern and Eastern Regions. This regional disparity suggests a need for prioritized interventions in these more vulnerable areas. The anticipated increase in extreme weather events—especially rainfall, temperatures, and wind speeds—is expected to exacerbate these challenges in the coming decades, particularly for unpaved roads, which are already vulnerable to such climatic conditions. Without proactive and targeted adaptation strategies, the socioeconomic consequences for these communities are likely to worsen. The regional differences in both

current impacts and future concerns indicate that localized interventions and adaptive strategies will be necessary to mitigate the growing challenges posed by climate change to road infrastructure and local economies. This calls for a decentralized approach to climate adaptation planning—one that considers the specific vulnerabilities and perceptions of individual regions and communities.

Table 6 shows the perceived adaptive capacities of unpaved roads across the four regions of Sierra Leone.

The analysis in Table 6 reveals significant variations in respondents' perceptions regarding the adaptive capacities of unpaved roads across several key indicators. These differences provide critical insights into both the challenges and strengths of road infrastructure in the Northern, Southern, Eastern, and Western regions. For instance, the availability of alternative routes in the Western Region indicates a higher level of adaptability, with 95.3 % of respondents reporting the presence of adequate alternative routes in good condition. In contrast, respondents from the other regions report either limited or poor-quality alternative routes—or none at all—highlighting issues of constrained connectivity. Regarding the state of unpaved road maintenance, the findings show that maintenance practices are generally inconsistent across all regions. While the implementation of measures such as regular upkeep, effective drainage systems, road stabilization, and roadside vegetation control remains inadequate overall, the Western Region stands out with relatively better levels of regular maintenance, reported at 79.1 %. These results underscore the importance of adaptive capacity in road networks—particularly the availability of alternative routes to ensure commuter flexibility during disruptions—and the need for balanced maintenance to preserve both resilience and efficiency in traffic flow [52].

With respect to community involvement in unpaved road maintenance, the data indicate limited participation across regions. Although the Southern and Eastern Regions exhibit some moderate levels of sustainable community engagement, most efforts remain unsustainable or minimal. This underscores a broader lack of community-driven road maintenance. Active local involvement is essential for sustainable road upkeep, as it leads to safer and smoother roads while fostering a sense of accountability and ownership among residents who rely daily on the infrastructure [53]. Such engagement contributes to the long-term durability and resilience of the road network. In terms of road infrastructure monitoring, the analysis reveals minimal effectiveness across all regions. As indicated in Table 6, most respondents report that monitoring systems are either nonexistent or inconsistently effective. This leaves roads vulnerable to avoidable failures. An effective monitoring system plays a crucial role in enhancing infrastructure resilience by supporting timely decision-making, improving response times, optimizing data collection and transmission, ensuring scalability, and ultimately contributing to better road maintenance and adaptability [54].

Concerning access to key public facilities, respondents overwhelmingly acknowledged the critical role unpaved roads play in providing connectivity to schools, hospitals, and market centers. This finding aligns with a study by Starkey et al. [55], and over 96 % of participants across all regions affirmed this connection, demonstrating the socioeconomic significance of these roads. Furthermore, the data indicate that unpaved roads are generally located in close proximity to all-weather roads in the Northern, Southern, and Eastern Regions, thereby supporting greater connectivity. However, the Western Region shows a marked gap, with only 36 % of respondents reporting such proximity.

Finally, the analysis of traffic patterns reveals that unpaved roads across all regions accommodate predominantly mixed traffic, including a wide variety of vehicle types. This finding is consistent with the broader context of sub-Saharan Africa, where most roads are unpaved, and where affordable transport services such as motorcycles, taxis (boda bodas), and light to medium trucks are vital for economic activity. These modes of transport support rural access to markets and essential services [56]. The data show that over 93 % of respondents confirmed this trend,

Table 6
Perceived adaptive capacities of unpaved roads in Sierra Leone.

Variables	Northern Region ($N = 105$)	Southern Region ($N = 64$)	Eastern Region ($N = 50$)	Western Region ($N = 211$)
Are there adequate alternative routes in good condition available to unpaved secondary roads in your locality?				
There are adequate alternative routes to most unpaved roads in this community.	46 (43.8)	17 (26.6)	18 (36)	201 (95.3)
There are limited alternative routes, and they are not in good condition.	87 (82.9)	56 (87.5)	33 (66)	143 (67.8)
There are no alternative routes to unpaved roads in this community.	84 (80)	53 (82.8)	36 (72)	151 (71.6)
What has been the state of maintenance and management of unpaved roads in the community over the past few decades?				
Unpaved roads have been regularly maintained.	7 (6.7)	17 (26.6)	7 (14)	167 (79.1)
Effective drainage systems have been installed on unpaved roads.	17 (16.2)	44 (68.6)	29 (58)	98 (46.4)
Stabilization measures have been applied to enhance the durability of unpaved roads.	5 (4.8)	39 (60.9)	32 (64)	68 (32.2)
Roadside vegetation control has been implemented to improve road stability.	7 (6.7)	1 (1.6)	6 (12)	25 (11.8)
None of these measures have been consistently applied.	82 (78.1)	44 (68.8)	38 (76)	87 (41.23)
What is the level of local community involvement in maintaining unpaved roads in the locality?				
Locals are actively involved in the sustainable maintenance of unpaved roads.	33 (31.4)	26 (40.6)	22 (44)	43 (20.4)
Locals are involved, but their efforts are not sustainable.	64 (60.9)	48 (75)	32 (64)	98 (46.4)
Locals are rarely or not involved in maintaining unpaved roads.	73 (69.5)	56 (87.5)	40 (80)	128 (60.7)
Is there an effective road infrastructure monitoring system in place to ensure the timely prevention of failures?				
A comprehensive monitoring system is in place and effectively prevents road failures.	6 (5.7)	13 (20.3)	8 (16)	40 (19)
A monitoring system exists, but it is not consistently effective in preventing failures.	79 (75.2)	54 (84.3)	43 (86)	110 (52.1)
There is no monitoring system in place for the timely prevention of road failures.	21 (20)	31 (48.4)	23 (46)	42 (19.9)

(*continued on next page*)

Table 6 (*continued*)

Variables	Northern Region ($N = 105$)	Southern Region ($N = 64$)	Eastern Region ($N = 50$)	Western Region ($N = 211$)
Do unpaved roads in the community provide access to key public facilities such as schools, hospitals, and market centres?				
Unpaved roads provide access to most key public facilities in the community.	102 (97.1)	63 (98.4)	48 (96)	210 (99.5)
Unpaved roads provide limited access to key public facilities.	44 (41.9)	29 (45.3)	18 (36)	56 (26.5)
Unpaved roads do not provide access to key public facilities.	31 (29.5)	17 (26.6)	18 (36)	21 (9.9)
How close are unpaved roads to all-weather roads in your community?				
Unpaved roads are in close proximity to all-weather roads.	86 (81.9)	61 (95.3)	45 (90)	76 (36)
Unpaved roads are moderately close to all-weather roads.				
Unpaved roads are far from or not connected to any all-weather roads.				
What types of traffic have been observed on unpaved secondary roads in the study communities over the last few decades?				
Only small cars use the unpaved roads.	3 (2.9)	64 (100)	50 (100)	14 (6.6)
Only medium-sized vehicles use the unpaved roads.	9 (8.6)	64 (100)	50 (100)	15 (7.1)
Only heavy vehicles use the unpaved roads.	4 (3.8)	64 (100)	50 (100)	15 (7.1)
Only agricultural tractors or motorcycles use the unpaved roads.	7 (6.7)	64 (100)	50 (100)	16 (7.6)
Mixed traffic, including diverse types of vehicles, uses the unpaved roads.	93 (88.6)	60 (93.8)	48 (96)	205 (97.2)

Note: *Numbers in parentheses are percentages, and numbers without parentheses are frequencies.*
Source: Field data (2024).

reflecting the functional adaptability of unpaved roads in serving diverse transportation needs.

Table 7 presents barriers to adaptation and coping practices. The analyzed survey data highlight regional disparities in community perceptions of the barriers to adapting to climate change impacts on unpaved roads in Sierra Leone. Across all regions, the most significant barriers identified include insufficient funds and resources (93.8 %) and socioeconomic constraints (46.4 % overall, with particularly high levels reported in the Northern and Southern Regions). Inadequate knowledge and skills also emerged as prominent barriers, with 85.8 % of respondents citing this issue—especially in the Northern Region (78.1 %). These findings align with Cinderby et al. [57], who emphasized that limited knowledge exchange hampers efforts to enhance climate resilience, underscoring the need to increase awareness of effective adaptation strategies for transport infrastructure. Limited institutional support was reported in all regions except the Western Region, where it was minimal (14.2 %). The increasing impacts of climate change, along with cultural and societal barriers, were reported more frequently in the

Table 7
Barriers to adaptation/coping practices for unpaved roads by the local community in Sierra Leone.

Variables	Northern Region ($N = 105$) n (%)	Southern Region ($N = 64$) n (%)	Eastern Region ($N = 50$) n (%)	Western egion ($N = 211$) n (%)
What are the key challenges affecting local coping practices in response to the impacts of extreme weather events on unpaved roads?				
Insufficient funds and resources limit participation.	97 (92.4)	57 (89.1)	35 (70)	198 (93.8)
Inadequate knowledge and skills constrain effective engagement.	82 (78.1)	38 (59.4)	29 (58)	181 (85.8)
Limited institutional support hampers coping efforts.	91 (86.7)	63 (98.4)	42 (84)	30 (14.2)
The increasing impacts of climate change exacerbate coping difficulties.	72 (68.6)	46 (71.9)	42 (84)	33 (15.6)
Socioeconomic constraints pose significant barriers to adaptation.	101 (96.2)	61 (95.3)	46 (92)	98 (46.4)
Cultural and societal factors affect the effectiveness of coping practices.	61 (58.1)	58 (90.6)	43 (86)	20 (9.5)

Note: *Numbers in parentheses are percentages, and numbers without parentheses are frequencies.*
Source: Field data (2024).

Southern and Eastern Regions. These findings indicate a need for targeted interventions that address both structural and cultural challenges to adaptation.

Survey responses further show that the impacts of climate change on unpaved roads vary across regions. The Southern and Eastern Regions experience the most significant changes in rainfall, heatwaves, windstorms, and humidity. Meanwhile, extreme events such as floods, windstorms, and droughts have had pronounced effects in the Northern and Southern Regions. These climate impacts have contributed to road deterioration, resulting in increased transportation costs and economic disruptions—particularly in the Southern and Eastern Regions. Challenges such as limited alternative routes, poor road maintenance, and inadequate community involvement further underscore the need for targeted interventions and enhanced public awareness to improve infrastructure resilience.

4.1. Ethical considerations

To ensure ethical integrity in the FGD and KII, several measures were implemented. Informed consent was obtained from all participants after they were fully briefed on the study's purpose, the voluntary nature of their participation, and their right to withdraw at any time without consequence. Discussions were conducted in safe, neutral settings to encourage open dialogue and minimize discomfort or coercion. Confidentiality and anonymity were strictly maintained—no real names were recorded or published, and all responses were attributed using pseudonyms to protect participant identities. Additionally, participants were assured that the data collected would be used solely for academic and policy-relevant purposes. Ethical clearance was obtained from the appropriate institutional review board. Culturally appropriate protocols were also followed to respect local norms and sensitivities, particularly when engaging with traditional leaders and community members.

4.2. FGD and KII

To understand local perceptions of climate change and its implications for unpaved roads, FGD and KII were conducted across the four regions of Sierra Leone. These qualitative sessions explored diverse perspectives on climate change, its variability, and the resulting impacts on ecosystems—particularly road infrastructure. The findings were categorized under three primary themes: (i) perceptions of climate change and variability, (ii) the impacts of these changes on the local environment, especially unpaved roads connecting livelihood hubs, and (iii) the role of human activities in exacerbating these impacts.

Eight focus groups—two from each region—were convened, each comprising a minimum of six participants. These participants represented a diversity of backgrounds in terms of gender, age, education, occupation, and income. The groups included individuals from local councils, NGOs, community-based organizations, road management authorities, and youth groups. Participants frequently identified changing climatic patterns, including heavier rainfall, rising temperatures, and more frequent windstorms. These changes were linked to a range of adverse effects such as flooding, landslides, droughts, and storms. Several participants also emphasized the role of human activities in intensifying the socioeconomic challenges facing their communities—particularly in relation to road infrastructure. To protect participant anonymity, pseudonyms are used in the excerpts presented below, which illustrate the breadth of perceptions gathered during the discussions.

4.2.1. On climate change and variability

A 61-year-old farmer from the Northern Region shared his observations:

> *"I have lived in this community for over 22 years now, and I have observed a decline in overall rainfall in our region compared to previous years, but the intensity of rainfall has increased. Prolonged rain periods, such as those lasting 2 to 3 days or up to a week, have become rare. Instead, sporadic and intense downpours are more common nowadays than 10 or 15 years ago."*

Recounting her lived experience, a 48-year-old woman from the same region, who trades in basic foodstuffs and rain gear, noted:

> *"The* shortened rainy season and unpredictable rainfall patterns have significantly disrupted *my* trade. *It has become difficult to sell my goods and purchase agricultural products in exchange as I used to do in previous years."*

A district engineer in the Southern Region reported notable changes in climate patterns, including increased rainfall, frequent windstorms, and rising temperatures. He emphasized that torrential rains in 2016, 2020, and 2024 caused extensive flooding across several roads, overwhelming infrastructure and disrupting transportation networks.

An NGO worker with nearly two decades of experience in the Eastern Region provided further insight:

> "Many people fail to understand why their crop yields have been inconsistent. In some years, they experience good harvests, whereas in others, yields are significantly lower. This inconsistency is linked to variations in rainfall patterns. For example, some years see rains starting early and ending quickly, whereas in others, they begin late but last longer than expected. In some instances, droughts occur, and the traditional pattern of six months of rain followed by six months of dry weather is increasingly disrupted by climate change."

The worker emphasized the urgent need for nationwide education on climate variability.

4.3. On the impact of climate change and variability on unpaved roads

Most participants demonstrated a strong awareness of the impacts of climate change, though many could not fully explain the scientific processes behind these changes. Their understanding was primarily informed by personal experience and media sources. Commonly cited climate impacts included the increasing frequency of windstorms, rainstorms, wildfires, flooding, droughts, and heightened dew levels. Research shows that these climate variables are particularly detrimental to road infrastructure—especially unpaved roads, which are inherently more vulnerable. Such impacts often result in severe erosion, road washouts, debris flows, gully formation, potholes, and other forms of degradation [4,26].

For example, a local council worker in the Northern Region reported that the Robol Junction–Mile 91 road was severely flooded in 2012, 2016, and 2022. During each of these periods, the road remained impassable for several weeks until floodwaters receded and damaged drainage infrastructure was repaired. The chief engineer responsible for national road management noted that increased rainfall frequency and duration have significantly raised maintenance costs. Prolonged and intermittent rainy seasons have led to a rise in the number of potholes, collapse of culverts, and clogging of drainage systems. He observed that these challenges have been persistent over the past 20 years. This aligns with findings from Taylor et al. [58], who link such variations to climate change, emphasizing the risks posed to unpaved road networks [59].

A road contractor working on the Kenema–Zimmi Road (87 km) in the Eastern Region echoed similar concerns during an FGD. He explained that the increasing frequency of rainfall, windstorms, heatwaves, drought conditions, and debris flow have compounded maintenance challenges. These include a higher number of potholes to patch, sunken sections to restore, and a constant need to desilt culverts and drainage systems. He also noted the shift from a previously predictable six-month rainy season to one now extending over eight months, thereby disrupting traditional maintenance cycles.

A local traditional leader in Masimera, a Northern town along the Mathoir–Lunsar road, commented:

> *"The heavy rainfall often hampers our agricultural activities owing to deteriorating road conditions. The impassability of our roads for over six months each year severely hinders trade and impacts our livelihoods."* A retired teacher from the same town added: *"We have been facing consistent and intense rains that frequently lead to road closures due to washouts."*

These observations align with meteorological trends indicating rising temperatures and prolonged dry spells, which increasingly affect both ecosystems and infrastructure [6,9,26,].

Participants across all regions identified their primary economic activities as subsistence agriculture, which typically involves the annual clearing of land for cultivation. Timber logging and charcoal production were common throughout the four regions, while iron ore mining was particularly prominent in the Northern Region. In the Southern and Eastern parts of the country, rutile, gold, and diamond mining were widespread. Sand mining, primarily for construction purposes, was prevalent nationwide. However, most participants were generally unable to connect these activities to the broader impacts of climate change and variability affecting their communities.

When asked whether they believe human activities contribute to or exacerbate the impacts of climate change and variability—especially concerning the predominantly unpaved road network—participants expressed varying degrees of understanding. These anthropogenic activities are known to harm ecosystems, biodiversity, and habitats [9]. A 64-year-old farmer from Mathoir village, located along the Mathoir–Masimera road, shared that he has been engaged in such activities since childhood, working alongside his father. While he did not initially recognize these activities as drivers of the significant environmental impacts currently experienced, he acknowledged that once land is cleared of vegetation, runoff accelerates, which facilitates soil erosion on the exposed land.

Findings from community perceptions across Sierra Leone's four

regions reveal a strong awareness of environmental changes. Nevertheless, participants often struggled to directly link their economic activities to the broader processes of climate change and variability. Several, however, did acknowledge notable shifts in local weather patterns, including rising temperatures, stronger winds, and increased dust emissions. These changes were frequently attributed to human activities such as subsistence agriculture, land clearing, timber logging, and charcoal burning.

The clearing of land for cultivation was particularly associated with accelerated debris flows and increased soil erosion, challenges that participants identified as major obstacles to maintaining unpaved roads. Loss of vegetation through deforestation intensifies surface runoff and destabilizes landscapes, rendering roads more vulnerable to damage during extreme weather events. Although these activities are central to local livelihoods, they contribute to environmental degradation that ultimately undermines the very road infrastructure communities depend upon for connectivity and economic exchange [9].

The study underscores that while Sierra Leonean communities recognize the impacts of climate change on unpaved roads, many lack an understanding of how their own practices—such as deforestation, unsustainable farming, and poor land use—aggravate road degradation by increasing erosion and runoff during severe weather. This highlights an urgent need for targeted education and mitigation strategies that encourage sustainable land management, reforestation, improved drainage systems, and ecosystem-based road design. Such approaches would enhance resilience, maintain rural connectivity, and support long-term economic development. Community discussions further emphasize the necessity for policies integrating climate education with infrastructure resilience. Although awareness of climate impacts on roads exists, local activities such as deforestation and mining exacerbate these effects. Policymakers should prioritize climate literacy, sustainable land use, and resilient road engineering to protect rural access, reduce maintenance costs, and safeguard livelihoods amid climate change. Finally, insights from Sierra Leone's community perceptions provide a valuable foundation for regional comparisons with neighboring countries such as Liberia, Guinea, Ghana, and Nigeria. Such analyses can identify shared vulnerabilities and adaptation strategies, informing harmonized, community-driven, and climate-resilient road development policies across West Africa.

5. Conclusions and recommendations

This study reveals significant concerns among local communities across Sierra Leone regarding the impacts of climate change and variability on unpaved roads—critical lifelines for socioeconomic activities. Communities report diverse changes in weather patterns over recent decades, including increased rainfall intensity and more frequent windstorms, which exacerbate road degradation through washouts, erosion, and structural damage. Despite regional differences, there is a shared recognition of the vulnerability of unpaved roads and an urgent need for resilient infrastructure solutions. The findings underscore the importance of integrating local knowledge, values, and community concerns into the design of effective adaptation strategies. Communities face numerous challenges in coping with these impacts, and their insights are essential for shaping targeted interventions that mitigate damage to road infrastructure while promoting sustainable climate action. Strengthening community engagement and addressing equity considerations within climate policies are critical to enhancing the resilience of unpaved roads and supporting broader climate change mitigation and adaptation efforts.

6. Policy implications

By aligning local insights with global climate adaptation frameworks, this research enhances its relevance and applicability, enabling scalable, context-sensitive solutions and encouraging investment in resilience-building measures. Policymakers should prioritize the strengthening of unpaved road infrastructure through interventions such as improved drainage systems, erosion control, and reforestation initiatives, alongside the promotion of community-based adaptation and the enforcement of sustainable land use practices. These findings offer practical guidance for government ministries, local councils, national road agencies, traditional authorities, development partners, and NGOs. By linking climate variability, infrastructure vulnerability, and local land use practices, the study supports coordinated, cross-sectoral policy responses aligned with SDGs 9 (Infrastructure) and 13 (Climate Action). This alignment provides a valuable framework for national planning and donor-funded interventions to build climate-resilient rural infrastructure.

6.1. Theoretical contributions of the study

This study advances the theoretical understanding of climate adaptation and infrastructure vulnerability by centering grassroots perspectives and challenging conventional top-down models that often neglect local lived experiences. It introduces a nuanced socio-ecological framework that highlights the role of human-induced factors—such as poor drainage management, deforestation, and land misuse—as key contributors to the vulnerability of infrastructure. By emphasizing the dynamic interplay between environmental stressors and community behavior, this research refines existing frameworks and advocates for participatory, place-based strategies in developing climate-resilient infrastructure. Its mixed-methods approach and focus on local knowledge contribute to inclusive and sustainable development models, particularly relevant for low-income, high-risk settings like Sierra Leone.

7. Study strengths, limitations and future research cinsiderations

This study provides valuable insights into how local communities perceive and discuss climate change and variability, along with its implications for unpaved road infrastructure. Although the findings cannot be generalized due to the small convenience sample, the research offers a rich case study, particularly in rural settings where such perspectives are underdocumented in Sierra Leone. The focus on local experiences adds depth to the understanding of climate change impacts on infrastructure in these regions. However, the study is limited by the demographic composition of its participants, as the majority were illiterate male household heads, with limited representation of women and individuals from diverse social backgrounds.

Future research should adopt a broader, multidisciplinary approach to capture diverse lived experiences across the varying biomes and social contexts of Sierra Leone. This would deepen the understanding of how climate change and variability affect unpaved roads and the role of human and environmental factors. Incorporating geospatial and remote sensing technologies, such as satellite imagery and climate data, alongside community-based insights, can enhance climate impact monitoring, support predictive maintenance, and inform early warning systems. This integration would strengthen both the scientific and policy foundations for planning climate-resilient rural infrastructure. Furthermore, a primary limitation of this study lies in its reliance on frequency counts and percentages for data analysis. Although it provides a foundational understanding of local perceptions, this approach does not explore the statistical significance of differences between groups or investigate potential relationships between variables. This limits the depth of analytical interpretation regarding the strength and nature of the observed patterns. Future research should build upon these findings by employing more robust statistical techniques, including descriptive statistics (such as mean and standard deviation), data visualization (such as histograms and boxplots), inferential statistics (such as ***t*-tests and ANOVA),** and regression analysis. This would allow for a more nuanced understanding of the data, including the statistical significance

of regional variations and the exploration of potential correlations between climate change perceptions, observed impacts, and socioeconomic consequences on unpaved road infrastructure.

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CRediT authorship contribution statement

Phodie Musa Kamara: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yaw Adubofour Tuffour:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Frank Baffour-Ata:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Formal analysis, Conceptualization. **Daniel Atuah Obeng:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

All 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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