

1 Case study

# 2 Integrating The IPCC- Sendai framework for Climate Resilient 3 Academic infrastructure: A case study of NUST Institute of 4 Civil Engineering

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## 8 Abstract

9 Climate change is increasingly undermining the performance assumptions of exist- ing  
10 building infrastructure, particularly in developing countries where rapid urbanization,  
11 limited adaptive capacity, and aging building stocks heighten exposure to climate-  
12 induced hazards. This study presents a building-scale climate resilience assessment of the  
13 NUST Institute of Civil Engineering (NICE), Islamabad, by operationalizing the Intergov-  
14 ernmental Panel on Climate Change (IPCC) Climate-Resilient Development (CRD) frame-  
15 work in conjunction with the Sendai Framework for Disaster Risk Reduction (SFDRR). A  
16 semi-quantitative, indicator-based methodology is applied, integrating observed and re-  
17 analysis climate data from the Pakistan Meteorological Department (PMD), ERA5, and  
18 NASA POWER datasets with planning, design, operation, and maintenance-level build-  
19 ing indicators. A composite Climate Risk Index (CRI) is developed using normalized scor-  
20 ing and weighted aggregation, and robustness is examined through sensitivity analysis.  
21 Results indicate that heat stress represents the dominant climate risk pathway for the  
22 NICE building, driven by limited passive cooling capacity and high internal heat gains,  
23 while extreme rainfall and drainage-related risks remain moderate but increasing. The  
24 study identifies feasible, evidence-based adaptation measures and provides a transferable  
25 framework for institutional buildings in climate-vulnerable regions.

26 **Keywords:** Climate Resilience; Academic Infrastructure; IPCC–Sendai Framework; Heat  
27 Stress; Adaptation Planning.

28

## 29 1. Introduction

30 Climate change is reshaping the foundational assumptions upon which modern  
31 building infrastructure has been designed. Rising temperatures, intensifying rainfall, al-  
32 tered mon- soon dynamics, and the increasing occurrence of compound extreme events  
33 are pro-gres- sively challenging the resilience of buildings worldwide [1], [2]. Recent years  
34 mark a criti- cal threshold: 2023 and 2024 were recorded as the warmest years in modern  
35 history and were accompanied by widespread flooding across Europe, Africa, and Asia,  
36 revealing the vulnerability of infrastructure conceived under historical climatic baselines  
37 [3], [4]. These impacts are disproportionately severe in developing countries, where rapid  
38 urban expan- sion, limited preparedness, aging building stocks, and constrained institu-  
39 tional ca- pacity amplify exposure and systemic risk [5].

40 In response, a growing body of research emphasizes climate-resilient infrastructure  
41 development and retrofitting through adaptive building design, passive cooling strate-  
42 gies, hybrid ventilation systems, improved insulation, optimized drainage, and Nature-  
43 Based Solutions (NBS) [6], [7]. Despite this progress, significant gaps persist. Existing  
44 studies of-ten remains conceptual, while the translation of global resilience frameworks  
45 into locally grounded, building-scale assessments remains limited particularly for institu-  
46 tional infra- structure in South Asia [8]. Questions surrounding the relative effectiveness  
47 of passive versus active adaptation measures, the scalability of nature-based interven-  
48 tions, and the operational feasibility of resilience frameworks at the building level remain  
49 insufficiently ad- dressed [9], [10].

50 Global policy and scientific frameworks provide a strong foundation for addressing  
51 these challenges [11]. The Sendai Framework for Disaster Risk Reduction emphasizes pro-  
52 active risk governance, investment in resilience, preparedness, and the principle of “Build  
53 Back Better” as core pillars of disaster-resilient infrastructure systems [12], [13]. Comple-  
54 menting this, the IPCC advances the concept of Climate-Resilient Development (CRD),  
55 which integrates physical, social, and institutional adaptation pathways to manage cli-  
56 mate risk while advancing sustainable development objectives [1]. However, despite  
57 wide-spread adoption at national and regional scales, these frameworks are rarely opera-  
58 tionalized at the scale of individual buildings, particularly within higher-education infra-  
59 structure[5].

60 Academic buildings represent a critical yet under-examined infrastructure typology.  
61 Continuous occupancy, functional complexity, and long design lives render university  
62 buildings particularly vulnerable to climate stressors [14], [15] . Adverse impacts include  
63 direct physical damage from extreme rainfall and flooding, as well as indirect effects such  
64 as overheating, operational disruption, and degraded learning environments [5]. In South  
65 Asia, many academic buildings constructed in the early 2000s were not designed to with-  
66 stand the magnitude of climatic extremes now emerging, increasing exposure to heat  
67 stress and intense precipitation (NASA POWER, ERA5, PMD).

68 The NUST Institute of Civil Engineering (NICE), completed in 2008 in Islamabad,  
69 exemplifies this challenge. Designed for historical climate conditions, the building is in-  
70 creasingly exposed to rising temperatures, altered precipitation regimes, and intensified  
71 surface runoff. Given NICE’s role in educating future engineers, reassessing its climate  
72 resilience is both a scientific necessity and an institutional responsibility.

73 Accordingly, this study applies an integrated IPCC–Sendai assessment framework to  
74 evaluate the climate resilience of the NICE building[16]. By combining climate data anal-  
75 ysis with a structured, indicator-based building assessment, the study identifies dominant  
76 vulnerability pathways and proposes feasible, evidence-based adaptation measures. The  
77 work contributes to applied climate resilience research by demonstrating a transferable  
78 approach for operationalizing global resilience frameworks at the building scale in devel-  
79 oping country contexts.

## 80 **2. Materials and Methods**

81 This study employs a framework-based, mixed-methods assessment approach to  
82 evaluate climate resilience at the building scale. The methodology integrates qualitative  
83 and semi- quantitative analysis aligned with the IPCC Climate-Resilient Development  
84 (CRD) frame- work and the Sendai Framework for Disaster Risk Reduction [2], [12].

### 85 *2.1 Case Study Selection*

86 The NUST Institute of Civil Engineering (NICE), Islamabad, Pakistan (33.64°N,  
87 72.98°E), was selected as a representative higher-education building for building-scale cli-

88 mate resilience assessment. Completed in 2008, the facility was designed under historical  
89 climate conditions and functions as a high-occupancy academic and research hub. Its lo-  
90 cation within the rapidly urbanizing Islamabad metropolitan region exposes it to increas-  
91 ing heat extremes and intense precipitation, making it a policy-relevant case for institu-  
92 tional climate resilience evaluation.

## 93 2.2 Conceptual Framework

94 The assessment integrates the IPCC AR6 CRD framework with the Sendai Frame-  
95 work to operationalize climate resilience through three components: exposure, sensitivity,  
96 and adaptive capacity. Exposure represents the degree of climate hazard affecting the  
97 building, sensitivity reflects the building's physical and functional response, and adaptive  
98 capacity denotes the ability to anticipate, cope with, and recover from climate stresses.  
99 This combined framework enables alignment between global policy objectives and build-  
100 ing-scale assessment.

## 101 2.3 Climate Data Sources and Processing

102 Historical climate conditions (Appendix A.1, A.2) were characterized by using pub-  
103 licly available datasets. The following data sources were employed:

- 104 • NASA POWER(derived from MERRA-2 reanalysis): Monthly near-surface air tem-  
105 perature, land surface temperature, and precipitation data for the period 2008–2024  
106 extracted at the study-site coordinates (33.64°N, 72.98°E). Elevation information as-  
107 sociated with this dataset represents an average value for the corresponding  $0.5^\circ \times 0.625^\circ$   
108 latitude–longitude grid cell and was used solely for contextual interpretation.
- 109 • ERA5 reanalysis (Copernicus Climate Data Store): Regional temperature and pre-  
110 cipitation data used to cross-check long-term trends derived from NASA POWER.
- 111 • Pakistan Meteorological Department (PMD): Observed precipitation data and  
112 re- ports used to supplement and validate rainfall trends and extreme precipitation char-  
113 acteristics for the Islamabad region, in the absence of corresponding long-term observed  
114 temperature records

115 Monthly climate data were aggregated to annual mean values, and linear least-  
116 squares regression was applied to quantify long-term temperature and precipitation  
117 trends. All data processing and statistical analyses were conducted using Microsoft Excel.

## 118 2.4 Exposure and Sensitivity Assessment

119 Exposure assessment focused on climate hazards relevant to the study area, includ-  
120 ing heat stress, extreme rainfall, and localized surface flooding. Sensitivity was evaluated  
121 qualitatively through assessment of building characteristics such as envelope properties,  
122 ventilation systems, roofing materials, shading, drainage conditions, and construction  
123 materials. Exposure and sensitivity levels were classified using an ordinal scale (low, me-  
124 dium, high) based on observed conditions and supporting climate data trends.

## 125 2.5 Adaptive Capacity Assessment

126 Adaptive capacity was assessed qualitatively across planning, design, operation, and  
127 maintenance dimensions, consistent with IPCC CRD and Sendai Framework priorities.  
128 Indicators included the presence of existing adaptation measures, operational flexibility  
129 during extreme events, maintenance practices, and institutional capacity to implement re-  
130 siliience-oriented interventions. Adaptive capacity scores were used to contextualize ex-  
131 posure and sensitivity findings rather than as standalone metrics.

132 2.6 *Adaptation Pathways*

133 Potential adaptation pathways were identified and evaluated based on contextual  
 134 feasibility, local suitability, scalability, and alignment with institutional and operational  
 135 constraints. The assessment considered nature-based solutions, green-blue-grey infra-  
 136 structure approaches, and passive building retrofitting strategies, prioritizing measures  
 137 that could be realistically implemented within the existing institutional context.[17]

138 2.7 *Data Availability, Ethics, and AI Disclosure*

139 All climate datasets used in this study are publicly available through NASA POWER  
 140 and the Copernicus Climate Data Store (ERA5). Derived datasets and analysis spread-  
 141 sheets will be made available in an open-access repository prior to publication. This study  
 142 did not involve human or animal subjects and therefore did not require ethical approval.  
 143 Generative artificial intelligence tools were used only for language refinement and struc-  
 144 tural editing of the manuscript.

145 **3. Results**

146 This section presents the final outcomes of the integrated climate resilience assess-  
 147 ment for the NUST Institute of Civil Engineering (NICE), developed by operationalizing the  
 148 IPCC Climate-Resilient Development (CRD) framework alongside the Sendai Frame-  
 149 work for Disaster Risk Reduction. Results are structured to provide quantified, compara-  
 150 ble, and decision-oriented outputs, suitable for policy-informed infrastructure planning.

151 3.1. *Climate Hazard Exposure Results*

152 Regional climate trends for the Islamabad area, supported by secondary datasets from  
 153 the Pakistan Meteorological Department (PMD), ERA5 reanalysis, and NASA POWER  
 154 data, indicate a consistent increase in extreme temperature events and rainfall intensity.  
 155 These trends were translated into exposure scores using a standardized ordinal scale  
 156 (Low = 1, Medium = 2, High = 3)

157 **Table1:** Climate Hazard Exposure Scores for NICE

Climate Hazard	Exposure Description	Exposure Score
Heat stress	temperature periods affecting building	3 (High)
Intense rainfall / urban flooding	temperature periods affecting building performance	2 (Medium)
Water scarcity	ceeding localized drainage capacity Seasonal variability and peak-demand pressure during dry periods	2 (Medium)

158 3.2. *Sensitivity Results*

159 Sensitivity analysis assessed how the physical configuration and functional usage of  
 160 the NICE building respond to identified climate hazards. The assessment focused on ther-  
 161 mal behavior, site hydrology, and operational dependency.

162 The building demonstrates high sensitivity to thermal stress, indicating that even  
 163 moderate increases in ambient temperature significantly affect indoor comfort and energy  
 164 demand.

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**Table 2.** Sensitivity Assessment Results

System Component	Observed Condition	Sensitivity Score
Thermal performance	Limited passive cooling, reliance on mechanical systems	3 (High)
Surface drainage	Predominantly impermeable surfaces and localized run off concentration	2 (Medium)
Operational dependency	Continuous academic and laboratory occupancy	3 (High)

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*3.3 Adaptive Capacity Results*

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Adaptive capacity was evaluated across planning, design, operational, and institutional dimensions, aligned with IPCC CRD pathways and Sendai Framework priorities on disaster risk governance and preparedness.

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Overall adaptive capacity is moderate, driven primarily by institutional knowledge and slightly by physical or design-based resilience measures.

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**Table 3:** Adaptive Capacity Scores

Adaptive Dimension	Current Status	Capacity Score
Planning & governance	Climate resilience not formally embedded in infrastructure planning	2 (Medium)
Building design & retrofitting	Absence of climate-focused retrofitting measures	1 (Low)
Operations & maintenance	Responsive but largely reactive facility management	3 (Medium)
Institutional capacity	Availability of technical expertise and research-driven environment	3 (High)

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*3.4. Integrated Climate Risk Index*

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To synthesize exposure, sensitivity, and adaptive capacity results, an Integrated Climate Risk Index (ICRI) was developed using the relationship:

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$$ICRI = (Exposure \times Sensitivity) / Adaptive Capacity$$

This approach enables relative comparison of climate risks across hazard categories

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**Table 4:** Integrated Climate Risk Profile for NICE

Hazard	Exposure	Sensitivity	Adaptive Capacity	Relative Risk Level
Heat stress	3	3	2	High
Urban flooding	2	2	2	Moderate
Water scarcity	2	2	2	High

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Heat stress represents the dominant climate risk, resulting from the combined effects of high exposure, high sensitivity, and only moderate adaptive capacity.

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*3.5 Risk-to-Intervention Mapping*

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Assessment results were translated into targeted resilience opportunities consistent with Sendai Framework priorities and IPCC Climate-Resilient Development pathways.

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The results demonstrate that climate risk at the NICE facility is hazard-specific and inter- action-driven, with heat stress emerging as the most critical vulnerability. While institutional capacity provides a strong foundation for adaptation, the absence of climate-

responsive design and retrofitting measures significantly constrains overall resilience. The assessment confirms that integrating global frameworks with localized building-scale analysis yields actionable insights for climate-resilient infrastructure planning in developing-country contexts.

**Table 5.** Priority Resilience Interventions Identified

Identified Risk	Recommended Intervention	Framework Alignment
High thermal risk	Passive cooling, shading devices, envelope optimization	IPCC CRD, SDG 13
Flooding risk	Green–Blue–Grey Infrastructure (GBGI), drainage upgrades	Sendai Priority 3
Resource stress	Water efficiency measures and monitoring	SDG 6
Limited preparedness	Digital monitoring and resilience indicators	Sendai Priority 1

## 4. Discussion

### 4.1 Interpretation of Findings in Relation to Previous Studies

The assessment identifies heat stress as the dominant climate risk affecting the NICE–NUST facility, driven by increasing regional temperatures and amplified by high building sensitivity. This finding is consistent with previous studies on academic and public-sector buildings in South Asia, which show that infrastructure designed under historical climatic assumptions is increasingly vulnerable to overheating and operational disruption. As reported in earlier research, structural and design-related factors—rather than institutional awareness or technical capacity emerge as the primary drivers of climate vulnerability.

### 4.2 Way Forward: From Assessment to Action

The findings support the working hypothesis that effective climate adaptation at the building scale requires moving beyond conceptual frameworks toward enforceable implementation mechanisms. At NICE–NUST, the principal limitation is the absence of mandatory integration of climate resilience into physical planning, design, and development decisions. Addressing this gap requires embedding climate-responsive measures into all future expansion, retrofitting, and new construction activities through strict compliance with national regulatory frameworks, including the Building Code of Pakistan (2021), the Green Building Code of Pakistan (2023), the Rainwater Harvesting Provisions (2023), and national fire and electrical safety codes [18][19]. Oversight by the designated Authorities Having Jurisdiction is essential to ensure consistent and effective implementation.

In the broader context of climate-resilient development, the results highlight academic engineering campuses as strategic entry points for scalable adaptation in developing-country settings. Aligning global resilience frameworks with national regulations and localized building-scale action provides a practical pathway for reducing climate risk. Future research should incorporate in-situ microclimatic monitoring, building energy simulations, and post-retrofitting performance evaluation to strengthen quantitative evidence and support comparative analysis across campuses.

## 5. Conclusions

This study operationalizes the IPCC Climate-Resilient Development framework alongside the Sendai Framework for Disaster Risk Reduction at the building scale through a case study of the NUST Institute of Civil Engineering. The assessment demonstrates that heat stress is the dominant climate risk, resulting from high exposure, elevated sensitivity, and limited climate-responsive retrofitting despite moderate institutional adaptive capacity.

The findings indicate that climate resilience in academic infrastructure cannot rely on incremental or discretionary measures alone, but requires the systematic integration of nationally mandated building, sustainability, water, and safety codes into institutional development and expansion processes. By translating global climate frameworks into regulation-aligned, building-scale action, this study provides a transferable and policy-relevant model for advancing climate-resilient academic infrastructure in Pakistan and comparable developing-country contexts.

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## Abbreviations

The following abbreviations are used in this manuscript:

NUST	National Institute of Sciences & Technology	NUST Institute of Civil Engineering
IPCC	Intergovernmental Panel on Climate Change	CRD Climate Resilient Development
GBGI	Green-Blue-Grey Infrastructure	
SDG	Sustainable Development Goals	
PMD	Pakistan Metrological Department	
NBS	Nature Based Solution	
NASA POWER	NASA Prediction of Worldwide Energy Resources	

## Appendix A

### Appendix A.1

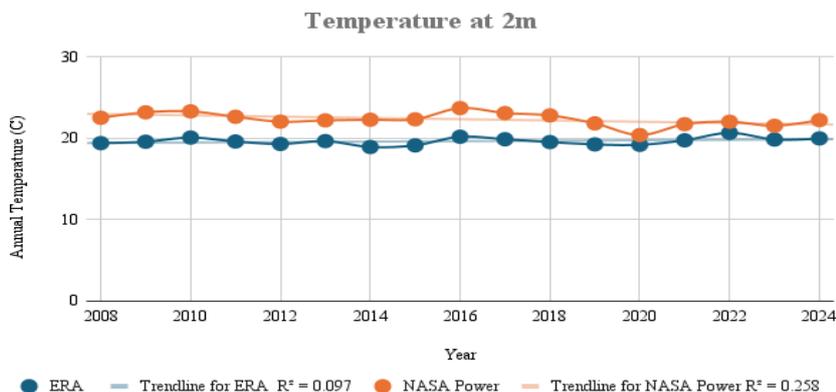
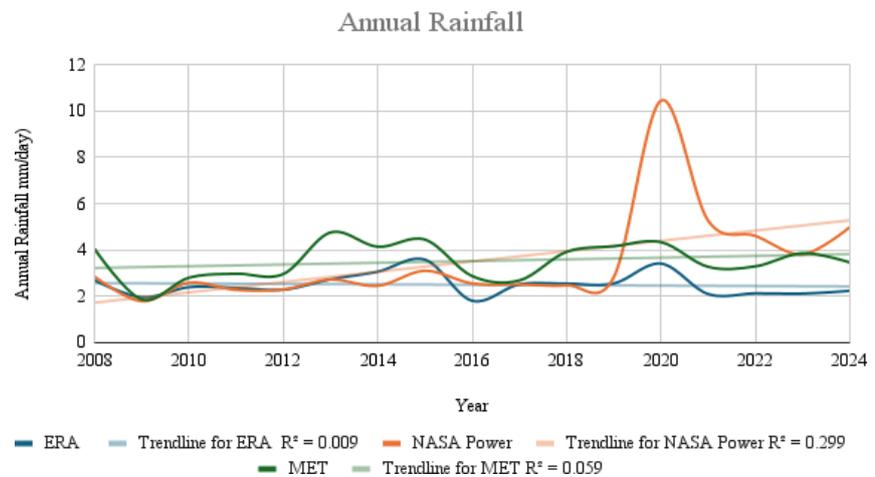


Figure A.1: Temperature trend recorded by ERA5 and NASA POWER

## Appendix A.2



**Figure A.2:** Annual Precipitation Trend recorded by ERA%, NASA POWER and PMD

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