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Retrofit for Enhanced Building Resilience in Flood Vulnerable Settlements: A Quantitative Review

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Abstract: ***The global history of flood is full of documented cases of massive devastation and havocs to the built environment. In recent times, global warming has led to climate change resulting in increased frequency of flooding. The magnitude, scope and impact of these flood events on the built environment cannot be overemphasized. This research is aimed at reviewing flood events in Nigeria and their impact on buildings to generate data for adaptive measures through retrofitting to enhance building resilience. The measures shall serve as framework for Architects/Designers in designing flood resilient buildings for impact mitigation in vulnerable settlements. A search of related literature review was conducted on related literature to provide background, secondary quantitative data and status of research in the area of flood architecture, building resilience and retrofitting for flood mitigation. The research reviewed and used quantitative secondary data from International Agencies/organizations, Federal, State and Local Government agencies of Nigeria, Non-governmental Organizations and other stakeholders. Findings from this study showed a total disregard for flood building resilience (FBR) need in vulnerable settlements such as flood plains, low-lying areas, blighted zones, slums and areas near water bodies. Results are presented in detailed charts, figures, plates and tables. The research concluded that all buildings in vulnerable settlements be so designed as to give the buildings a high level of resilience to major damages/collapse during and after flood incidents and where such input were not put in place, building should be retrofitted to adapt to flooding for impact mitigation and enhanced resilience.***

Keywords: Building Resilience, Flood, Retrofitting, Vulnerable settlements. Correspondence: odlivingston@gmail.com

1.0 Introduction

Flood is generally defined as the overflow or eruption of a large body of water beyond its normal confines over dry land on higher terrain (Daniel & Udo, 2019). Flood impacts humans, the built environment, animals and plants (Ujene & Oguike, 2020). The Global debate on Climate change has raised the awareness and concern related to immense damage occasioned by incidents of natural disasters such as flooding and its impact on the development of the built environment (Food Safety- Climate Change and the Role of WHO, 2020). Data from 1975 to 2022 has shown a trend in impact of flooding (Jonkman, 2024 & The Global Risk Report by the World Economic Forum,2023). The magnitude of economic damages caused by flood disasters is generally under reported globally by governments (The Global Risk Report by the World Economic Forum,2023). A further assessment of global extreme climate event has shown the relevance of understanding local risks and management options (Kreibich et al. 2022 & Curran et al., 2023). Europe recoded 128 flood events between 2010 and 2016 alone with about half of the event occurring in just four (4) countries of Italy (22%), France (12%), Germany (9%) and Spain (1%) (Paprotny et al., 2018). Africa has recorded a number of flood disasters with implications of loss of lives and properties (Lumbroso, 2020; Mashi et al., 2020; Echendu, 2021; Elagib, et al., 2021 & Rentschler, et a., 2021). In Nigeria, studies have shown that in the last 3 decades the frequency of flooding events has increased leading to loss of lives and property due largely to poor implementation of environmental laws and low building resilience (Bamidele&Badiora, 2019; Adetuji&Oleyele, 2018; & Onwuemele, 2018). With flood destroying homes in its wake the need design of buildings with flood resilience becomes imperative looking at well documented evidence of damages to the buildings and built environment (Ibrahim, O. 2023; & Aminu, Saka, & Ali, 2022). There is a total lack of legal and policy framework for managing flooding in Nigeria and the has not been a concerted effort at designing frameworks to solding flooding challenges

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(Cirella & Iyalomhe, 2018; & Okoye, 2019). Hence, there is an urgent need for a design framework and governance policy for buildings to be erected and a remediation/retrofitting for existing buildings. Other recent studies have revealed also that the prevalence of flooding events in Nigeria is a result of poor application/implementation of building and planning policies (Ladan, 2022; Ladan & Mayaki, 2023; Ladan & Saulawa, 2021; & Nnodim & Ezekiel, 2020).

1.1 Research Questions

i. How do entrance levels relative to road height influence the extent of flood damage in residential buildings?
ii. What is the impact of different building materials on flood resilience in urban settlements?
iii. How effective are different flood mitigation measures (e.g., sealed windows, elevated foundations) in reducing flood damage in residential areas?

What is the relationship between flood frequency and evacuation times in different types of residential buildings?

1.3 Research Objectives

The research objectives align with the study questions and are to:

i. Determine the impact of entrance levels relative to road height on the extent of flood damage in residential buildings.
ii. Assess the effect of various building materials on the flood resilience of urban settlements.
iii. Evaluate the effectiveness of various flood mitigation measures in reducing flood damage in residential areas.
iv. Analyze the relationship between flood frequency and evacuation times in different types of residential buildings.

1.3 Variables

1. How do entrance levels relative to road height influence the extent of flood damage in residential buildings?

a) Independent Variable: Entrance Level
b) Dependent Variable: Flood Damage Extent

2. What is the impact of different building materials on flood resilience in urban settlements?

c) Independent Variable: Building Materials
d) Dependent Variable: Flood Resilience

3. How effective are different flood mitigation measures (e.g., sealed windows, elevated foundations) in reducing flood damage in residential areas?

e) Independent Variable: Flood Mitigation Measures
f) Dependent Variable: Mitigation Effectiveness

4. What is the relationship between flood frequency and evacuation times in different types of residential buildings?

g) Independent Variables: Flood Frequency, Building Type
h) Dependent Variable: Evacuation Time.

1.4 Hypotheses

a. **Null Hypothesis (H_0):** The height of the entrance level relative to the road height does not have a significant influence on the extent of flood damage in residential buildings

H_0:β_1=0---(1)

b. **Alternative Hypothesis (H_1):** There is a significant relationship between entrance levels relative to road height and the extent of flood damage in residential buildings.

H_1:β_1≠0---(2)

1.5 Scope

The scope of the document focuses on analyzing the relationship between entrance levels relative to road height and the extent of flood damage in residential buildings. It specifically investigates the first of four research questions, concentrating on the hypothesis that entrance level heights significantly influence flood damage. The study also outlines the use of stratified sampling for data collection and employs methods like Pearson correlation and linear regression to analyse the data. Future research is planned to address the other research questions and hypotheses presented in the document.

1.6 Sampling

Stratified Sampling

since the study intends to compare different strata, such as building materials, design applications or settlement types, ensuring that each subgroup is adequately represented, the stratified sampling was used. Advantages include: Ensures representation from each subgroup and provides more precise estimates by reducing variability within strata. While the demerit is: it is more complex and time-consuming to administer and requires knowledge of the population structure (the population structure data from NIMet informed the sampling process, ensuring that the research was based on accurate and relevant data about study location for flood impact and building resilience).

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Systematic Sampling

Every nth settlement is chosen from a list and useful if settlements are listed in a non-random order that reflects their spatial distribution, unfortunately, these settlements were listed randomly. Though had the following merit: Simple and easy to implement and ensures even coverage of the population but the disadvantages in the case and location under review could not allow us use it; demerits: Risk of periodicity in the population list causing bias and may not be representative if the population has a hidden order.

Simple Random Sampling

Each settlement has an equal chance of being selected and likely if there is no specific focus on certain types of settlements. We had a focus on flood settlements hence, it was not used. With advantages as: Ensures each settlement has an equal probability of selection and reduces selection bias. However, the demerit became apparent as our goal was equal representation of sub-groups that did not require the complete list of the population. These demerits are: May not represent all subgroups within the population and requires a complete list of the population.

Cluster Sampling

In this sampling method, the population is divided into clusters, some of which are randomly selected. All observations within selected clusters are studied; time limitation for the study cannot allow us study all the buildings. Efficient if settlements are naturally grouped by geography or other criteria. A few of the merit of using such sampling technique involves; Cost-effective and efficient for geographically dispersed populations and reduces travel and administrative costs. However, the demerits: Increased variability if clusters are heterogeneous and the fact that this sampling method is less precise than simple random or stratified sampling did not allow us use it.

2.0 Literature Review

This theoretical review section is divided into four (4) sub-sections covering:

a. Causes of flooding, hazards and management
b. Impact of flooding on the built environment
c. Eco-friendly/sustainable approaches to building resilience and
d. The theoretical framework for Architects/designers in the built environment industry.

2.1 Causes of Flooding, Hazards and Management

Flooding is usually caused by excessive rainfall events resulting in great water output (MacLeod et al. 2021). While Tramblay et al. (2021) argued that flooding is linked to maximum level of soil moisture rather than precipitation. According to the Nigeria Hydrological Services Agency (2020), cause of flooding in Nigeria include: soil moisture, high level of rainfall, climate change resulting in higher frequency of precipitation, management of dams and area topography. Echendu (2021) stated that there are four (4) major causes of flooding in Accra metropolis, Ghana. These causes include ignorance to hazard/safety issues, poor city planning, building on drainages and natural water ways and poor waste management systems. In other developing countries of Africa, causes of flooding include excessive rainfall, building on natural water ways and drainage channels, rise in sea level as a result of climate change, soil moisture capacity, dam operations letting out excess water and poor waste management (Olanrewaju, et al.,2019; Nigeria Hydrological Services Agency, 2020, & MacLeod et al. 2021). Olanrewaju, et al. (2019) and Mashi et al. (2019) evaluated flood risk in Nigeria and noted after reviewing several relevant literatures that flooding in Nigeria is a result of severe vulnerability and lack of coping/mitigation capacity of residents coupled with increasing incidents of weather-related disasters occasioned by climate change. Their study helped to reveal that the incidents of flooding is now more frequent in Nigeria due to poor urban planning and management of the built environment.

2.2 Impact of Flooding on the Built Environment (BE)

In the past decade, the built environment in Africa has been greatly impacted by flooding events (Lumbroso, 2020; & Elagib et al., 2021). In the last 50 years, Nigeria recorded its worst floods in the years 2012 and 2018 (Nigeria Hydrological Services Agency, NIHSA. 2020), Impacts of flooding in other years were less severe. These impacts can be direct or indirect. Flooding is a regular occurrence in Nigeria. Despite this, data on impact is lacking at national and sub-national levels making analysis and cross-referencing/comparison between vulnerable areas difficult (Lucas, 2021).

2.3 Eco-friendly/Sustainable Approaches to Building Resilience: The Environment and Building

Buildings when designed by qualified Architects helps to integrate resilience features to climatic events such as flooding. The deliberate design of buildings in flood-prone areas to withstand and adapt to flood events entails making decisions on choice building resilience technologies (BReT) to employ, passive design techniques to employ and material/construction specifications to use. In addition to these structural design measures, policy measures to prescribe and regulate building resilience with Building Codes (BC) must be employed for a holistic solution in the long-term.

Retrofit to Adapt to Flooding

This section deal with retrofitting existing buildings in vulnerable areas to adapt to flood impacts. Barsley (2019) highlights the importance of retrofitting buildings to enhance flood resilience in prone areas, where inadequate resilience can lead to significant damage. The research focuses on measures like elevating entrances, flood-resistant materials, and mitigation features to reduce flood impact. By investigating these aspects, the study aims to provide data-driven insights for retrofitting buildings to better withstand flooding challenges. This can be done by adding elements or technology that improves resilience. Buildings should be designed with intrinsic characteristics such as quality, type and quantity of openings as well as orientation to water flow (Postacchini, et al.,2019). The floor level above ground is key as its helps to protect the building, its occupants and furniture from flood-water (Mignot, Camusson, & Riviere, 2020). Architects can design/retrofit buildings to be sensitive to flooding according to typology/usage. These typologies are designed/retrofitted to meet adaptive flood performance. The building's features can be adapted to performed passive mitigation functions in flooding events. In mitigation efforts, Architects can employ amphibious design strategies while buildings can be designed to float like boats and use of high ground floor levels (Rosso, et al., 2020). Other retrofitting strategies involve the use of specific construction method/element or material with or outside the building to reduce vulnerability to extreme flooding events and the adoption of green architecture (green roof) for rain water retention and harvesting (Besir, & Cuce,2018; Campos, Cavalcante, & Duarte, 2020; & Morphosis. Available online: https://www.morphosis.com/).

Flood Risk Management (FRM)

Flooding according to Zhang et al. (2021) is the most frequently occurring climate hazard globally. In the study of Flood Risk Management (FRM), resilience has been defined as the ability to withstand, contain, retain and recover from a disturbance or a flood incident in reasonable time (Oladokun, et al., 2017). Table 1, illustrates the various resilience approaches in flood risk management.

Table 1: Flood Resilience/Risk Management Approaches

System Attribute	Characteristics	Stress	Aim/Strategy
resistance	ability to withstand disturbance without responding	shock	stability (preserve status quo) flood protection
engineering resilience	ability to bounce back and recover from disturbance recover maintaining efficiency of function	shock	constancy (efficiency of function, preserve status quo) robustness fail safe design appropriate engineering components and systems
ecological resilience	capacity to absorb disturbance, recover maintenance existence of function	shock	persistency redundancy multiple equilibrium stats
socio-ecological or adaptive resilience	capacity to absorb disturbance, recover, reorganize, and anticipate and adapt while undergoing change	gradual/ shock	persistence (existence of unction) learning adaptive capacity, transformation

Source: Zevenbergen, Gersonius & Radhakrishan, (2020)

2.4 Theoretical framework for Architects/Designers in the Built Environment

Studies have shown that over 98% of building in Nigeria were designed with only aesthetics in mind without or little flood resilience input (Oladokun et al., 2017). Damages by flooding can be grouped into two (2) categories. There is direct damages and indirect damages. Direct damages are damages caused as a result of a direct contact with flood water by humans, animals, buildings and infrastructure while indirect damages are damages that occur to elements not directly exposed to flood water but are connected to elements affected directly (Merz et al., 2010).

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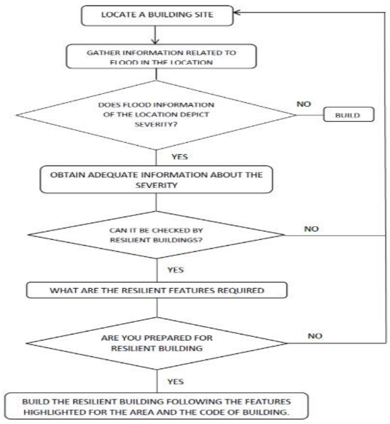

Figure 1: Theoretical Framework for Flood Damage and Management in the case study location (Adapted from Gaviaglio, et al., 2019).

3.0 Methodology

This research employed a quantitative approach to analyze the impact of entrance levels relative to road height on the extent of flood damage in residential buildings. The study was conducted in flood-prone areas of Nigeria, focusing on settlements that have experienced significant flooding events in the past decade.

3.1 Data Collection

Data were obtained from both primary and secondary sources. Primary data involved field observations and measurements of entrance levels and flood damage in selected residential buildings across various flood-prone settlements. The secondary data were collected from government publications, scholarly articles, and reports from organisations like the Nigerian Meteorological Agency (NIMet), which provided information on population structure and flood risk zones.

3.2 Sampling Techniques

To ensure a representative sample, stratified sampling was employed. This method was chosen to compare different strata such as building materials, design applications, and settlement types, ensuring that each subgroup was adequately represented. The population structure, retrieved from NIMet, guided the stratification process, allowing for targeted sampling in areas with varying flood exposure levels.

3.3 Data Analysis

The collected data were analysed using statistical methods, including Pearson correlation and simple linear regression. The Pearson correlation was used to assess the strength and direction of the relationship between entrance levels and flood damage extent, while linear regression helped quantify the impact of entrance levels on flood damage.

Statistical software was employed to perform these analyses, ensuring accuracy and reliability of the results. The findings were then presented in charts, figures, and tables to illustrate the relationships and patterns observed in the data.

3.4 Ethical Considerations

The study ensured that all data collection and analysis processes adhered to ethical standards, including obtaining necessary permissions from property owners and ensuring the confidentiality of sensitive information.

4. Results and Discussions

Nigeria has an estimated population of 202 million and this has made the country to be considered as the seventh most populous country in the world (World Bank, 2024).

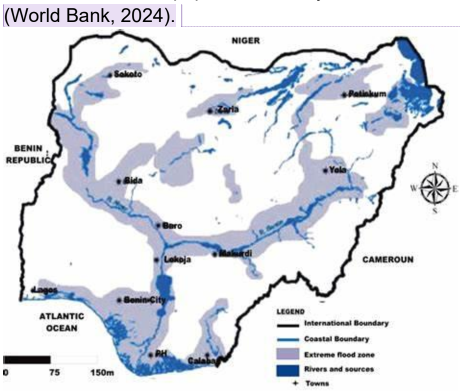

Figure 2: Map of Nigeria showing flood patterns

Nigeria is located between latitude 4°N to 14° N; and longitude 3°E to 15°E with a land area 923,769 km^2 approximately. A map of the Nigeria showing various states, major rivers and lakes. A key observation in this study, if the fact that most Nigerian buildings are bungalows. The draw backs of building without resilience is shown in Table 1.

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Additionaally, methodology should be separated from results and also from discussion to achieve a systematic arrangement of the research report sections!! This would have provded an easy to follow sequence, necessary for research comprehension!!

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Plate 1: Flood in Ibadan
Source: NEMA (2014)

Plate 2: Some victims of Ibadan Flooding
Source: NEMA (2014)

Plate 3: Some victims Ibadan Flooding
Source: NEMA (2014)

Plate 4: Flood impact in Lokoja
Source: www,yabaleft (2018)

Table 2a: Design and Flood Resilience Factors

S/N	Design Factor/ Observation	Consequences	Retrofitting/ Remediation Work
1	Building type	Easy access to flood water entering the building.	Design specification must take road level data and build at least 900mm above such datum.
2	Most entrances are observed to be below road level or less than 300mm above ground level	Creates easier access to flood water.	Architects/Designers must provide adequate height for building entrances in vulnerable settlements/areas.
3	Most windows used are not sealed upon locking.	Unsealed windows allow for passage of water into the building.	Architects must specify proper windowing sealing in the schedule.

(Adapted: Adebimpe *et al.*,2018).

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Table 2b: Design and Flood Resilience Factors

S/N	Design Factor/ Observation	Consequences	Retrofitting/ Remediation Work
4	Un-screeded floors and are not with tiles. Floor covered with rugs and underlays. Wooden, mud, fibre wood and similar synthetic floor.	Can easily be damaged and requires longer time to recover.	Floor specification by Architects must take water integrity into consideration. Insist on the installation of damp proof membranes in all buildings.
5	Un-rendered, unpainted and treated walls.	Allows for easy soaking of walls and defacing of wall finishes.	Walls must be built of materials with high water-proofing qualities
6	No consideration for rain water harvest by Architects.	Contributes greater volume water discharged as run-offs.	Include specification for water harvesting into reservoirs and subterranean storage.

(Adapted: Adebimpe *et al.*,2018).

Table 2c: Design and Flood Resilience Factors

S/N	Design Factor/Observation	Consequences	Retrofitting/Remediation Work
7	Lack/Poor drainage systems	increases the incidences of flooding.	Create adequate drainages and maintain properly.
8	Poor waste disposal and management systems	Blockage of water ways with refuse.	A robust waste disposal and management system must be put in place.
9	Buildings are constructed along the canal, dam, river, swamps, water ways, over drainages, flood plains, etc.	Location is key in avoiding the impact of flood. Buildings sited in flood prone areas are generally more affected by flood incidents.	Architects must advice Clients adequately on the impact of flooding in any building location. The Architect must design for resilience in all flood prone areas.

(Adapted: Adebimpe *et al.*,2018).

4.1 Correlation Analysis between Entrance Levels and Flood Damage Extent

Pearson correlation analysis is used over other tools in this context due to several reasons:

When used in predictive models, the precise numerical values can improve the accuracy and reliability of the predictions, as they capture the nuances of the relationships between variable. Pearson correlation is a statistical measure that is particularly well-suited for assessing linear relationships between variables. This is appropriate in situations where the relationship between the variables is observed to be linear in nature, as is the case with the data on entrance levels and flood damage extent.

Wooldrdge (2016) posited that since pearson correlation is being sensitive to outliers, it can help identify situations where a few extreme values are driving the observed relationship. This information can be valuable in understanding the robustness and generalizability of the findings, as well as in identifying potential data quality issues or unusual circumstances that may be influencing the results (Yuriy, I., 2021; Ruso, J., et al., 2021; 2022; Dutta, S., & Dadhich, B., 2024).

Table 3.1: Data Used for Analysis

Entrance Level	Flood Damage Extent
0.1	1000
0.3	1200
0.2	1100
0.5	1500
0.4	1300
0.3	1250
0.6	1600
0.7	1800
0.2	1150
0.8	1900

The Pearson correlation coefficient r is calculated as follows:

$r = ⟦\sum(Xi - X)(Yi - Y)⟧ / (\sum(Xi - X)2 \sum Yi - Y)2)$….(4)

Where:

- ✓ x_i and y_i are the individual sample points.

x¯ and y¯ are the means of the respective variables.

This analysis confirms a strong positive linear relationship between entrance levels and flood damage extent, highlighting the need to consider entrance level designs in flood-prone areas to mitigate potential damage

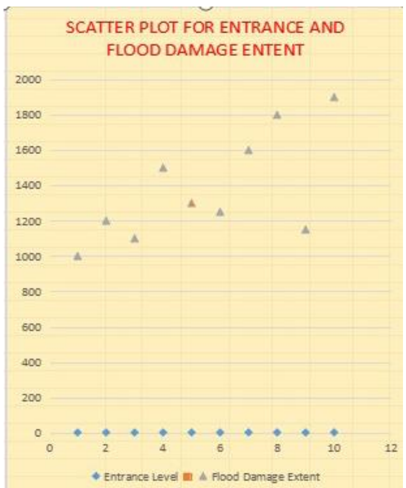

Figure 3: Scatter Plot for Entrance and Flood Damage extent.

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4.2 Simple Linear Regression Analysis

To understand the relationship between entrance levels and flood damage extent, we performed a simple linear regression analysis using the provided observation schedule data.

$y=\beta_0+\beta_1x+\epsilon$………………………………………… (5)

Where:

- ✓ y is the dependent variable (Flood Damage Extent).
- ✓ x is the independent variable (Entrance Level).
- ✓ β_0 is the intercept.
- ✓ β_1 is the slope coefficient.

ϵ is the error term.

Table 3.2: Simple Linear Regression Analysis Resul

Coefficient	Estimate	Standard Error	t-value	p-value
Intercepts (β_0)	927.27	73.89	12.55	<0.001
Slope (β_1)	1190.91	147.92	147.92	<0.001

Intercepts (β_0) is 927.27 and the Slope (β_1) is 1190.91.

Intercept (β_0): The estimated intercept is 927.27, represents the expected flood damage extent when the entrance level is zero.**Slope (β_1):**Represent the estimated slope as 1190.91, which indicates that for each unit increase in entrance level, the flood damage extent increases by approximately 1190.91 units. **P-value:**Is the p-value for the slope coefficient is less than 0.001, indicating that the relationship between entrance level and flood damage extent is statistically significant. Conclusively, simple linear regression analysis demonstrates a significant positive relationship between entrance levels and flood damage extent. As entrance levels increase, the extent of flood damage also increases, which suggests that entrance level is a critical factor in flood damage in residential buildings. This investigation will be used to inform urban planning and building design strategies to extenuate flood damage, highlighting the importance of considering entrance level relative to road height in flood-prone areas.

5.0 Conclusion and Recommendations

5.1 Conclusion

This research investigated the impact of entrance levels relative to road height on the extent of flood damage in residential buildings. By employing statistical analyses such as Pearson correlation and linear regression, the study found a significant positive relationship between entrance levels and flood damage extent. Specifically, it was observed that buildings with higher entrance levels tend to experience more severe flood damage, highlighting the importance of considering entrance level design in flood-prone areas.

The research also addressed several other key questions. It assessed the effectiveness of different building materials on flood resilience and found that the choice of materials significantly influences the ability of buildings to withstand flooding. Moreover, the study evaluated various flood mitigation measures, such as sealed windows and elevated foundations, concluding that these measures are effective in reducing the extent of flood damage in residential areas.

This study underscores the critical need for proactive design and retrofitting strategies in vulnerable settlements. The findings have significant implications for urban planning and building design in flood-prone regions, emphasizing the necessity for incorporating flood resilience into the architectural and construction processes. The research contributes to a growing body of knowledge that can inform policy decisions, guide the development of building codes, and ultimately lead to safer, more resilient communities. Future studies are recommended to explore additional factors such as the economic feasibility of these retrofitting measures and their long-term benefits in mitigating flood risks.

These findings highlight the critical importance of considering entrance level designs in flood-prone areas to mitigate potential damage. The current disregard for flood building resilience in vulnerable settlements such as flood plains, low-lying areas, and areas near water bodies is evident from the data. Therefore, there is an urgent need for a design framework and governance policy to ensure that buildings in these areas are constructed or retrofitted to enhance their resilience to flooding.

5.2 Recommendations

Based on the findings, the following recommendations are made:

1. Design and Retrofit Buildings for Flood Resilience: All buildings in vulnerable settlements should be designed or retrofitted to enhance their resilience to flooding. This includes elevating entrance levels, using flood-resistant materials, and implementing effective flood mitigation measures such as sealed windows and elevated foundations.

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2. Policy and Regulatory Framework: Governments at all levels should develop and enforce a robust policy and regulatory framework that mandates flood resilience in building designs. This should include strict adherence to building codes and planning policies that prioritize flood mitigation.

3. Awareness and Training: There should be increased awareness and training for architects, builders, and home-owners on the importance of flood resilience in building design. Educational programme and workshops can help disseminate best practices and innovative solutions for flood mitigation.

4. Further Research: Additional research is needed to explore other factors influencing flood damage extent, such as building materials and specific flood mitigation measures. This can help develop more comprehensive strategies for flood resilience in residential buildings.

By implementing these recommendations, it is possible to significantly reduce the impact of flooding on residential buildings in vulnerable settlements, thereby safeguarding lives and property from future flood events.

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