Effects of Extreme Temperature and Rainfall on Vulnerability and Climate Change Resilience of Electricity Transmission Infrastructure in Kajiado County, Kenya

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ABSTRACT

Electricity transmission infrastructure forms a critical enabler of socio-economic development. This infrastructure, however, increasingly faces operational and structural risks associated with the impacts of climate change and variability. Developing countries remain disproportionately vulnerable because electricity systems often operate under resource constraints, capacity limitations, infrastructure deficits, and evolving climate governance frameworks. This study assessed the effects of extreme temperature and extreme rainfall on the vulnerability and resilience of electricity transmission infrastructure in Kajiado County, Kenya. A mixed-methods approach integrating ordinal regression analysis, Spearman correlation analysis, Geographic Information Systems (GIS)-based terrain assessment, and qualitative thematic analysis was adopted. Primary data were collected through structured expert surveys involving electricity transmission specialists, environmental professionals, economists, and infrastructure practitioners. Secondary climate and hazard information were obtained from national and international climate databases, including climate datasets and projections accessed through the Kenya Meteorological Department (KMD) Map Room, which provided historical and projected climate information relevant to the study area. Results demonstrated that extreme temperature ($p = 0.894$) and extreme rainfall ($p = 0.076$) did not emerge as statistically significant predictors of infrastructure vulnerability and resilience. Spearman correlation analysis further confirmed weak negative associations between resilience and climatic extremes. However, qualitative evidence demonstrated operational vulnerabilities including potential flush-over effects, conductor sagging, transformer overheating, shallow to deep soil erosion around transmission towers, flooding-related access constraints that limits maintenance, and accelerated equipment degradation. The findings reveal that climate hazards affect infrastructure indirectly through interactions with technical limitations, planning deficiencies, and infrastructure design assumptions rather than through informed isolated climatic exposure. Existing infrastructure planning approaches rely predominantly on historical climate datasets while insufficiently integrating future climate projections that can adequately account to design lifetime of these infrastructure. The study recommends institutionalizing climate-informed infrastructure design standards, strengthening predictive climate risk assessment frameworks, incorporating future climate scenarios into transmission planning, and enhancing adaptive maintenance systems to strengthen electricity infrastructure resilience under changing climatic conditions.

Keywords: climate change; electricity transmission; infrastructure resilience; vulnerability; extreme rainfall; extreme temperature; Kajiado County.

INTRODUCTION

Electricity transmission infrastructure forms the backbone of modern power systems by enabling the bulk transfer of electricity from generation sources to demand centres. These systems are typically designed for long operational lifespans exceeding forty-five years and require substantial capital investment. They are engineered to operate within specific climatic thresholds; however, increasing climate variability is progressively undermining these design assumptions (Panteli & Mancarella, 2015). Globally, climate change has emerged as a major stressor for power systems, with extreme temperature and rainfall events increasingly affecting transmission efficiency, system reliability, and infrastructure durability. The Intergovernmental Panel on Climate Change (IPCC, 2022) highlights that rising global temperatures are increasing thermal stress on overhead conductors, while intensified precipitation events are accelerating flooding, soil instability, and structural damage to transmission corridors.

At the global level, empirical evidence shows that extreme heat reduces the current-carrying capacity of transmission lines by increasing conductor sag and thermal expansion, thereby raising the risk of clearance violations and outages. Similarly, extreme rainfall contributes to foundation weakening, landslides, and corrosion of structural components, particularly in exposed transmission corridors (IPCC, 2022). Studies in Europe and North America further indicate that climate-induced transmission failures are becoming more frequent, with cascading effects on grid stability and economic productivity (Panteli & Mancarella, 2015). Consequently, modern energy systems are increasingly being redesigned to incorporate climate resilience and adaptive planning frameworks.

Regionally, Africa faces heightened vulnerability due to its relatively low adaptive capacity and infrastructure deficits. According to the World Bank (2021), many Sub-Saharan African countries continue to rely on transmission infrastructure designed under historical climate assumptions, with limited integration of forward-looking climate projections. This exposes power systems to increasing operational risks, especially as the continent experiences rising average temperatures and more erratic rainfall patterns. In East Africa, climate variability has been linked to frequent disruptions in electricity supply networks, particularly where transmission lines traverse flood-prone and semi-arid regions. However, most regional studies have concentrated on hydropower variability and generation-side impacts, leaving transmission infrastructure vulnerability significantly under-researched.

In Kenya, the electricity sector has expanded rapidly over the past two decades, driven by increased demand, regional interconnection projects, and investments in renewable energy. Despite these developments, research has predominantly focused on electricity generation systems, particularly hydropower and geothermal energy, due to their direct sensitivity to rainfall and geothermal conditions (Obuya et al., 2019). Transmission infrastructure, which forms the critical link between generation and consumption, has received comparatively limited empirical attention. Yet, Kenya's transmission network is increasingly exposed to climate-induced stresses such as extreme heat in arid and semi-arid regions and intense rainfall events in highland and coastal zones. These climatic conditions affect conductor performance, tower stability, and right-of-way accessibility, ultimately compromising system reliability.

At the national and local level, Kajiado County presents a particularly important case study due to its climatic and infrastructural characteristics. The county experiences high temperature variability, prolonged dry spells, and episodic heavy rainfall events, all of which directly affect infrastructure stability. Its semi-arid climate contributes to thermal stress on transmission lines, while occasional flash floods and soil erosion events undermine tower foundations and access roads. In addition, Kajiado hosts strategic transmission corridors that connect Nairobi to southern and western Kenya, making it a critical hub for national grid reliability and regional power trade. Despite this strategic importance, there remains limited localized empirical evidence on how extreme temperature and rainfall interact with transmission infrastructure vulnerability and resilience in the county. This constitutes a significant research gap in both academic literature and policy planning.

Furthermore, existing infrastructure planning frameworks in Kenya and other developing economies often rely heavily on historical climate data rather than predictive climate scenarios. Although policy documents increasingly recognize the importance of climate risk integration, implementation remains weak due to institutional capacity constraints, limited technical expertise, and fragmented coordination between energy and climate agencies (World Bank, 2021). As a result, climate adaptation in transmission infrastructure remains largely reactive rather than proactive. This limits the ability of infrastructure systems to anticipate future climate risks, thereby increasing long-term vulnerability.

Electricity transmission systems are therefore increasingly operating under a mismatch between original design assumptions and current climatic realities. This mismatch is particularly evident in regions like Kajiado County, where rising temperatures and rainfall variability are not fully accounted for in infrastructure planning and maintenance strategies. Consequently, there is a growing need for empirical, context-specific studies that examine how climate extremes influence transmission infrastructure performance, vulnerability, and resilience.

This study is therefore motivated by the need to address this gap by examining the effects of extreme temperature and rainfall on the vulnerability and climate resilience of electricity transmission infrastructure in Kajiado County, Kenya. It recognizes that climate impacts are not isolated phenomena but interact with technical design characteristics, environmental conditions, institutional frameworks, and operational practices. Understanding these interactions is essential for strengthening adaptive capacity and improving infrastructure resilience.

By focusing on Kajiado County, the study contributes geographically grounded evidence that is both context-specific and policy-relevant. The findings are expected to inform climate-resilient infrastructure planning, improve maintenance strategies, and support the integration of climate risk assessment into transmission system design. Ultimately, this study contributes to the broader global discourse on climate-resilient energy systems while providing actionable insights for Kenya's energy sector and similar developing contexts.

Therefore, this paper is guided by the following objectives:

i. To assess the effects of extreme temperature on the vulnerability and climate change resilience of electricity transmission infrastructure in Kajiado County, Kenya
ii. To examine the effects of extreme rainfall on the vulnerability and climate change resilience of electricity transmission infrastructure in Kajiado County, Kenya.

LITERATURE REVIEW

Theoretical Framework

This study is anchored on Folke's Resilience Theory, which conceptualizes resilience as the capacity of systems to absorb disturbances, adapt to changing conditions, and transform while maintaining essential functions (Folke, 2006). Originally developed within social-ecological systems thinking and building on Holling's foundational work on ecological resilience, the theory has increasingly been applied to infrastructure systems exposed to environmental shocks and long-term climatic stressors. In the context of electricity transmission infrastructure, resilience is understood as the ability of the system to continue delivering reliable electricity services despite exposure to climate-related disturbances such as extreme temperature and extreme rainfall.

Folke's Resilience Theory is particularly relevant to this study because it shifts focus from static infrastructure performance to dynamic system behavior under stress. It emphasizes three key dimensions: absorptive capacity, which refers to the ability of infrastructure systems to withstand shocks without major functional failure; adaptive capacity, which describes the ability to adjust operational, technical, and managerial processes in response to changing climate conditions; and transformative capacity, which reflects long-term structural or institutional changes that enhance system sustainability under future climatic uncertainty. These dimensions align directly with the study's focus on how electricity transmission infrastructure in Kajiado County responds to climate variability over time.

The theory strongly supports the study's first specific objective on the effects of extreme temperature on the vulnerability and resilience of electricity transmission infrastructure, as extreme heat directly challenges system stability through thermal stress, conductor expansion, and equipment performance degradation. It also supports the second objective on the effects of extreme rainfall, as excessive precipitation introduces risks such as flooding, soil erosion, and structural instability of transmission foundations. Under Folke's framework, these climatic events are treated not only as physical stressors but also as triggers that test the adaptive capacity of the entire infrastructure system.

Despite its strengths, Folke's Resilience Theory has limitations when applied in isolation. It provides a strong conceptual foundation for understanding system adaptation but offers limited operational guidance for quantifying vulnerability or evaluating specific infrastructure components under climatic stress. It also requires integration with empirical methods such as statistical modelling and spatial analysis to fully capture infrastructure performance dynamics. For this reason, the theory in this study is complemented by quantitative approaches such as ordinal regression and Spearman correlation analysis, which operationalize resilience outcomes in measurable terms.

Effects of Extreme Temperature on Vulnerability and Resilience of Electricity Transmission Infrastructure

Extreme temperature is widely recognized as a major climatic stressor affecting the performance and reliability of electricity transmission infrastructure. High ambient temperatures increase conductor resistance, reduce ampacity, and induce thermal expansion, which leads to conductor sagging and increased risk of ground clearance violations. These physical changes increase the likelihood of system faults and operational inefficiencies, particularly in long-span transmission networks. Studies on power systems increasingly emphasize that rising global temperatures are altering the operational boundaries of electricity grids, necessitating adaptive design strategies (Panteli & Mancarella, 2015; IPCC, 2022). From a systems perspective, these impacts are compounded in interconnected infrastructure networks where localized thermal stress can propagate system-wide disturbances (Levin, 1998).

From a resilience perspective, extreme temperature challenges the ability of infrastructure systems to maintain stability and recover from stress. Resilience frameworks emphasize robustness, redundancy, rapidity, and resourcefulness as key dimensions of system performance under stress (Cimellaro et al., 2014). However, extreme heat reduces robustness by accelerating material degradation and increasing equipment failure probability. Adaptive transformation strategies, such as dynamic line rating and high-temperature conductors, are increasingly being explored to enhance system flexibility (Barabadi et al., 2020). Nevertheless, in many developing contexts, limited technological capacity constrains the implementation of such adaptive solutions, thereby increasing vulnerability to thermal stress.

More recent evidence reinforces these concerns. Wenz et al. (2023) demonstrate that compound heat and humidity events increasingly exceed safe operating thresholds for outdoor infrastructure workers and equipment in tropical and sub-tropical regions, undermining maintenance continuity. Similarly, Vautard et al. (2022) project that climate warming will amplify the frequency and intensity of heat extremes in Africa by mid-century, with direct implications for thermal management of transmission conductors. In the East African context, Kisembe et al. (2024) find that increasing dry-season temperatures in semi-arid zones such as Kajiado are already contributing to anomalous conductor ampacity reductions and localized outage events. These findings qualify the statistical insignificance observed in the present study, suggesting that while current climatic conditions may not yet drive measurable statistical effects across the full study sample, localized and future thermal risks remain operationally significant and should inform forward-looking infrastructure planning frameworks.

Effects of Extreme Rainfall on Vulnerability and Resilience of Electricity Transmission Infrastructure

Extreme rainfall significantly influences the vulnerability of electricity transmission infrastructure through hydrological and geomorphological processes. Heavy precipitation events often result in flooding, soil erosion, and waterlogging, which compromise the structural stability of transmission towers and substations. Flood conditions can also restrict access for maintenance and emergency response, increasing downtime and operational costs. In addition, saturated soils reduce foundation stability, particularly in areas with weak geotechnical conditions. These impacts are well documented in infrastructure vulnerability studies, which highlight rainfall as a key driver of system disruption in climate-sensitive regions (Obuya et al., 2019; IPCC, 2022).

Beyond direct physical impacts, rainfall extremes interact with broader infrastructure systems, creating cascading and compounding risks. For example, flooding access roads can delay repair operations, while erosion in upstream areas can destabilize downstream infrastructure components. Multi-hazard frameworks emphasize that infrastructure systems rarely face isolated risks, but rather interconnected hazard chains that amplify overall vulnerability (Argyroudis et al., 2020). This perspective is particularly relevant for electricity transmission networks, which span diverse terrains and environmental conditions. Additionally, scenario-based and probabilistic approaches demonstrate that rainfall-induced failures can trigger cascading disruptions across interconnected systems, including transport and communication networks (Shafieezadeh & Burden, 2014).

Resilience to extreme rainfall depends significantly on engineering design, maintenance capacity, and institutional preparedness. Infrastructure systems with well-designed drainage systems, reinforced foundations, and proactive vegetation management exhibit higher resistance to rainfall-induced disruptions. However, resilience is also influenced by recovery capacity, including the speed at which systems can restore functionality after flooding events. Recovery dynamics studies show that infrastructure systems in developing regions often experience prolonged recovery periods due to resource constraints and limited redundancy (Zhu et al., 2017; Vadali et al., 2015). Furthermore, resilience-based optimization models highlight the importance of integrating economic efficiency with adaptive recovery planning in infrastructure systems exposed to climate hazards (Lau et al., 2018). These findings underscore the need for integrated planning approaches that combine engineering, environmental, and institutional dimensions to enhance resilience under increasing rainfall variability.

Recent scholarship further contextualizes rainfall-related infrastructure vulnerability within changing climate trajectories. Nkechi et al. (2023) document a marked increase in flash flood frequency across East African transmission corridors between 2010 and 2022, with tower foundation erosion identified as the most common failure mechanism. Tabari (2022) confirms that extreme precipitation intensities in semi-arid regions are increasing disproportionately relative to mean rainfall trends, a pattern directly relevant to study areas such as Kajiado. Moreover, Boulange et al. (2023) highlight that existing drainage and foundation standards in sub-Saharan electricity networks were calibrated against historical 50-year return period rainfall events that are now being exceeded more frequently, pointing to a systematic under-preparation in infrastructure design. Collectively, these recent findings qualify the non-significant statistical results of the present study by demonstrating that the absence of measurable current-period statistical effects does not preclude significant future vulnerability, particularly as climate projections indicate worsening rainfall extremes over the study area’s operational horizon.

METHODOLOGY

Research Design

This study adopted a mixed-methods research design combining quantitative and qualitative approaches to examine the effects of extreme temperature and extreme rainfall on the vulnerability and resilience of electricity transmission infrastructure in Kajiado County, Kenya. The mixed-methods approach was selected to enable triangulation of statistical results with contextual insights from field experts, thereby enhancing the validity and depth of findings. Quantitative methods were used to assess statistical relationships between climate variables and infrastructure resilience, while qualitative methods were used to interpret operational realities and system-level dynamics. This integrated approach aligns with infrastructure resilience research frameworks that emphasize multi-dimensional analysis of complex systems (Cimellaro et al., 2014; Argyroudis et al., 2020).

Study Area

The study was conducted in Kajiado County, located in southern Kenya. The county is characterized by semi-arid climatic conditions, high temperature variability, and increasingly erratic rainfall patterns. It forms part of a critical corridor for Kenya’s national electricity transmission network, connecting major generation and load centres. The area is also exposed to climate-related hazards such as flooding, soil erosion, and prolonged dry spells, which affect infrastructure stability and accessibility. These conditions make Kajiado County an appropriate case study for assessing climate impacts on electricity transmission resilience under real-world operational conditions.

Data Collection Methods

Primary data was collected using structured questionnaires administered to electricity transmission experts, including engineers, environmental specialists, economists, and infrastructure planners. The questionnaire captured perceptions on extreme temperature effects, extreme rainfall effects, and infrastructure resilience outcomes. In addition, key informant interviews were conducted to obtain qualitative insights into operational challenges such as equipment overheating, line sagging, flooding impacts, and maintenance constraints.

Secondary data was obtained from authoritative sources including the Kenya Meteorological Department, World Bank databases, African Development Bank reports, and the IPCC. Supplementary spatial data such as flood risk maps and terrain information were obtained from GIS databases and national disaster management agencies. These datasets provided contextual support for assessing environmental exposure and infrastructure vulnerability.

Variables and Measurement

The study variables were categorized into independent, intervening, and dependent variables. The independent variables included extreme temperature and extreme rainfall, representing climate stressors. The dependent variable was electricity transmission infrastructure vulnerability and resilience, conceptualized as system performance under climatic stress. Intervening variables included socioeconomic factors, technical system characteristics, environmental conditions, and policy and regulatory frameworks.

All variables were measured using a structured Likert-scale instrument, where respondents rated perceived impacts and resilience levels. This enabled ordinal-level measurement suitable for non-parametric statistical analysis. The conceptual framework assumed that climate variables influence resilience both directly and indirectly through intervening institutional and technical conditions.

Data Analysis Methods

Quantitative Analysis

Quantitative data were analyzed using ordinal regression analysis and Spearman rank correlation analysis. The ordinal regression model was selected because the dependent variable (resilience level) was ordinal in nature and did not meet assumptions of normality. The model estimates the probability of infrastructure resilience categories under varying climate conditions. Spearman correlation analysis was used to assess monotonic relationships between variables due to non-normal data distribution.

GIS Analysis

GIS were used to assess spatial exposure of electricity transmission infrastructure to climate hazards. GIS analysis incorporated flood risk mapping, elevation profiling, and terrain classification to evaluate vulnerability hotspots. This spatial approach is consistent with multi-hazard resilience assessment frameworks that emphasize the role of environmental context in infrastructure vulnerability (Argyroudis et al., 2020).

Qualitative Analysis

Qualitative data from interviews were analyzed using thematic content analysis. Key themes included overheating equipment, conductor sagging, flooding disruptions, soil erosion, and maintenance accessibility challenges. These insights were used to complement statistical findings and provide a systems-level understanding of infrastructure resilience dynamics.

Ethical Considerations

The study ensured ethical compliance through informed consent, confidentiality of respondents, and voluntary participation. Data collected was used strictly for academic purposes. Respondents' identities were anonymized to ensure privacy and adherence to research ethical standards.

RESULTS

Quantitative Findings

To determine the relationship between extreme rainfall and the climate change resilience of electricity transmission infrastructure in Kajiado County, a Spearman correlation analysis was conducted. The results are presented in Table 1.

Table 1 presents the Spearman correlation coefficient between extreme rainfall and infrastructure resilience. The coefficient indicates the strength and direction of the monotonic association between these two variables. A negative coefficient suggests that higher levels of extreme rainfall are associated with reduced resilience, while statistical significance ($p < 0.05$) would confirm the reliability of this relationship in the study context.

Table 1: Extreme Rainfall and Climate Change Resilience of Electricity Transmission Infrastructure in Kajiado County, Kenya

Variable	Resilience Correlation (ρ)	p-value	Interpretation
Extreme Rainfall	-0.083	0.45	Not significant

To further validate this relationship, an ordinal regression model was estimated, with the results presented in Table 2.

Table 2 presents the ordinal regression model output for extreme rainfall as a predictor of infrastructure resilience. The model estimates the probability of transitioning across resilience categories given varying levels of rainfall extremes, with the Wald statistic indicating the contribution of the predictor and the 95% confidence interval reflecting the precision of the regression estimate.

Table 2: Ordinal Regression Model for Extreme Rainfall

Predictor	Estimate	Std. Error	Wald	df	Sig.	95% CI (Lower–Upper)
Extreme Rainfall	-0.508	0.286	3.151	1	0.076	-1.068 to 0.053

Having examined the effects of extreme rainfall, the analysis turns to extreme temperature. The quantitative results indicated that extreme temperature did not have a statistically significant effect on the vulnerability and climate change resilience of electricity transmission infrastructure in Kajiado County. The Spearman correlation result ($\rho = -0.011$, $p = 0.921$) showed a very weak negative relationship between extreme temperature and resilience. This implies that increases in extreme temperature were associated with a negligible reduction in resilience levels; however, the relationship was not statistically significant.

Similarly, the ordinal regression analysis ($\beta = 0.031$, $p = 0.894$) confirmed that extreme temperature was not a significant predictor of infrastructure resilience. This suggests that, within the study context, extreme temperature alone was not sufficient to explain variations in the resilience of electricity transmission infrastructure.

Table 3 presents the Spearman correlation coefficient between extreme temperature and infrastructure resilience. The correlation coefficient captures the monotonic relationship between increasing temperature extremes and resilience outcomes, thereby indicating whether higher thermal stress is systematically associated with lower resilience levels in the study area.

Table 3: Spearman Correlation Extreme Temperature and Climate Change Resilience of Electricity Transmission Infrastructure in Kajiado County, Kenya

Variable	Resilience Correlation (ρ)	p-value	Interpretation
Extreme Temperature	-0.011	0.921	Not significant

Table 4 presents the ordinal regression model output for extreme temperature as a predictor of infrastructure resilience. The regression estimate, associated standard error, and Wald statistics are reported together with the significance level and 95% confidence interval, allowing an assessment of whether extreme temperature exerts a statistically meaningful influence on the probability of different resilience outcomes.

Table 4: Ordinal Regression Model for Extreme Temperature

Predictor	Estimate	Std. Error	Wald	df	Sig.	95% CI (Lower–Upper)
Extreme Temperature	0.031	0.234	0.018	1	0.894	-0.427 to 0.489

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The findings further showed that extreme rainfall had a weak negative relationship with infrastructure resilience ($\rho = -0.083$, $p = 0.450$), although the relationship was not statistically significant at the 5% level. This indicates that higher rainfall extremes were associated with slightly lower resilience, but the effect remained weak in statistical terms.

The ordinal regression results ($\beta = -0.508$, $p = 0.076$) showed that extreme rainfall had a stronger influence compared to temperature and was close to statistical significance. This suggests that rainfall extremes may have a more pronounced effect on infrastructure resilience, although not strong enough to be considered statistically significant in this study.

Overall, the quantitative results showed that both extreme temperature and extreme rainfall were not statistically significant predictors of electricity transmission infrastructure resilience in Kajiado County. However, both variables exhibited negative relationships with resilience, indicating that increases in climate extremes may still contribute to reduced resilience, though indirectly or in combination with other non-climatic factors such as infrastructure design, maintenance systems, and institutional capacity.

The qualitative findings provided contextual explanations for the quantitative results by highlighting the practical effects of climate extremes on electricity transmission infrastructure. Regarding extreme temperature, respondents reported operational challenges such as conductor sagging, transformer overheating, and reduced equipment efficiency during periods of high heat. These effects were more evident during prolonged dry and hot seasons, where thermal stress increased the risk of operational strain. However, respondents also noted that many of these effects were managed through engineering design standards and routine maintenance, which reduced their severity.

In relation to extreme rainfall, respondents identified more disruptive impacts, including flooding of substations, erosion around transmission tower foundations, waterlogging of access roads, and delayed maintenance and fault response activities. These conditions were reported to significantly affect accessibility and system recovery during extreme weather events.

A key theme emerging from the qualitative data was that climate impacts were indirect and context-dependent rather than isolated drivers of vulnerability. Respondents emphasized that the severity of climate effects depended on factors such as terrain type, soil stability, drainage systems, and infrastructure design quality. Areas with weak soils and poor drainage experienced more pronounced rainfall-related disruptions.

Another important finding was the role of adaptive capacity and system resilience mechanisms. Respondents indicated that transmission infrastructure exhibited some resilience due to engineering design standards, redundancy in the grid system, and regular maintenance practices. These factors helped to buffer the direct impacts of climate extremes, thereby reducing observable statistical effects.

Overall, the qualitative findings revealed that although extreme temperature and rainfall were not statistically significant predictors in the quantitative analysis, they still had practical operational impacts that influenced system performance. These effects were largely indirect and mediated through environmental, technical, and institutional factors.

The findings of this study reveal that extreme temperature and extreme rainfall are not statistically significant predictors of electricity transmission infrastructure vulnerability and resilience in Kajiado County. This result is contrary to a large body of literature that positions climatic extremes as primary drivers of infrastructure disruption (IPCC, 2022; Panteli & Mancarella, 2015). However, the observed insignificance does not imply that climate variables are irrelevant; rather, it suggests that their effects are mediated through technical, socioeconomic, and governance systems.

The weak and non-significant relationship between extreme temperature and resilience ($r = -0.011$, $p = 0.921$) aligns with findings that modern transmission systems possess inherent thermal tolerance due to engineering design improvements (Lau et al., 2018). However, field evidence contradicts this statistical neutrality, revealing operational stress in the form of conductor sagging and transformer overheating. This confirms that statistical insignificance may mask localized but operationally meaningful impacts.

Similarly, extreme rainfall exhibited a weak negative correlation with resilience ($r = -0.083$, $p = 0.450$), suggesting limited direct statistical influence. Nevertheless, qualitative findings demonstrate that rainfall-induced flooding, soil erosion, and restricted accessibility significantly disrupt maintenance and operational continuity. These findings align with Obuya et al. (2019), who argue that infrastructure vulnerability in Kenya is often spatially and contextually mediated.

CONCLUSION

The study concludes that extreme temperature and extreme rainfall, when examined in isolation, do not exhibit statistically significant direct effects on the vulnerability and climate change resilience of electricity transmission infrastructure in Kajiado County. However, this does not imply that climate variability is inconsequential; rather, its impacts are largely indirect, emerging through interactions with infrastructure design limitations, maintenance capacity, environmental conditions, and institutional preparedness. The findings demonstrate that while transmission systems in the study area show a degree of resilience due to engineering design tolerances and operational redundancy, they remain susceptible to climate-related operational disruptions, particularly those associated with rainfall-induced hazards. Overall, the study reinforces the argument that infrastructure resilience is a multi-dimensional construct that cannot be fully explained by climatic variables alone but must be understood within a broader socio-technical and environmental systems framework.

RECOMMENDATIONS

The study recommends the integration of climate-informed design standards into electricity transmission infrastructure planning to ensure that both current and future climate extremes are adequately considered in engineering specifications. There is also a need to strengthen predictive climate risk assessment frameworks by incorporating downscaled climate projections into infrastructure planning and maintenance schedules, rather than relying primarily on historical climate data. Additionally, the study recommends enhanced investment in adaptive maintenance systems, including improved drainage around substations, reinforced tower foundations in erosion-prone areas, and rapid-response maintenance mechanisms during extreme rainfall events. Finally, it is recommended that institutional coordination between energy agencies, meteorological departments, and infrastructure planners be strengthened to support data-driven decision-making and enhance long-term.

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