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Research Article

Impact of Climate Change on Structural Design Damage and their Mitigation Strategies in Bauchi State Nigeria

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Abstract

This study investigates the impact of climate change on structural design damage and their mitigation strategies in Bauchi state Nigeria. Climate change marked by rising temperatures, extreme weather events and shifting rainfall patterns poses increasing risks to the integrity and lifespan of civil infrastructures including roads, buildings and drainages. This challenges traditional design standards which assumes climatic stability, making infrastructure more vulnerable to flooding, heat stress and material degradation. Using the Yamane formular, a sample size of 398 respondents was selected from a total population of 6352(2023 census). A stratified sampling technique and survey research design approach were employed. Findings reveal that most structural designs in Bauchi still follow conventional standards with minimal integration of climate change projections and existing resilience measures are largely reactive. The study concludes that adaptive infrastructure, climate informed design and performance monitoring are essential for long-term resilience. It recommends updating building codes to include climate resilience data, conducting vulnerability assessments, and promoting the use of durable, flexible and energy-efficient materials capable of withstanding extreme conditions.

Keywords: *Climate Change, Structural Design, Resilience, Yamane Formula.*

INTRODUCTION

Rising temperatures, increased frequency of extreme weather events, changes in precipitation patterns, and shifts in wind loads have collectively imposed new demands on infrastructure design and construction (IPCC, 2021). These impacts are not only global but can also be felt locally, particularly in developing countries like Nigeria where vulnerabilities are amplified by socioeconomic and environmental factors (NIMET, 2020).

Climate change is increasingly recognized as a critical factor influencing the design, performance, and resilience of civil infrastructures. Rising global temperatures, extreme weather events, sea-level rise, and shifts in precipitation patterns can have profound implications for the structural integrity of buildings, bridges, and other critical infrastructure. According to the Intergovernmental Panel on Climate Change (IPCC, 2021), the global mean temperature has increased by approximately 1.2°C above pre-industrial levels, with projections indicating further warming, intensifying extreme weather events such as storms, floods, and heatwaves. These changes necessitate a rethinking of structural design practices to account for the more volatile environmental conditions anticipated in the coming decades.

One key impact of climate change on structural design is the increased risk of extreme weather events. Rising temperatures can lead to more frequent and severe heatwaves, which can cause thermal expansion of materials, leading to deformation or even failure of structural components (Foster et al., 2018). Additionally, more intense storms and hurricanes, compounded by rising sea levels, exacerbate the vulnerability of coastal and low-lying infrastructure.

Structural elements designed to withstand historical climate conditions may no longer perform adequately under future scenarios, necessitating the adoption of more robust and adaptive design strategies. As noted by Akinmoladun et al. (2020), traditional design codes and materials may not provide sufficient resilience against future extreme weather events and shifting climate patterns.

In response to these challenges, there has been a growing emphasis on integrating climate adaptation strategies into the design and planning of infrastructure. Engineers are increasingly incorporating climate projections into their models to account for more extreme temperature ranges, precipitation levels, and storm intensities (Kuhn et al., 2017). These models, however, are often subject to significant uncertainty due to the unpredictable nature of climate change. This has led to the development of resilience-based design strategies, which prioritize flexibility, redundancy, and the ability to adapt to changing conditions over time. Resilience-oriented approaches seek to enhance the capacity of structures to recover from extreme events rather than simply prevent damage, acknowledging that some degree of failure is inevitable in a more volatile climate.

Bauchi State, located in the northeastern part of Nigeria, is increasingly experiencing the adverse effects of climate variability. Research carried out in the last three decades, indicate that rising temperatures and erratic rainfall behaviours negatively impact essential soil properties in Bauchi state, creating substantial risk for structural foundations and infrastructure durability (Muhammad Suleiman et al., 2025).

To counter increasing risks posed by climate change in Bauchi state, current structural and urban planning practices require significant reform. (Ndububa & Mukaddas, 2016). According to Usman et al., (2025), Urban planning, revised building codes and passive design strategies are some of the strategic shifts required for effective climate –resilient design in regions such as Bauchi. These measures are essential for transitioning from traditional construction methods toward sustainable, climate-adaptive infrastructure capable of withstanding the unpredictability of shifting environmental conditions. (Eze, et al., 2024).

Understanding the impact of climate change on structural design within Bauchi is therefore vital for enhancing the resilience of infrastructure. This involves not only assessing current vulnerabilities but also evaluating the extent to which adaptive strategies are being employed in ongoing construction practices. Such insights are essential for informing future building codes, urban planning regulations, and climate adaptation policies that are tailored to the specific climatic threats facing Bauchi.

DEFINITION OF TERMS

Climate change

Climate change refers to statistically significant, long-term alterations in global or regional climate patterns, typically persisting for decades or longer. These changes affect temperature, precipitation, sea levels, and the frequency and intensity of extreme weather events. Although climate variability has occurred naturally throughout Earth's history, the current pace and scale of change are largely anthropogenic driven by increased greenhouse gas (GHG) emissions due to industrial activities, deforestation, urbanization, and the unsustainable exploitation of natural resources (IPCC, 2021).

Structural Design

Structural design refers to the systematic process by which buildings and other civil engineering structures are planned, analysed, and constructed to ensure stability, strength, safety, serviceability, and sustainability under expected loads and environmental conditions (McCormac & Nelson, 2014). It involves careful selection of materials, load estimation, geometrical configuration, and application of design codes to produce efficient and durable structures that meet both functional and aesthetic needs. At its core, structural design aims to ensure that structures can safely carry the loads imposed on them—dead loads (permanent/static), live loads (temporary/dynamic), environmental loads (wind, snow, seismic), and climate-induced stresses such as thermal loads and flood pressures—without experiencing excessive deformation, instability, or failure (Nilson, Darwin & Dolan, 2010). The design must also account for long-term factors such as creep, shrinkage, fatigue, and corrosion.

Resilience Strategies

Resilience strategies in structural design refer to the set of methods, principles, and innovations aimed at enhancing the ability of buildings and infrastructure to withstand, adapt to, and recover from adverse environmental and climate-related events. These strategies are becoming increasingly important due to the growing frequency and intensity of climate-induced hazards such as flooding, heatwaves, heavy rainfall, strong winds, and rising sea levels. The central objective of incorporating resilience into structural design is to ensure that buildings remain safe, functional, and durable under both predictable and unforeseen environmental conditions (Davoudi et al., 2012; Folke, 2006).

Resilience Theory

Resilience Theory emerged from the field of ecology and was first articulated by Holling (1973), who defined resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change, so as to still retain essentially the same function, structure, identity, and feedback." In the context of built environments and structural design, resilience refers to the ability of buildings and infrastructure systems to maintain core functions during and after exposure to climatic stresses such as extreme weather events, temperature fluctuations, and flooding (Folke, 2006; Davoudi et al., 2012).

Sustainable Design Theory

Sustainable Design Theory Complements Resilience Theory by focusing on how structures can be planned, constructed, and maintained in ways that minimize environmental impact and promote long-term ecological and economic balance. The core idea is to "meet the needs of the present without compromising the ability of future generations to meet their own needs," as originally defined by the Brundtland Report (WCED, 1987).

In structural design, sustainability translates into the responsible use of resources, energy efficiency, and lifecycle-conscious construction. This includes selecting low-carbon materials, reducing construction waste, maximizing natural lighting and ventilation, and designing buildings that require minimal energy for heating or cooling (Kibert, 2016). Sustainable buildings are often designed with an emphasis on adaptability and durability, thus reducing the need for costly and resource-intensive retrofits in response to climate change.

Structural Design Practices under Climate Change Challenges

Several studies have revealed that conventional design approaches, which often rely on historical climate data, are inadequate in the face of current and projected climate variability. For instance, Adelekan et al. (2015) examined building practices in coastal Nigeria and found that a significant number of residential structures were designed without considerations for sea-level rise or extreme rainfall events, making them increasingly susceptible to climate-induced stressors. Similarly, Santamouris (2016) noted that buildings in many global cities still prioritize cost efficiency and aesthetics over thermal comfort and climate adaptability, leading to increased indoor overheating and mechanical cooling demand.

Aim and Objectives of the Study

The aim of this study is to examine the Impact of climate change on structural design damage and their mitigation strategies in Bauchi State Nigeria. The specific objectives are: To analyse the structural design practices in the face of climate change challenges in Bauchi state, to assess the potential risks and vulnerabilities of existing structures to climate change impacts in Bauchi state, to identify the strategies that improve the resilience and performance of buildings and infrastructure in Bauchi state. And finally, to assess the impact of integrating climate change factors into design and construction in Bauchi state.

RESEARCH METHODOLOGY

Research Design

A quantitative method i.e survey research design was adopted due to its appropriateness to the topic under investigation. Survey design is a scientific method which involves observing and describing the behaviour of the subjects without influencing data for the purpose of answering research question under study (Gemson & Kyamru, 2021). The study is based on assessing the Impact of climate change on structural design damage and their mitigation strategies in Bauchi State Nigeria. It is based on an in-depth investigation of individual group and exploring causation to find the underlying principles.

Population of the Study

The population of the study comprises of the stakeholders, local engineers, architects, builders and urban planners, from relevant government agencies such as the Bauchi State Ministry of Environment and the Ministry of Housing and Urban Development. The study considered climate trends and structural developments within the past 10–15 years. Detailed economic or cost-benefit analyses of climate adaptation technologies were also evaluated. Emphasis was mainly on practical, context-specific insights that can inform local policy, planning, and construction practices.

Table 1: Distribution of Respondents According to Departments in Bauchi State Civil Service.

S/N	Designation	Sector	Frequency	Percentage (%)
1	Stakeholders	Ministry of Works	1,270.46	20.00%
2	Architects	Ministry of Housing	1,270.46	20.00%
3	Builders	Ministry of Urban Development	1,270.46	20.00%
4	Urban Planners	Ministry of Budget and Planning	1,270.46	20.00%
5	State Civil Service	Ministry of Environmental	1,270.46	20.00%
Total			**6,352.30**	**100%**

Sampling Design

Simple random sampling techniques were used to collect the sample size from the population. This sampling technique was selected due to its flexibility.

Sample Size

The sample size of this study was derived using the Yamane's formular stated as follows:

$$n = \frac{N}{1 + N(e)^2}$$

Where;

n = Sample size

N = the total population of the stakeholders, local engineers, architects, builders, urban planners, etc

e = Error margin (5%)

1 = Constant

Therefore,

$$\text{Sample size, n} = \frac{6352.3}{1 + 6352.3(0.05)^2}$$

$$\text{Sample size}, n = 398$$

Sampling Technique

Systematic sampling techniques were employed to obtain data and relevant information for the study.

Data Collection

Questionnaires were administered as instruments of data collection. Respondents were provided with guidelines on how to respond to the questions, but independent responses were also allowed. Face-to-face method of administration was used, with each respondent given considerable time to answer the questions.

Instruments were developed to obtain the required information required to address the various objectives of the study. The four (4) points Likert's scale was scored as follows: Strongly agree, 1 point; Agree, 2 points; Disagree, 3 points; and Strongly Disagree, 4 points. The questionnaire consisted of five sections, namely A to E. Section A is on the demographic information of the respondents; section B contains information required in addressing objective one, i.e. To analyze the structural design practices in the face of climate change challenges in Bauchi state. Section C addresses objective 2 i.e. To assess the potential risks and vulnerabilities of existing structures to climate change impacts in Bauchi state. While section D, tackles objective 3 i.e. To identify strategies that improve the resilience and performance of buildings and infrastructure in Bauchi state. Section E contains information on objective 4 i.e. To assess the impact of integrating climate change factors into design and construction in Bauchi state.

Instrument Reliability and Validity

To ensure the reliability and content validity of the instrument, the researcher structured questionnaire was submitted for vetting to ensure their appropriateness, relevance and clarity. Test-re-test reliability method was employed to establish the reliability of the research instrument. In test-re-test reliability, the same measuring instrument was used to obtain two separate measurements on the same population at different times. The higher the degree of correlation between the two measurements, the higher the reliability of the instrument.

Data Analysis

The data was collected and analyzed using descriptive statistical analysis. This entails the use of frequency curves and percentages presented into table. This includes descriptive statistics of frequencies, percentages, means and standard deviations. Inferential statistics of Pearson Product Moment Correlation Coefficient analysis was used to test the hypothesis. All tests were carried out at 0.05 alpha level of significance. Correlation and regression analysis were conducted to establish the association between dependent and independent variables. The independent variables are structural design practices, potential risks and vulnerabilities, resilience and performance, design and construction, while the dependent variables are: impact of climate change on structural design and resilience strategies.

RESULT AND DISCUSSION

The chapter presents the results of the study based on the data collected using the methodology espoused in the previous chapter. The data was analyzed using the Statistical Package for Solutions and Services (SPSS) and visualized using Microsoft Power BI. This chapter is organized into two main sections. The first sections consist of the demographic information of respondents on Impact of climate change on structural design damage and their mitigation strategies in Bauchi State Nigeria on the structural design practices, potential risks and vulnerabilities, strategies that improve the resilience and performance and integrating climate change factors. In the second section, the main findings on the structural design practices, potential risks and vulnerabilities, strategies that improve the resilience and performance and integrating climate change factors are presented.

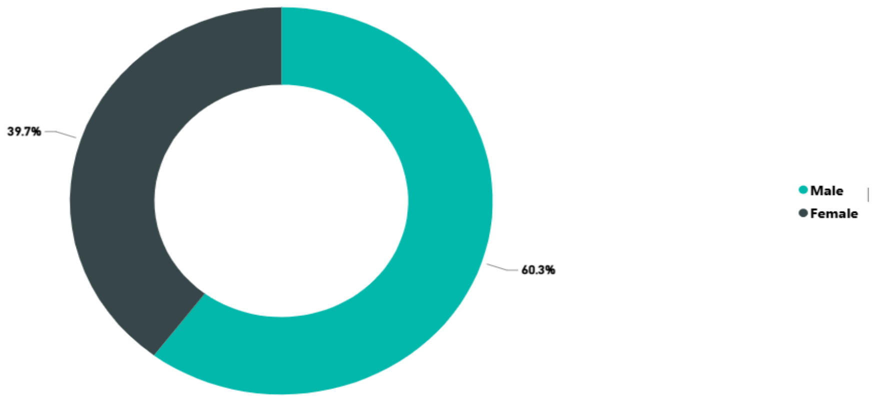

Figure 1: Distribution of respondents according to gender

Figure 1 shows that out of 398 respondents, 240 were male (60.3%) while 158 were female (39.7%). This indicates a clear gender imbalance in the sample, with a significantly higher number of male participants. Such a distribution may reflect either the actual composition of the target population or a skew introduced during the sampling process. The lack of missing data ensures that the gender breakdown is complete.

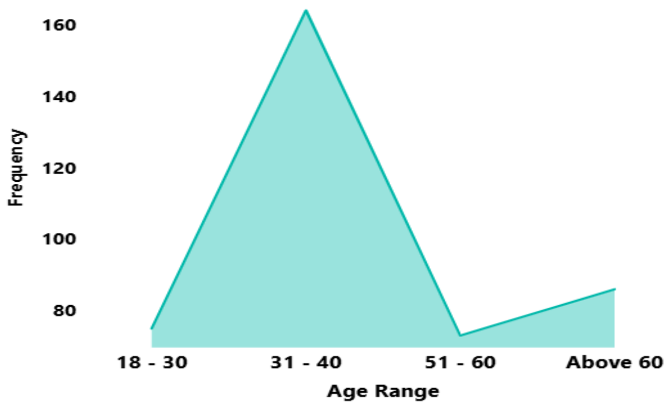

Figure 2: Distribution of Respondents according to Age range

Figure 2 presents the age distribution of the 398 respondents categorized into four ranges. The largest age group is 31–40 years, comprising 41.2% of the total sample, followed by those above 60 years at 21.6%. The 18–30 and 51–60 age groups are nearly equal, representing 18.8% and 18.3% respectively. This distribution suggests that the sample is largely composed of individuals in their early to mid-career stages, particularly those in the 31–40 age bracket. The presence of a notable proportion of older respondents, especially those above 60, adds generational diversity to the dataset. However, younger adults (18–30) are underrepresented in comparison. This could have implications for the interpretation of findings if age is expected to influence perceptions or behaviors relevant to the study. It may also suggest that the issues under investigation are of greater interest or relevance to more mature age groups. Overall, the age spread supports a moderately diverse demographic profile, but any conclusions should consider the relative underrepresentation of the youngest cohort.

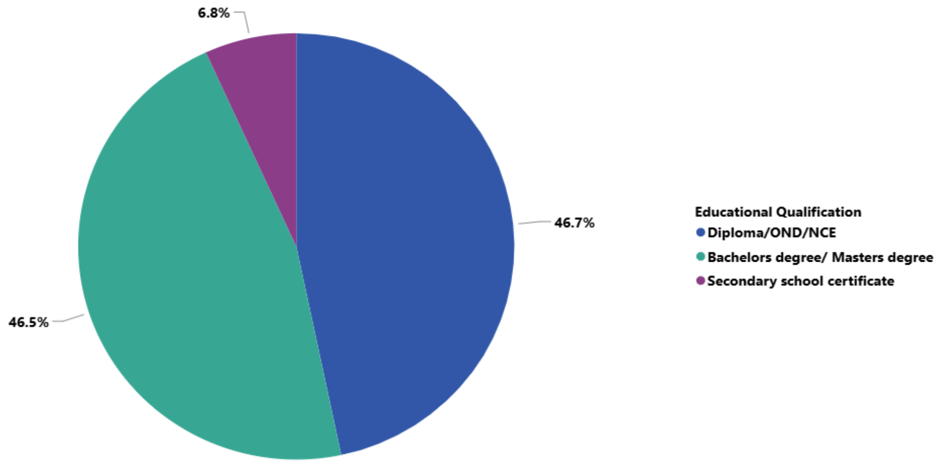

Figure 3: Educational Qualification of Respondents

Figure 3 presents the educational qualifications of the 398 respondents. The data shows that a majority hold either a diploma or higher education degree. Specifically, 46.7% have a Diploma/OND/NCE, while 46.5% possess a bachelor's or master's degree. Only 6.8% have attained education up to the secondary school level. This distribution reflects a highly educated sample, with over 93% of respondents having qualifications beyond secondary education. Such a profile suggests that the respondents are likely to have a considerable level of literacy, technical knowledge, or professional training, which may influence their perspectives, decision-making, or engagement with the subject under study. The near-equal distribution between diploma holders and those with university degrees also introduces a balanced educational dynamic within the higher-educated segment.

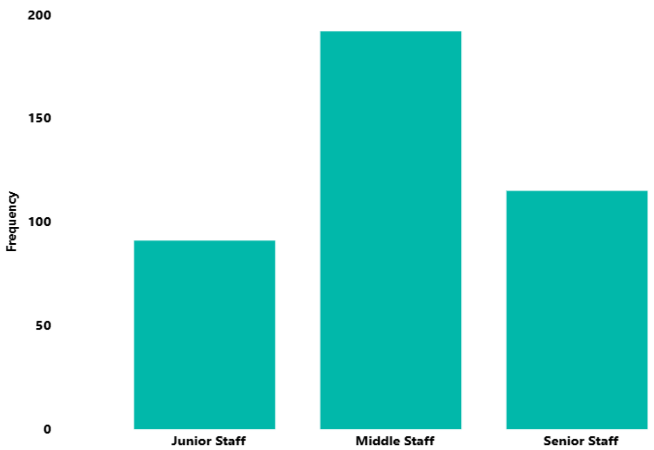

Figure 4: Positions/designation of Respondents

Figure 4 presents the distribution of respondents based on their position or designation within the ministry. Among the 398 individuals surveyed, the largest group falls within the middle staff level, accounting for 48.2% of the sample. Senior staff members make up 28.9%, while junior staff constitute 22.9%. This indicates that nearly half of the respondents occupy mid-level positions, suggesting that the study captures insights from individuals who likely possess both operational experience and a degree of administrative responsibility. The substantial representation of senior staff adds perspectives from those in decision-making or supervisory roles, while the inclusion of junior staff ensures that lower-level operational viewpoints are not excluded. Overall, the distribution offers a broad view across different hierarchical levels in the ministry, enhancing the comprehensiveness of the data. However, the relatively lower representation of junior staff may imply that their specific challenges or contributions could be underrepresented in the findings.

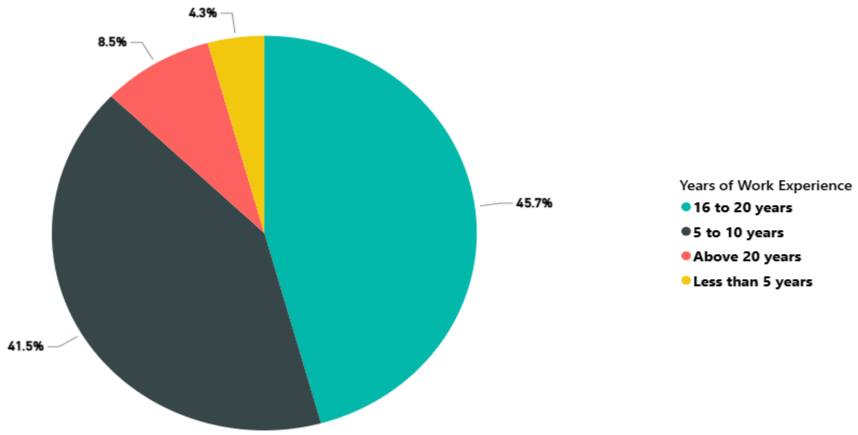

Figure 5: Respondents years of Work Experience

Figure 5 outlines the years of work experience among respondents in the public sector. The data reveals that the majority have substantial experience, with 45.7% having worked for 16–20 years and 41.5% with 5–10 years of experience. A smaller proportion, 8.5%, reported over 20 years of service, while only 4.3% had less than 5 years of experience. This distribution indicates that the sample is predominantly composed of seasoned public sector employees, with over 95% having more than 5 years of experience. This suggests that the insights gathered are likely to be grounded in significant practical knowledge and institutional familiarity. The dominance of mid- to late-career professionals may enhance the reliability of responses related to long-term policy, administrative processes, or public service delivery. However, the relatively small representation of newer employees could mean that perspectives from those just entering the sector are underrepresented, which might limit understanding of onboarding challenges or early-career development issues within the public system.

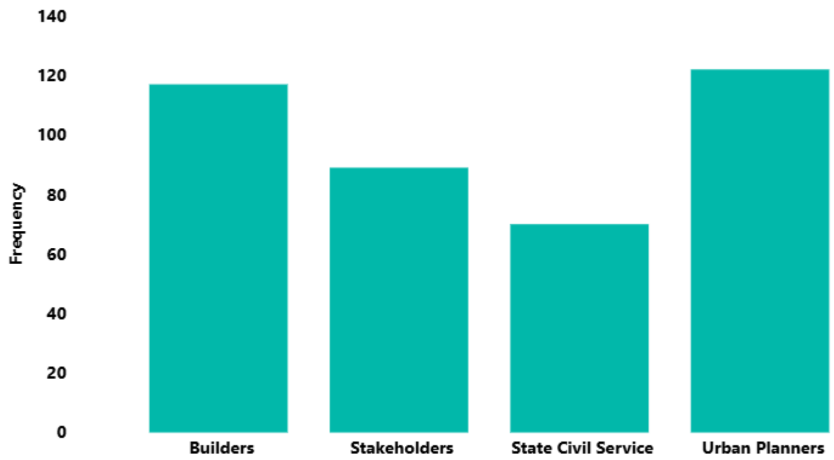

Figure 6: Respondents Department/Unit

Figure 6 presents the distribution of respondents across different departments or units. The largest group comprises urban planners, who represent 30.7% of the sample, followed closely by builders at 29.4%. Stakeholders account for 22.4%, while those from the state civil service make up the remaining 17.6%. This spread indicates a relatively balanced representation among key professional groups relevant to urban development and governance. The strong presence of urban planners and builders suggests that the data is rich in technical and planning-related perspectives, which could be critical if the study focuses on infrastructure, policy implementation, or land use. The inclusion of stakeholders and civil servants adds diversity, incorporating voices from administrative and community-focused roles. However, the slightly lower representation of state civil service staff may imply that broader bureaucratic or policy-level views are less prominent.

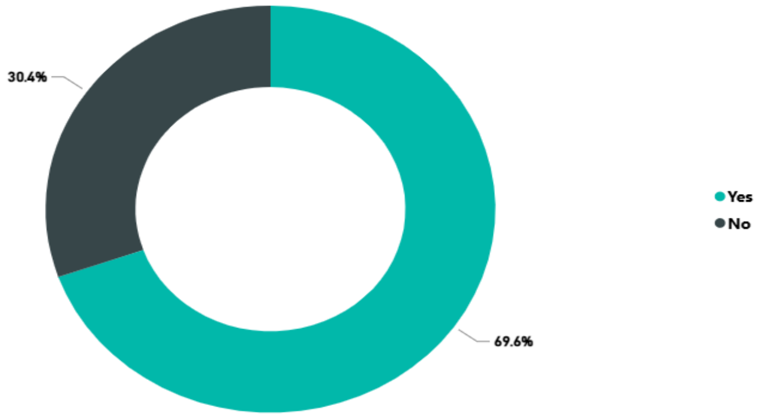

Figure 7: Respondents' knowledge on climate change

Figure 7 presents data on respondents' knowledge of climate change. Out of 398 individuals, 277 (69.6%) indicated that they are knowledgeable about climate change, while 121 (30.4%) reported that they are not. This suggests a high level of awareness among most respondents, which is significant, especially if the study explores environmental policies, sustainability, or climate related initiatives. The strong knowledge base among nearly 70% of participants may contribute to more informed opinions and responses regarding climate change issues. However, the fact that nearly a third of respondents lack awareness highlights a gap that could affect policy communication, community engagement, or implementation of climate strategies. This split also underscores the importance of targeted education and awareness programs within the public sector to ensure a more uniformly informed workforce.

Table 2: Model Performance Evaluation

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.485[a]	.235	.227	.29942

Table 2 presents the model summary for a regression analysis. The R value of 0.485 indicates a moderate positive correlation between the independent variables and the dependent variable. The R Square value of 0.235 shows that approximately 23.5% of the variance in the dependent variable is explained by the model.

The Adjusted R Square, which accounts for the number of predictors and adjusts for sample size, is slightly lower at 0.227, confirming that the model explains about 22.7% of the variance after adjusting for potential inflation. This difference between R Square and Adjusted R Square is small, suggesting a relatively stable model without excessive over fitting.

The Standard Error of the Estimate (0.29942) reflects the average distance that the observed values fall from the regression line. A lower value indicates better model fit, but in this case, interpretation depends on the scale of the dependent variable. Overall, the model demonstrates a modest but statistically meaningful explanatory power. While it does not account for most of the variability in the outcome, it suggests that the predictors included do have a noteworthy influence, though additional variables or model refinement could potentially improve its predictive strength.

Table 3: Model ANOVA Analysis

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	10.821	4	2.705	30.176	.000[b]
1	Residual	35.233	393	.090		
	Total	46.055	397			

a. Dependent Variable: Climate changes

b. Predictors: (Constant), Structural design practices, Potential risks and vulnerabilities, Resilience and performance, Design and construction

The ANOVA table above tests the overall significance of the regression model used to assess how well the independent variables structural design practices, potential risks and vulnerabilities, resilience and performance, and design and construction predict the dependent variable, climate changes.

The F-value of 30.176 and the significance level (p-value) of .000 indicate that the model is statistically significant. This means there is a very low probability that the observed relationship occurred by chance.

The regression sum of squares (10.821) compared to the residual (35.233) suggests that the model explains a notable portion of the variance in the dependent variable. With a total sum of squares of 46.055, the model accounts for approximately 23.5% of the variance (as shown earlier in the R^2 value from the model summary), confirming the explanatory strength of the predictors.

The combination of the four independent variables significantly predicts climate change-related outcomes in the study context, validating the relevance of these factors in designing climate-responsive infrastructure in Bauchi State.

Table 4: Model Regression Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	.134	.292		.460	.646
	Structural design practices	.018	.049	.018	.367	.714
1	Potential risks and vulnerabilities	.034	.057	.033	.602	.548
	Resilience and performance	.397	.043	.523	9.199	.000
	Design and construction	.389	.077	.251	5.016	.000

a. Dependent Variable: Climate changes

Table 4 presents the coefficients for each predictor variable in the regression model that examines their influence on climate-related outcomes.

Resilience and performance have the highest standardized beta coefficient (0.523), indicating it is the strongest predictor of climate change impact perception or response. It is also statistically significant (p = .000), with a very high t-value (9.199), showing a robust contribution to the model.

Design and construction also contribute significantly (Beta = 0.251, p = .000), suggesting how integrating climate change into construction practices strongly affects climate responsiveness.

In contrast, structural design practices (p = .714) and potential risks and vulnerabilities (p = .548) are not statistically significant predictors in the model. Their low beta values and high p-values imply that they do not have a meaningful independent effect when other variables are controlled.

The constant value (0.134) is not significant, which means the model's predictive power is mainly driven by the independent variables rather than any baseline effect.

The results highlight that resilience and performance strategies, along with climate-informed design and construction, are the key factors significantly influencing responses to climate change in Bauchi State. This underscores the importance of focusing on adaptive infrastructure and performance monitoring over simply adhering to traditional design norms or general risk awareness.

CONCLUSION

The study concludes that climate change is a critical factor influencing structural safety and sustainability in Bauchi State, but current design practices and resilience strategies are not sufficiently aligned to mitigate future risks. There is an evident mismatch between knowledge and implementation: although many professionals understand the challenges posed by climate change, this awareness has not yet translated into widespread adoption of resilient design and construction methods. Existing structures remain vulnerable to climate-induced stresses, and the absence of proactive adaptation strategies leaves infrastructure increasingly exposed. Integrating climate considerations into all phases of design and construction is no longer optional but a necessity. The study concludes that climate change is already influencing the environmental context in Bauchi State, posing serious challenges to infrastructure resilience and long-term functionality. Although there is considerable awareness and a moderately experienced professional base, existing structural practices and policies are not adequately aligned with the demands of a changing climate.

The current resilience measures are insufficient for future risks, and without proactive adaptation in both policy and practice, public infrastructure in Bauchi will face increasing vulnerabilities.

RECOMMENDATIONS

1. Regulatory bodies should update existing codes and guidelines to incorporate climate resilience, including data on future temperature patterns, rainfall intensity, and soil behaviour under extreme weather.
2. Vulnerability assessments and systematic evaluations of existing public and private structures should be conducted to identify those most at risk and prioritize them for retrofitting or upgrading.
3. Promote resilient design strategies and encourage use of materials and structural systems that can withstand extreme climate conditions, including modular, flexible, and energy-efficient designs.
4. Integrate climate data into urban and regional planning processes and use localized climate models to inform zoning, drainage planning, and infrastructure layout.
5. Strengthen capacity and training, invest in professional development programs for engineers, architects, and policymakers focused on climate-adaptive design and construction.
6. Incentivize sustainable construction, introduce financial or regulatory incentives for builders and developers who implement climate-resilient practices.
7. Establish monitoring mechanisms, create systems to track the performance of climate-adapted buildings and infrastructure over time, feeding data back into design improvements.

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