



Toward An Equity-Centered Healthy Housing Design Policy Framework for Climate and Pandemic Resilience: Lessons from Covid-19 And Frequent Climate-Related Hazards in Bangladesh's Urban Informal Settlements and Rural Communities

Mahbubul Islam¹; Mahfuza Tabassum²; Shima Ali Sadia³; Mahmudul Islam⁴; Abdullah Al Mamun⁵

- [1]. Bachelor of Architecture, University of Asia Pacific, Bangladesh;
Email: imahbubul@outlook.com
- [2]. B.Sc in Civil Engineering, University of Asia Pacific, Bangladesh;
Email: tabassum.ce.uap@gmail.com
- [3]. Bachelor of Medicine and Surgery, University of Dhaka, Bangladesh;
Email: sadiashimaali@gmail.com
- [4]. M.Sc in Geotechnical Engineering, Bangladesh University of Engineering Technology, Bangladesh;
Email: mahmudul.ie@gmail.com
- [5]. Bachelor of Architecture, University of Asia Pacific, Bangladesh;
Email: amamun1990@outlook.com

Doi: [10.63125/b667fy44](https://doi.org/10.63125/b667fy44)

Received: 10 October 2021; **Revised:** 21 November 2021; **Accepted:** 14 December 2021; **Published:** 03 January 2022;

Abstract

Healthy housing represents a critical intersection between public health, socioeconomic equity, climate resilience, and emergency preparedness, particularly in Bangladesh, where urban informal settlements and rural communities experience distinct but overlapping residential vulnerabilities. This quantitative cross-sectional comparative study examined the relationships among housing quality, socioeconomic inequality, climate-hazard exposure, household health, pandemic-related housing functionality, and residential resilience among 500 households, comprising 250 households from urban informal settlements and 250 from rural climate-exposed communities. Data were collected through structured household questionnaires, housing observations, and environmental assessments and were analyzed using descriptive statistics, group-comparison tests, multivariable regression, mediation analysis, interaction analysis, and sensitivity testing. The overall Healthy Housing Index (HHI) was 53.7 ± 14.2 , with urban households recording significantly lower scores than rural households (50.8 vs. 56.6; $p < 0.001$; $d = 0.42$). Urban households showed particularly pronounced deficiencies in spatial adequacy, ventilation, drainage, sanitation, and indoor thermal conditions, whereas rural households experienced greater structural weakness and exposure to floods, cyclones, erosion, and salinity. The mean Climate-Hazard Exposure Index was 61.4 ± 17.3 , while the Household Resilience Index averaged 50.3 ± 15.6 . Each 10-point increase in HHI was associated with lower adjusted odds of respiratory symptoms (AOR = 0.76, 95% CI: 0.65–0.89), diarrheal or infectious illness (AOR = 0.71, 95% CI: 0.59–0.85), and heat-related symptoms (AOR = 0.69, 95% CI: 0.59–0.81). Healthy housing positively predicted household resilience ($\beta = 0.34$, $p < 0.001$), whereas climate-hazard exposure showed a negative association ($\beta = -0.29$, $p < 0.001$). Kutchra dwellings experienced substantially greater mean structural damage (44.7%) than semi-pucca (29.6%) and pucca dwellings (16.3%; $p < 0.001$). Housing deprivation also partially mediated the association between socioeconomic disadvantage and residential vulnerability, accounting for approximately 42.9% of the total association. The final multivariable model explained 46.8% of variation in household resilience.

Keywords

Healthy Housing; Housing Equity; Climate Resilience; Pandemic Resilience; Bangladesh.

INTRODUCTION

Healthy housing can be defined as residential shelter and its surrounding physical and social environment that protect and promote the physical, mental, and social well-being of occupants by providing adequate space, structural safety, thermal comfort, ventilation, clean air, safe water, sanitation, hygiene, accessibility, privacy, and protection from environmental hazards. The World Health Organization conceptualizes healthy housing broadly, linking the condition of the dwelling with health-related characteristics of the immediate residential environment and emphasizing inadequate living space, indoor temperatures, household injury hazards, accessibility, water quality, indoor air quality, noise, and exposure to harmful substances as important determinants of health (Keenan, 2020). Within this perspective, housing is not simply a physical structure constructed to provide shelter; it represents an important social determinant through which income, environmental exposure, infrastructure, public services, household composition, and social inequality become translated into measurable differences in health. Equity-centered healthy housing design extends this definition by emphasizing the fair distribution of housing-related protection, resources, services, environmental quality, and adaptive capacity among populations with different socioeconomic and demographic characteristics. Equity in this context does not necessarily mean providing identical housing conditions to every household. It concerns reducing avoidable and systematically distributed differences in housing conditions that place economically and socially disadvantaged populations at greater risk (Banai, 2020). Climate resilience refers to the capacity of housing, households, infrastructure, and communities to withstand, respond to, recover from, and maintain essential functions during climate-related disturbances such as floods, cyclones, storm surges, extreme heat, heavy rainfall, waterlogging, salinity intrusion, and other environmental stresses. Pandemic resilience adds another dimension by describing the capacity of residential environments to support infection prevention, isolation, hygiene, ventilation, physical distancing, caregiving, and essential domestic activities during widespread infectious-disease emergencies. COVID-19 demonstrated internationally that these dimensions of housing quality are closely interconnected because measures such as staying at home, maintaining interpersonal distance, isolating infected household members, washing hands frequently, and reducing interpersonal contact were conditioned by dwelling size, occupancy density, ventilation, water access, sanitation, and household economic security (French et al., 2020). Research across housing and health, environmental epidemiology, disaster resilience, urban planning, social determinants of health, and infectious-disease studies therefore establishes housing as a multidimensional exposure environment rather than a single material asset. This conceptualization is especially relevant to urban informal settlements and resource-constrained rural communities, where physical vulnerability, socioeconomic disadvantage, inadequate infrastructure, and environmental hazards frequently overlap within the same household environment.

The international significance of healthy housing has expanded through growing recognition that housing conditions constitute a major structural determinant of population health, environmental justice, disaster vulnerability, and social inequality (Zabaniotou, 2020). Research conducted across high-, middle-, and low-income countries has associated overcrowding, dampness, mould, inadequate ventilation, indoor air pollution, unsafe temperatures, deficient sanitation, poor water supply, insecure tenure, structural instability, and neighborhood environmental hazards with communicable diseases, respiratory illness, injuries, heat-related illness, cardiovascular stress, psychological distress, and reduced well-being. WHO's evidence-based housing guidance explicitly connects improved housing conditions with disease prevention, quality of life, poverty reduction, climate-related protection, and progress toward health and sustainable-city objectives. International housing research has consequently moved beyond a narrow concern with the number of available dwelling units toward assessment of whether housing provides safe and health-supportive environments. This distinction is particularly important because access to a dwelling does not automatically ensure access to healthy housing. Informal settlements illustrate this problem at a global scale (Grasham et al., 2019). Such settlements commonly contain structurally deficient dwellings, high occupancy density, insecure tenure, insufficient drinking-water and sanitation services, and greater exposure to floodplains, unstable slopes, waste disposal areas, industrial pollution, and other environmental hazards. Studies of cities in South Asia, sub-Saharan Africa, Latin America, and other rapidly urbanizing regions have

documented how these conditions create spatial concentrations of health vulnerability. The COVID-19 pandemic intensified international attention to this relationship because housing became simultaneously a site of protection, disease exposure, work, education, care, quarantine, and social interaction (Benjamin, 2020).

Figure 1: Equity-Centered Healthy Housing Resilience Framework



Studies examining COVID-19 transmission in disadvantaged urban neighborhoods reported higher vulnerability in densely populated and slum environments, with residential crowding and intensive interpersonal contact limiting the practical effectiveness of household-level distancing strategies. Climate-related hazards create a parallel housing-health pathway through physical destruction, indoor overheating, dampness, displacement, contaminated water, sanitation failure, food insecurity, and interruption of healthcare and other essential services. International evidence from disaster-prone communities has also demonstrated that housing vulnerability is socially differentiated: households with limited financial resources frequently possess fewer opportunities to retrofit dwellings, relocate temporarily, access insurance, secure formal land rights, or rapidly replace damaged materials (Sheffield et al., 2017). Across more than thirty studies and major evidence reviews spanning housing health, climate adaptation, disaster risk reduction, environmental justice, informal settlement research, thermal comfort, household energy, water and sanitation, and pandemic epidemiology, a consistent analytical principle emerges: residential exposure is produced through interactions among building characteristics, household resources, infrastructure, environmental hazards, and institutional arrangements. Healthy housing is therefore internationally relevant as both a public-health condition and an equity-sensitive component of resilience.

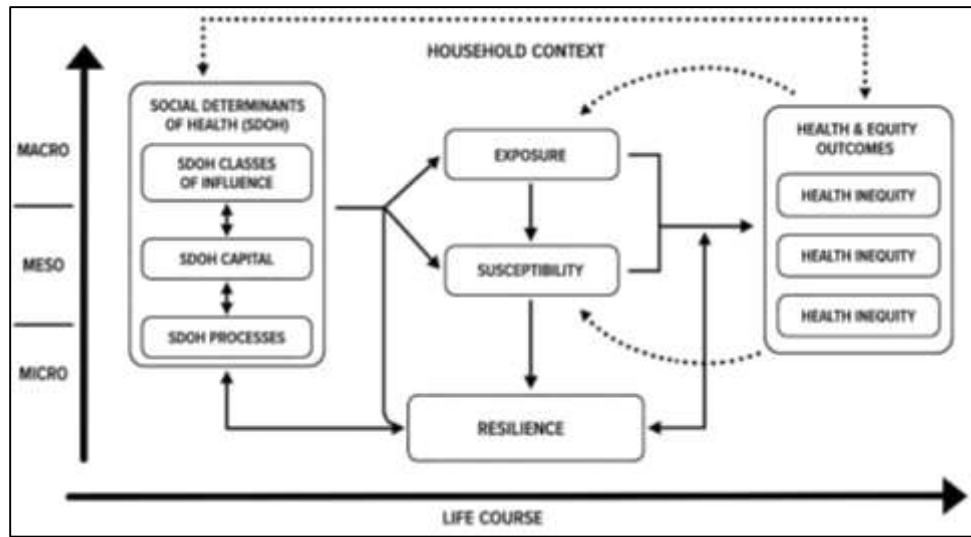
COVID-19 provided an unusually visible demonstration of how housing characteristics influence the distribution and management of infectious-disease risks (Sellers & Ebi, 2018). During periods when governments and public-health agencies relied heavily on stay-at-home orders, household isolation, quarantine, hand hygiene, remote schooling, and reduced mobility, the feasibility of these measures varied substantially according to residential conditions. A household occupying several rooms with adequate ventilation, reliable water, private sanitation, sufficient floor area, and the capacity to separate symptomatic individuals encountered a substantially different exposure environment from a household in which multiple people shared one or two poorly ventilated rooms, sanitation facilities were communal, water collection required leaving the dwelling, and household income depended on daily work outside the home (Klassen & Murphy, 2020). International studies conducted during the

pandemic associated residential crowding, neighborhood deprivation, socioeconomic disadvantage, household size, occupational exposure, and inadequate housing conditions with unequal patterns of infection and pandemic burden. Research focused specifically on developing-world cities also identified slum neighborhoods as highly vulnerable locations for COVID-19 transmission because high population density and patterns of close interpersonal contact created structural barriers to conventional distancing measures. These observations positioned housing design within epidemiological discussions that had traditionally concentrated more heavily on individual behavior, clinical capacity, and community-level transmission. Ventilation became especially significant because indoor airflow, opening configurations, occupancy patterns, and duration of exposure influenced respiratory transmission risks (Paterson et al., 2014). Water and sanitation conditions were equally relevant to the practicality of recommended hygiene practices, while dwelling size influenced opportunities for household isolation. Housing also shaped indirect pandemic experiences. Confinement increased the amount of time residents spent indoors, making thermal discomfort, poor air quality, noise, lack of daylight, insufficient privacy, and overcrowding more consequential to everyday well-being. The relationship between housing and health was therefore not restricted to direct viral transmission. School closures converted homes into learning environments, mobility restrictions transformed dwellings into workplaces for some occupations, and interruptions in services increased the importance of household-level water, energy, food storage, sanitation, and digital access. For economically marginalized communities, these overlapping functions were often compressed into small and environmentally stressed residential spaces (Rahaman et al., 2019). COVID-19 consequently served as a housing-based stress test that exposed differences in the capacity of dwellings to support fundamental public-health functions. The pandemic experience also created a relevant analytical bridge between infectious-disease resilience and climate resilience because several physical characteristics—ventilation, usable space, reliable water, sanitation, thermal protection, safe energy, adaptable internal layouts, and dependable neighborhood infrastructure—affect household capacity under both categories of hazard (Djalante et al., 2020).

Bangladesh provides a particularly important empirical setting for examining the intersection between healthy housing, climate-related hazards, socioeconomic inequality, and household resilience. Its densely settled deltaic geography exposes communities to multiple environmental hazards, including riverine and coastal flooding, tropical cyclones, storm surges, extreme rainfall, waterlogging, erosion, salinity intrusion, heat stress, and associated disruptions to water, sanitation, energy, transportation, livelihoods, and health services. Coastal areas face particularly significant storm-tide exposure, while scientific assessments have identified strong geographic variation in hazard intensity across the country's low-lying coastal regions (Zavaleta-Cortijo et al., 2020). Housing mediates these environmental exposures at the household scale. Structural materials, floor elevation, foundation stability, roof construction, wall strength, drainage, ventilation, orientation, shading, water-storage systems, sanitation arrangements, cooking environments, access routes, and proximity to protective infrastructure can influence the degree to which an external hazard becomes an internal health risk. Floodwater entering a dwelling can produce dampness, contamination, damage to stored food and household assets, sanitation disruption, and prolonged exposure to unhealthy indoor conditions. Cyclonic winds can damage lightweight roofs and walls, while storm surges can simultaneously affect structures, freshwater supplies, sanitation systems, and livelihoods. Salinity intrusion creates another pathway linking climate-related environmental change with household health because safe water availability can deteriorate in coastal communities, increasing dependence on alternative water sources and creating additional domestic burdens (Dzigbede et al., 2020). Heat represents a different but increasingly important housing exposure. Lightweight roofs, limited insulation, inadequate shading, dense settlement patterns, insufficient vegetation, restricted airflow, and heat-producing indoor activities can generate high indoor temperatures. Evidence from informal settlements outside Bangladesh also shows that relatively simple roof and material interventions can produce substantial differences in indoor thermal conditions, illustrating how building characteristics mediate heat exposure among low-income households. These hazards rarely operate independently. Heavy rainfall may coincide with drainage failure; cyclones may damage water infrastructure; floods may contaminate sanitation facilities; heat may interact with unreliable electricity; and displacement may

increase household crowding (Taylor, 2020).

Figure 2: Healthy Housing Equity Resilience Framework



Bangladesh has achieved internationally recognized reductions in disaster mortality through preparedness, warning systems, and risk-management measures, while substantial household-level and livelihood losses remain important dimensions of disaster exposure. Quantitative examination of housing therefore requires attention not only to whether households experience a particular hazard, but also to how dwelling characteristics, socioeconomic resources, infrastructure access, and location jointly structure the severity of exposure.

An equity-centered analysis of Bangladesh requires differentiation between urban informal settlements and rural communities because both experience housing vulnerability through distinct yet overlapping pathways (Zhang et al., 2020). Urban informal settlements are shaped by high population and building density, constrained land availability, insecure or complex tenure arrangements, limited household income, inadequate drainage, insufficient sanitation, unreliable water and electricity services, combustible or thermally inefficient building materials, and restricted opportunities for structural upgrading. Residential vulnerability is further affected by the location of settlements near water bodies, drainage channels, transportation corridors, industrial activities, waste sites, or other environmentally exposed spaces. International health-equity evidence identifies structurally deficient housing, overcrowding, inadequate utilities, insecure tenure, and hazardous settlement locations as recurring characteristics that intensify housing-related risks in slum environments. Research on Dhaka has additionally illustrated socioeconomic differences in exposure to environmental characteristics such as greenery and sky visibility, showing how the urban built environment can distribute environmental amenities unevenly among residents. Rural housing vulnerability takes a different spatial form (Amico et al., 2020). Rural households may occupy less densely built environments while facing greater exposure to riverbank erosion, floods, cyclones, storm surges, salinity, inadequate road connectivity, limited emergency access, fragile water systems, and longer distances from healthcare and other public services. Rural housing may also depend on locally available materials whose performance varies under prolonged inundation, strong winds, moisture, and extreme temperatures. Income constraints affect both settings, yet their consequences differ according to land ownership, livelihood structure, service availability, settlement density, construction practices, and hazard geography. Equity is therefore analytically important because aggregate national indicators can conceal major differences in who occupies hazardous housing, who has access to protective infrastructure, and who possesses the financial or institutional resources required to recover after damage (Cajete, 2020). Women, children, older adults, persons with disabilities, low-income households, informal workers, renters, and socially marginalized populations may experience residential hazards differently because of mobility,

caregiving responsibilities, control over household resources, accessibility requirements, and patterns of exposure. Housing conditions can consequently generate layered vulnerability when socioeconomic disadvantage coincides with structural weakness, inadequate services, and repeated environmental exposure. A quantitative framework capable of comparing urban informal settlements and rural communities can treat these dimensions as measurable constructs rather than assuming that vulnerability is uniform across low-income populations (Swinburn et al., 2019).

Existing scholarship provides substantial evidence on individual components of housing and health, yet the intersection among healthy housing design, pandemic resilience, climate resilience, and distributive equity requires integrated measurement. WHO housing guidance demonstrates that health-supportive residential conditions encompass multiple domains, including sufficient living space, safe indoor temperatures, injury prevention, accessibility, water quality, air quality, and protection from harmful environmental exposures. Disaster-risk studies separately examine structural resistance, hazard exposure, adaptive capacity, preparedness, recovery, and access to infrastructure. Pandemic studies emphasize household density, ventilation, sanitation, hygiene, isolation capacity, and patterns of interpersonal contact (Ali et al., 2016). Environmental-justice and health-equity research adds socioeconomic position, tenure, gender, disability, age, service deprivation, spatial marginalization, and unequal access to protective resources. When these literatures are considered together, healthy housing resilience can be conceptualized as a multidimensional construct comprising structural safety, environmental health quality, thermal performance, ventilation, water and sanitation security, spatial adequacy, accessibility, household adaptability, service reliability, and hazard-specific protection. Quantitative analysis makes it possible to operationalize these dimensions through observable indicators and examine their statistical relationships with household vulnerability and resilience outcomes. For example, structural resilience may be measured through roof and wall materials, foundation type, floor elevation, building condition, and history of hazard damage (Bardosh et al., 2017). Environmental health can be represented by ventilation openings, cooking-fuel arrangements, dampness, indoor heat, water quality, sanitation type, waste management, and crowding. Pandemic-related residential capacity can include persons per room, availability of separate sleeping spaces, ventilation, handwashing facilities, private or shared sanitation, water reliability, and capacity to isolate an ill household member. Climate-related resilience can incorporate flood depth, frequency of inundation, cyclone damage, heat exposure, salinity, drainage performance, access to shelters, and recovery time. Equity can be measured through household income, tenure status, gender-related characteristics, disability, age composition, livelihood security, access to finance, and differences between geographic or settlement categories (Cinderby et al., 2016). More than thirty studies across these intersecting fields collectively support the treatment of housing resilience as a system of correlated physical, environmental, socioeconomic, and institutional variables rather than as a single construction-quality measure. Such integration is particularly relevant in Bangladesh because the same household may simultaneously experience crowding, heat, flood exposure, unsafe water, inadequate sanitation, insecure income, and limited capacity to finance repairs, creating cumulative residential vulnerability that single-hazard measures cannot adequately represent (Brousselle et al., 2020).

Within Bangladesh, the central research problem concerns how healthy housing characteristics, socioeconomic inequalities, pandemic-related residential conditions, and recurrent climate-hazard exposure can be quantitatively integrated into an equity-centered housing design policy framework applicable to both urban informal settlements and rural communities. Existing bodies of research provide valuable knowledge about disaster preparedness, climate vulnerability, informal settlements, housing quality, environmental health, COVID-19, water and sanitation, household poverty, and community resilience, while these domains are frequently examined through separate disciplinary and policy lenses (Ameis et al., 2020). The separation is analytically restrictive because household experiences do not follow institutional boundaries. A dwelling exposed to recurrent flooding may also have poor ventilation, insufficient floor area, unreliable water, shared sanitation, heat-retaining roofing, limited accessibility, and inadequate financial resources for repair. Similarly, housing that performed poorly during COVID-19 because of crowding or limited isolation space may contain design characteristics that also influence thermal stress, indoor air quality, hygiene, and disaster recovery.

Bangladesh's exposure to repeated climate-related hazards strengthens the value of examining these relationships within the same empirical model. Coastal storm-tide research demonstrates the substantial hazard environment confronting low-lying regions, while international healthy-housing evidence establishes clear connections among dwelling quality, environmental conditions, and population health (Farrell et al., 2020). The quantitative orientation of the present study therefore centers on measurable variation in housing conditions and household resilience rather than treating healthy housing primarily as a normative architectural concept. Core variables can encompass structural quality, dwelling materials, floor elevation, ventilation, thermal conditions, household crowding, water and sanitation access, hygiene facilities, drainage, energy reliability, tenure, income, household composition, hazard frequency, previous housing damage, displacement, recovery capacity, and access to institutional support. Statistical assessment of these variables permits examination of differences between settlement types and socioeconomic groups as well as associations among housing design characteristics, hazard exposure, pandemic-related functionality, and resilience outcomes (Bahadur & Tanner, 2014). An equity-centered policy framework in this context refers to a structured set of design standards, prioritization criteria, health indicators, resilience measures, and distributional considerations through which housing policies can account for unequal exposure and unequal protective capacity. The empirical focus on urban informal settlements and rural communities provides a basis for examining two major residential contexts in which housing inadequacy and environmental hazards intersect differently. The study is thus situated at the convergence of healthy-housing research, environmental health, climate-risk assessment, pandemic experience, disaster resilience, housing policy, and social equity, using quantitative evidence to characterize the relationships among these domains within the Bangladeshi housing context (Jarratt & Davies, 2020).

The primary objective of this quantitative study is to develop an equity-centered healthy housing design policy framework by systematically examining the relationships among housing conditions, climate-related hazard exposure, pandemic-related residential vulnerabilities, socioeconomic inequalities, and household resilience across Bangladesh's urban informal settlements and rural communities. Specifically, the study seeks to quantitatively assess the extent to which physical housing characteristics, including structural materials, dwelling condition, floor elevation, roof and wall construction, ventilation, indoor thermal conditions, availability of natural light, household crowding, spatial adequacy, accessibility, water supply, sanitation, hygiene facilities, drainage, household energy, and access to essential services, are associated with the capacity of households to maintain safe and healthy living conditions during climate-related hazards and public-health emergencies. A further objective is to measure the frequency and severity of household exposure to floods, cyclones, storm surges, waterlogging, extreme heat, salinity intrusion, erosion, and related environmental disturbances and to determine how these exposures interact with existing housing deficiencies to shape variations in residential vulnerability. Drawing lessons from household experiences during COVID-19, the study also aims to evaluate pandemic-relevant housing characteristics, particularly residential density, persons per room, ventilation adequacy, access to private or shared sanitation, availability of reliable water and handwashing facilities, capacity to isolate an ill household member, and the adaptability of domestic space for healthcare, education, work, and caregiving activities. Another objective is to examine whether socioeconomic and demographic factors—including household income, tenure status, livelihood security, household size, age composition, gender-related household characteristics, disability-related accessibility requirements, access to financial resources, and availability of institutional assistance—produce statistically significant differences in healthy housing conditions and resilience outcomes. The study additionally seeks to compare urban informal settlements and rural communities in order to identify variations in housing quality, environmental exposure, service availability, adaptive capacity, and recovery experiences across distinct settlement contexts. Through multivariate statistical assessment, the research aims to identify the housing, socioeconomic, environmental, and institutional variables that most strongly explain variations in household resilience and to determine whether cumulative housing disadvantages are associated with greater vulnerability to multiple hazards. Finally, the study seeks to translate the measured relationships into an empirically grounded equity-centered healthy housing policy framework consisting of measurable design domains, resilience indicators, vulnerability criteria, and priority categories that reflect the

differentiated housing realities of climate-exposed and socioeconomically disadvantaged households in Bangladesh.

LITERATURE REVIEW

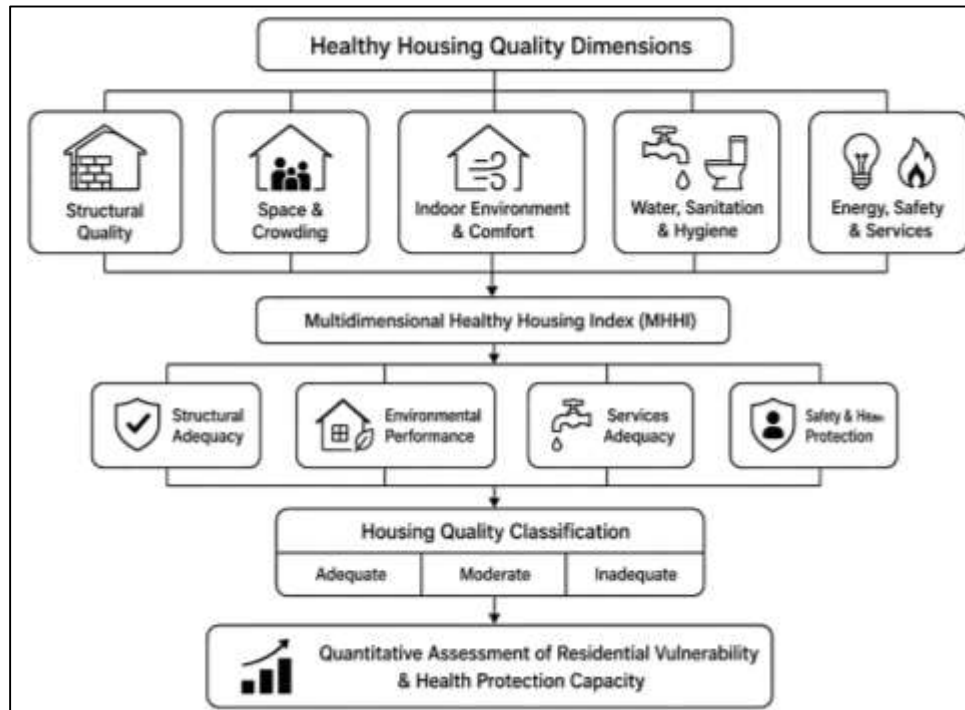
The literature on healthy housing, climate resilience, pandemic preparedness, and housing equity spans several interconnected disciplines, including public health, environmental epidemiology, architecture, urban planning, disaster-risk reduction, climate adaptation, social policy, and development studies. Within these bodies of scholarship, housing is increasingly conceptualized not merely as a physical shelter but as a multidimensional residential system through which environmental exposures, socioeconomic inequalities, infrastructure deficiencies, and health risks interact (Dwirahmadi et al., 2019; Kanti, 2020). For the present quantitative study, “Toward an Equity-Centered Healthy Housing Design Policy Framework for Climate and Pandemic Resilience: Lessons from COVID-19 and Frequent Climate-Related Hazards in Bangladesh’s Urban Informal Settlements and Rural Communities,” the literature review requires particular attention to variables that can be operationalized and statistically measured. These include housing structural quality, construction materials, ventilation, indoor thermal conditions, household crowding, water and sanitation access, hygiene facilities, drainage, energy reliability, tenure security, income, household composition, hazard frequency, disaster-related housing damage, displacement, recovery capacity, accessibility, and institutional support. Such variables permit healthy housing to be examined as a measurable exposure and resilience system rather than solely as an architectural or normative concept (Debasish, 2021; Gössling, 2020). This orientation is important in Bangladesh because housing vulnerability varies substantially by settlement type, geographic exposure, socioeconomic status, access to services, and household adaptive capacity. Earlier research on Bangladesh's urban informal settlements has documented severe crowding, limited sanitation and water services, poor drainage, and settlement in low-lying flood-prone locations. Research concerning climate migrants living in Bangladeshi urban slums has similarly identified interconnected livelihood and WASH difficulties, including challenges experienced in the COVID-19 context (Abdur & Iftekhhar, 2021; Rolfe et al., 2020). Recent quantitative and spatial approaches have additionally demonstrated the usefulness of community risk scoring and GIS-based multi-hazard assessment for examining flood, heat, and cyclone vulnerability in urban and rural Bangladesh. Consequently, the literature review is structured around clearly measurable relationships connecting housing quality, environmental health, climate-hazard exposure, pandemic functionality, socioeconomic inequality, and household resilience. The sections below provide an extended quantitative organization through which previous empirical evidence can be synthesized, variables can be distinguished as predictors, outcomes, mediators, moderators, and controls, and the theoretical and empirical gaps supporting the quantitative investigation can be systematically established (Frederick et al., 2014).

Healthy Housing

Healthy housing has increasingly been treated in empirical literature as a multidimensional construct that incorporates the physical condition of the dwelling, adequacy of residential space, quality of the indoor environment, access to essential services, and protection from household and environmental hazards. Studies by Bonnefoy, Thomson et al., Howden-Chapman et al., Jacobs et al., Krieger and Higgins, Rauh et al., Baker et al., Braubach et al., and other housing-health researchers have demonstrated that reliance on a single housing characteristic provides an incomplete representation of residential quality because households are simultaneously exposed to multiple conditions that can reinforce one another (Won et al., 2016). Quantitative housing studies have therefore operationalized housing quality through individual indicators and composite measures such as Housing Quality Indexes, housing deprivation scores, structural adequacy measures, housing-health indices, and multidimensional residential quality scales. Structural condition is commonly captured through observations of cracks, damaged walls, leaking roofs, unstable foundations, deteriorated floors, moisture penetration, and the general state of repair. Construction materials provide additional measurable information because wall, roof, and floor materials influence structural durability, thermal performance, protection against moisture, and resistance to environmental hazards. Floor elevation and foundation condition are particularly relevant in flood-exposed environments, while roof durability and wall stability are important indicators in locations affected by storms and strong winds

(Zhang et al., 2019).

Figure 3: Multidimensional Healthy Housing Quality Framework



Quantitative studies have also incorporated the number of rooms, total household size, usable floor area, and persons-per-room ratio to represent residential crowding and spatial adequacy. These measures are especially important because two dwellings with similar construction materials can provide substantially different living conditions when occupancy density differs. Household safety indicators further extend measurement beyond structural durability by considering exposed electrical wiring, unsafe cooking arrangements, fall hazards, fire risks, inadequate stairs, and other injury-related conditions. Across this literature, healthy housing is consequently measured through combinations of observable building attributes and household-level characteristics, allowing researchers to compare residential conditions across income categories, neighborhoods, settlement types, and geographic areas while identifying clusters of housing deprivation that would remain hidden when housing quality is represented through a single indicator (Thorbecke, 2015).

A second major body of quantitative literature defines healthy housing through indoor environmental quality and the degree to which dwelling design regulates occupants' exposure to air pollutants, excessive temperatures, moisture, inadequate daylight, crowding, and other residential stressors. Research by Howden-Chapman et al., Mendell et al., Fisk et al., Sauni et al., Krieger et al., WHO housing researchers, and studies conducted across low- and middle-income settings has established ventilation, dampness, mould, thermal conditions, and household occupancy as measurable dimensions of residential health (Alkire & Fang, 2019). Ventilation adequacy has been operationalized through window availability, window dimensions, opening area, cross-ventilation potential, air-change characteristics, room configuration, and residents' perceptions of airflow. Natural ventilation becomes particularly important in low-income housing where mechanical ventilation and air-conditioning are uncommon or financially inaccessible. Indoor temperature is similarly measured through maximum and minimum temperature, average temperature, indoor-outdoor temperature differences, duration of exposure above specified thermal thresholds, and occupant-reported thermal discomfort. Roofing and wall materials, dwelling orientation, shading, vegetation, window placement, cooking practices, and occupancy density can influence these measurements. Dampness and mould represent another well-established quantitative housing domain, commonly recorded through visible mould, water stains,

condensation, roof leakage, wall moisture, musty odor, and resident reports of persistent dampness (Charalampous et al., 2019). Daylight availability has also been incorporated into housing-quality assessment because limited openings and densely constructed neighborhoods can restrict natural illumination and airflow simultaneously. Crowding adds an important social-spatial dimension to these environmental measurements. Researchers have used persons per room, persons per bedroom, floor area per occupant, household size, sleeping arrangements, and shared-space availability to determine whether residential density exceeds acceptable standards. COVID-19 studies strengthened quantitative attention to these variables because household crowding, inadequate ventilation, shared facilities, and limited space for separating ill residents became measurable indicators of residential infectious-disease vulnerability (Palinkas, 2014). Taken together, this literature shows that indoor environmental quality cannot be adequately assessed by building condition alone. Ventilation, thermal exposure, moisture, daylight, occupancy density, and household activities constitute interconnected dimensions through which the physical dwelling becomes an everyday health exposure environment. Quantitative healthy-housing research also emphasizes that the quality of a dwelling depends on its connection to water, sanitation, hygiene, drainage, energy, and waste-management systems. Inadequate basic services can transform otherwise habitable structures into unhealthy residential environments. Drinking-water adequacy has been quantified through source type, location of the source, collection time, continuity of supply, quantity available to household members, water treatment practices, storage conditions, affordability, and reported contamination (Morton et al., 2017). Sanitation has similarly been measured according to facility type, household ownership, whether facilities are shared, number of users per facility, functionality, cleanliness, accessibility, and safe management of human waste. Handwashing facilities, availability of water and soap, and location of hygiene infrastructure have become important additional indicators, particularly in studies examining household preparedness and health protection during infectious-disease outbreaks. Drainage represents another critical dimension in dense informal settlements and flood-prone communities because blocked or absent drainage can increase standing water, household flooding, wastewater exposure, mosquito breeding, dampness, and deterioration of building materials. Researchers have consequently measured drainage through availability, type, functionality, blockage frequency, proximity to open drains, duration of waterlogging, and household experiences of wastewater intrusion. Energy reliability contributes to healthy housing through lighting, ventilation, cooling, communication, food storage, water pumping, and safe cooking (Peterson, 2014). Quantitative indicators commonly include electricity connection, daily availability, outage frequency, cooking-fuel type, cooking location, kitchen ventilation, and reliance on solid fuels. Waste management is measured through collection availability, disposal practices, collection frequency, proximity to waste accumulation, and household exposure to uncontrolled dumping. These dimensions are particularly significant in Bangladesh's urban informal settlements and rural communities, where housing quality can be strongly conditioned by neighborhood infrastructure and service reliability. WASH adequacy, drainage performance, energy security, and waste-management conditions therefore broaden quantitative healthy-housing assessment from the physical dwelling to the service systems required for maintaining a safe residential environment (Pelz et al., 2018).

A substantial strand of housing research has combined structural, environmental, spatial, and service-related indicators into composite measures designed to represent the overall condition of residential environments. Studies using Housing Quality Indexes, housing deprivation indices, multidimensional poverty measures, neighborhood-quality indices, vulnerability indices, and healthy-housing assessment frameworks have demonstrated the analytical value of combining several indicators when households experience simultaneous disadvantages. A Housing Quality Index commonly incorporates variables related to construction materials, structural condition, dwelling durability, occupancy, sanitation, water access, electricity, cooking facilities, and environmental conditions. Structural adequacy scores concentrate more specifically on the physical integrity and protective capacity of roofs, walls, floors, foundations, doors, windows, and related components (Sokołowski et al., 2020). Crowding measures add information about the relationship between available residential space and household population, while ventilation and indoor-temperature measures represent the performance of the internal environment.

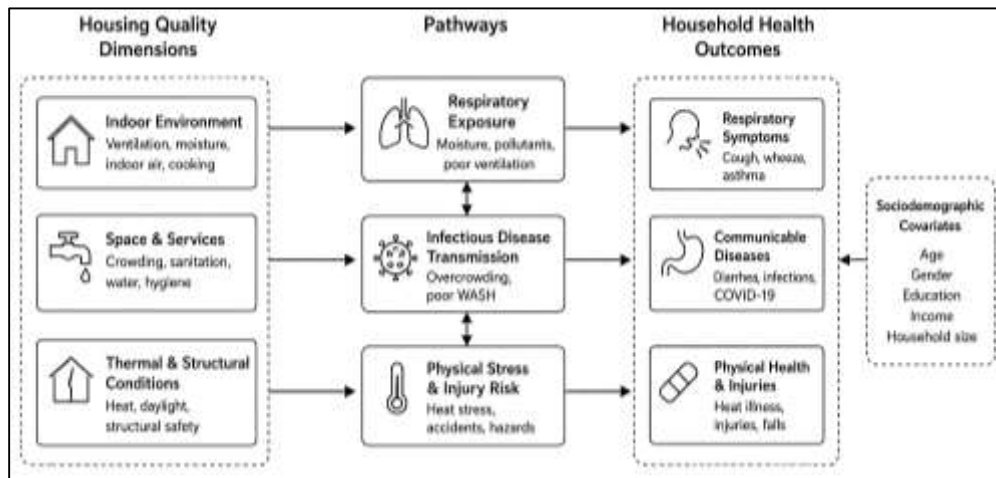
WASH indicators capture the adequacy and reliability of water, sanitation, and hygiene facilities, and drainage indicators characterize protection from stagnant water, wastewater, and localized flooding. Energy reliability, waste management, household safety, daylight, dampness, mould, and cooking conditions provide additional dimensions that can distinguish households whose physical structures appear similar but whose actual residential environments differ considerably. Composite Healthy Housing Indices can therefore organize these indicators into broader domains such as structural safety, spatial adequacy, indoor environmental quality, WASH and hygiene, energy and services, and household environmental safety (Liddell & Guiney, 2015). For Bangladesh, multidimensional measurement is particularly relevant because urban informal settlements and rural communities present different combinations of structural and infrastructural deprivation. An urban household may experience severe crowding, shared sanitation, drainage congestion, limited daylight, and indoor overheating, while a rural household may have greater residential space but weaker structural materials, unreliable electricity, unsafe water access, flood exposure, or inadequate sanitation. Quantitative classification through multidimensional indicators enables these different patterns of housing deprivation to be measured consistently and compared across settlement categories, socioeconomic groups, and levels of environmental exposure (Nocca, 2017).

Housing Quality and Household Health Outcomes

Housing quality has been consistently identified in quantitative public-health research as an important determinant of respiratory symptoms and broader household morbidity because the dwelling regulates everyday exposure to moisture, mould, airborne pollutants, temperature variations, combustion products, and ventilation conditions. Empirical investigations by Krieger and Higgins, Howden-Chapman and colleagues, Thomson and colleagues, Mendell and colleagues, Fisk and colleagues, Quansah and colleagues, Sharpe and colleagues, Jaakkola and colleagues, Norbäck and colleagues, and other housing-health researchers have reported measurable associations between deficient indoor environments and respiratory outcomes (Lester, et al., 2016). Dampness and visible mould have received substantial quantitative attention because persistent moisture promotes microbial growth and is frequently associated with coughing, wheezing, asthma symptoms, respiratory infections, and other adverse respiratory conditions. Studies using logistic regression and multivariable models have commonly treated visible mould, water leakage, condensation, damp walls, musty odors, and moisture damage as independent residential exposure variables while controlling for age, smoking, socioeconomic position, household composition, and other potential confounders. Ventilation represents another important component of these relationships. Poorly ventilated rooms can increase concentrations of indoor pollutants and moisture while extending occupants' exposure to contaminants generated through cooking, heating, smoking, cleaning, and routine household activities (Boch et al., 2020). Quantitative studies examining ventilation have used indicators such as window availability, frequency of window opening, ventilation rate, room configuration, occupancy density, and perceived indoor air quality. Cooking conditions are particularly relevant in lower-income households where biomass, wood, charcoal, crop residues, kerosene, and other polluting fuels may be used in poorly ventilated spaces. Research by Smith and colleagues, Bruce and colleagues, Dherani and colleagues, Pope and colleagues, and Fullerton and colleagues has connected household air pollution from solid-fuel combustion with respiratory disease and symptoms, particularly among women and children who may experience prolonged exposure near cooking areas (Angel & Bittschi, 2019). Residential crowding can further intensify these conditions by increasing occupancy-generated moisture and reducing available air volume per person. Collectively, the empirical literature demonstrates that respiratory health is statistically associated with clusters of housing deficiencies rather than with one isolated building characteristic, making dampness, mould, ventilation, indoor air quality, cooking fuel, occupancy, and structural maintenance central variables in quantitative assessments of household health. Housing deficiencies are also strongly represented in quantitative literature examining communicable diseases, gastrointestinal illness, and household transmission of infections (Rabinowitz et al., 2015). Studies by Baker and colleagues, Cardoso and colleagues, Gove and colleagues, Hargreaves and colleagues, Acevedo-Garcia, WHO-associated researchers, Fewtrell and colleagues, Wolf and colleagues, Prüss-Ustün and colleagues, Freeman and colleagues, and other investigators have demonstrated that household crowding, sanitation inadequacy, unreliable water supplies, unsafe

water storage, and deficient hygiene infrastructure contribute to measurable differences in infectious-disease risk.

Figure 4: Housing Quality and Health Outcomes



Overcrowding is commonly operationalized through persons per room, persons per bedroom, household size, floor area per occupant, or categorical crowding thresholds. Regression-based analyses have frequently found that higher residential density is associated with increased opportunities for close interpersonal contact, particularly when sleeping spaces and household facilities are shared (Kojima, 2015). Such conditions are relevant to respiratory infections, tuberculosis, influenza-like illnesses, and other communicable diseases transmitted through prolonged or close household contact. COVID-19 strengthened this evidence base by demonstrating how the feasibility of household isolation, distancing, and infection control varied according to dwelling size, room availability, occupancy density, ventilation, and access to private facilities. Water and sanitation research identifies a related pathway between housing conditions and gastrointestinal morbidity. Studies using odds ratios, relative risks, prevalence ratios, and multilevel models have associated unimproved sanitation, shared toilets, unsafe drinking-water sources, inadequate handwashing infrastructure, unreliable water availability, and poor household water-storage practices with diarrheal disease and other enteric infections (Berg et al., 2015). Children are particularly prominent in this literature because diarrheal morbidity can be highly sensitive to household and neighborhood WASH conditions. Drainage deficiencies may compound these exposures by allowing wastewater and contaminated floodwater to accumulate around dwellings, particularly in densely populated informal settlements. Bangladesh-based studies of urban slums and resource-constrained communities have documented combinations of shared sanitation, water insecurity, crowding, poor drainage, and environmental contamination that create interconnected residential health exposures. The quantitative literature therefore positions communicable-disease prevalence and diarrheal morbidity as measurable outcomes of both dwelling-level characteristics and surrounding service conditions, emphasizing that healthy housing assessment must incorporate spatial adequacy, sanitation functionality, water safety, hygiene resources, drainage, and ventilation alongside conventional measures of structural quality (Fried et al., 2014).

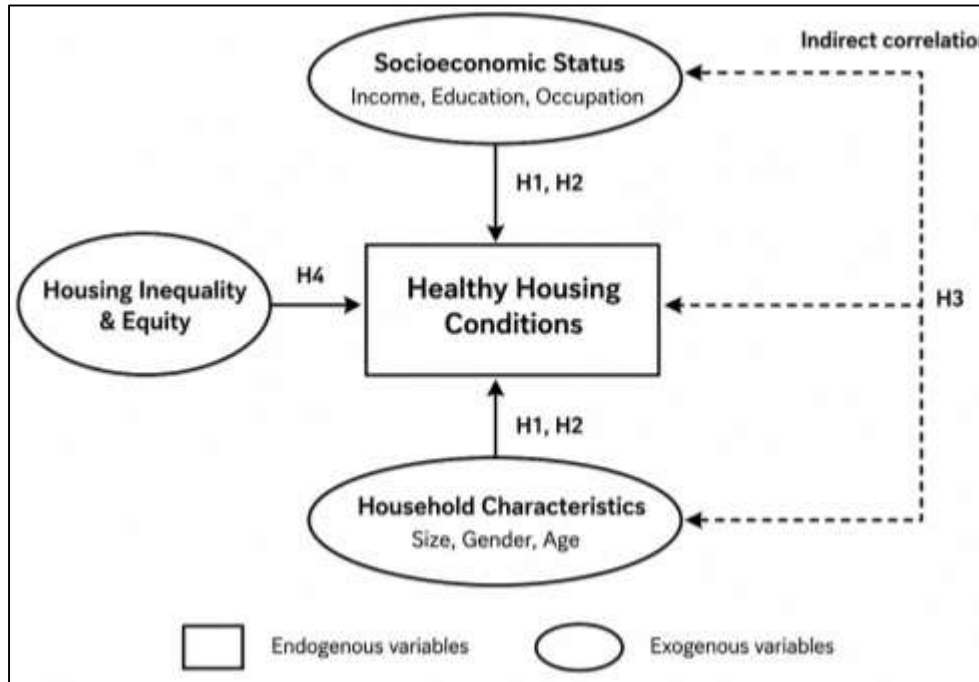
Thermal conditions, daylight availability, structural deterioration, and household safety constitute another set of housing characteristics associated with measurable physical-health outcomes. Research by Howden-Chapman and colleagues, Wilkinson and colleagues, Hajat and colleagues, Vardoulakis and colleagues, Thomson and colleagues, Braubach and colleagues, Ormandy and colleagues, and other environmental-health researchers has demonstrated that both excessively high and inadequately low indoor temperatures can influence health, particularly among older adults, children, individuals with limited mobility, and households with insufficient resources for cooling or temperature regulation (Frasquilho et al., 2015). In warm and humid environments, excessive indoor heat can produce thermal discomfort, dehydration, sleep disruption, fatigue, headaches, reduced physical functioning, and heat-

related illness. Quantitative investigations of residential heat exposure have employed indoor temperature measurements, maximum daily temperature, duration above heat thresholds, thermal comfort scores, roofing materials, ventilation characteristics, shading, building orientation, household density, and access to fans or cooling equipment. These variables are particularly important for informal and low-cost housing constructed with materials that absorb and transfer substantial solar heat. In Bangladesh, high humidity, warm-season temperatures, electricity interruptions, dense urban construction, and thermally vulnerable roofing materials can combine to produce substantial indoor heat exposure (Oakman et al., 2020). Daylight and window availability also form part of the indoor environmental literature because poorly illuminated dwellings can reflect limited openings, dense construction, and restricted ventilation while affecting daily activities and perceptions of residential quality. Structural hazards create additional direct pathways to physical morbidity. Damaged floors, unstable stairs, deteriorating walls, leaking roofs, exposed wiring, unsafe cooking areas, inadequate lighting, and poorly maintained building components have been examined as predictors of falls, burns, electrical injuries, cuts, and other household accidents. Studies employing housing hazard assessments and injury surveillance have shown that injury risks are unevenly distributed across dwelling conditions and household characteristics. Flooding and severe weather can intensify these hazards through structural deterioration, electrical exposure, slippery surfaces, contamination, and damaged access routes (Karimi & Brazier, 2016). Consequently, quantitative housing-health research treats physical health as an outcome shaped by both chronic environmental conditions and immediate safety hazards, supporting the inclusion of thermal exposure, structural condition, daylight, household safety, energy reliability, and hazard-related dwelling damage in assessments of residential health.

Socioeconomic Inequality

Socioeconomic position has been consistently identified across housing, public-health, environmental-justice, and urban-development literature as a major predictor of differences in residential quality. Income is particularly influential because it determines the range of residential locations, construction materials, dwelling sizes, infrastructure services, maintenance options, and environmental protections available to households. Quantitative studies commonly classify households by income quintiles, poverty status, expenditure levels, asset ownership, or composite socioeconomic indices and compare these measures with structural housing quality, overcrowding, water and sanitation access, energy conditions, and neighborhood environmental characteristics (Chihuri et al., 2016). Lower-income households are frequently concentrated in dwellings characterized by less durable construction, insufficient living space, inadequate ventilation, shared sanitation, unreliable water, drainage deficiencies, and greater proximity to environmental hazards. Educational attainment also contributes to housing differentiation because it is associated with employment opportunities, earnings, access to information, institutional navigation, and the capacity to understand or act on housing-related health risks. Occupational position produces another layer of inequality, particularly among informal workers, agricultural laborers, day laborers, domestic workers, transport workers, and other groups whose earnings may fluctuate considerably. Studies of informal settlements have shown that irregular income can restrict both housing choice and the ability to undertake repairs or protective modifications. These socioeconomic determinants are interrelated rather than independent (Krieger et al., 2017). Limited education may constrain occupational opportunities, insecure employment may produce unstable income, and low income may restrict access to structurally adequate housing and basic services. The quantitative literature therefore treats socioeconomic disadvantage as a multidimensional household condition that can be statistically associated with differences in structural integrity, environmental quality, residential space, infrastructure access, and household safety, providing an important basis for understanding why unhealthy housing is disproportionately concentrated among economically disadvantaged populations (Vermeiren et al., 2016). Employment security, housing tenure, and access to financial resources constitute additional socioeconomic mechanisms through which healthy housing conditions are distributed unevenly. Studies by Bentley and colleagues, Pollack and colleagues, Desmond and colleagues, Rolfe and colleagues, Clair and colleagues, Swope and Hernández, Hulse and Milligan, Bonnefoy, UN-Habitat researchers, and scholars examining housing insecurity have shown that the stability of household resources can be as important as absolute income in determining residential conditions (André et al., 2019).

Figure 5: Socioeconomic Predictors of Healthy Housing



Households dependent on temporary, seasonal, informal, or daily-paid employment may experience substantial fluctuations in disposable income, limiting their ability to pay for housing maintenance, safer construction materials, improved sanitation, reliable electricity, cooling equipment, water storage, or structural reinforcement. Financial insecurity can also increase the likelihood of occupying lower-cost housing in environmentally exposed locations. Tenure status interacts strongly with these conditions. Homeowners, renters, informal occupants, landless households, and households living under insecure tenure arrangements possess different degrees of control over dwelling modification and investment. Renters may have limited authority or financial incentive to alter roofs, walls, windows, drainage systems, sanitation facilities, or ventilation arrangements, while landlords may delay improvements when regulatory enforcement is weak. Informal occupants can face additional constraints because uncertainty regarding continued residence reduces the security needed for substantial housing investment (Mullen et al., 2020). Rural landless households may similarly occupy environmentally vulnerable locations or depend on housing arrangements that provide limited control over structural improvements. Quantitative research has operationalized these relationships through tenure categories, housing expenditure burden, rent-to-income ratios, employment status, household savings, credit access, debt, asset ownership, repair expenditure, and access to formal or informal financial assistance. Access to finance is particularly relevant following floods, cyclones, erosion, or other damaging events because households with savings, credit, insurance, remittances, or institutional assistance generally possess greater resources for repair and reconstruction. Housing deprivation therefore reflects not only the physical state of a dwelling at a particular moment but also the household's economic capacity and decision-making authority to maintain, modify, and restore that dwelling (Fitzpatrick & Watts, 2017). Socioeconomic inequalities in employment stability, tenure security, and financial access consequently contribute to systematic differences in both everyday housing quality and the ability to manage residential deterioration or hazard-related damage. Household demographic composition provides another important dimension of socioeconomic inequality because housing needs, resource availability, exposure patterns, and accessibility requirements vary according to household size, dependency structure, gender-related characteristics, age, and disability. Research by Evans and colleagues, Baker and colleagues, Marmot and colleagues, WHO researchers, Braubach and colleagues, Mitra and colleagues, Groce and colleagues, Pinilla-Roncancio and colleagues, UN-Habitat studies, and broader social-determinants scholarship

demonstrates that residential disadvantage is often intensified when limited household resources coincide with greater caregiving or accessibility needs (Mehdipanah et al., 2020). Household size is commonly associated with residential crowding when increases in the number of occupants are not matched by additional rooms or usable floor space. Persons-per-room ratios, persons-per-bedroom measures, floor area per resident, and household crowding categories have therefore become important quantitative indicators linking household composition to housing adequacy. Dependency ratio further captures the economic pressure created when a relatively small number of income earners support larger numbers of children, older adults, or economically dependent household members. High dependency can constrain the amount of income available for repairs, sanitation improvements, safer construction materials, energy services, and other housing expenditures. Gender-related household characteristics also shape residential vulnerability through differences in income control, property ownership, caregiving responsibilities, time spent inside the dwelling, and participation in household decisions (Meer & Combrinck, 2017). Female-headed households in resource-constrained settings may encounter particular housing disadvantages when unequal access to employment, credit, land, or property ownership intersects with caregiving responsibilities. Disability introduces an additional equity dimension because conventional housing-quality measures may classify a structurally sound dwelling as adequate while overlooking whether entrances, toilets, circulation spaces, sleeping areas, water points, evacuation routes, or community infrastructure are accessible to occupants with mobility, sensory, or other functional limitations. Older adults can experience similar barriers where stairs, uneven floors, poor lighting, narrow passages, or distant sanitation facilities increase everyday difficulty and injury risk. Quantitative measurement of healthy housing inequality must therefore account for household composition and differential needs rather than relying exclusively on income or structural quality (Morciano et al., 2015). These demographic characteristics help explain why households with apparently similar dwellings may experience substantially different levels of residential adequacy, safety, and capacity to cope with environmental and public-health stresses.

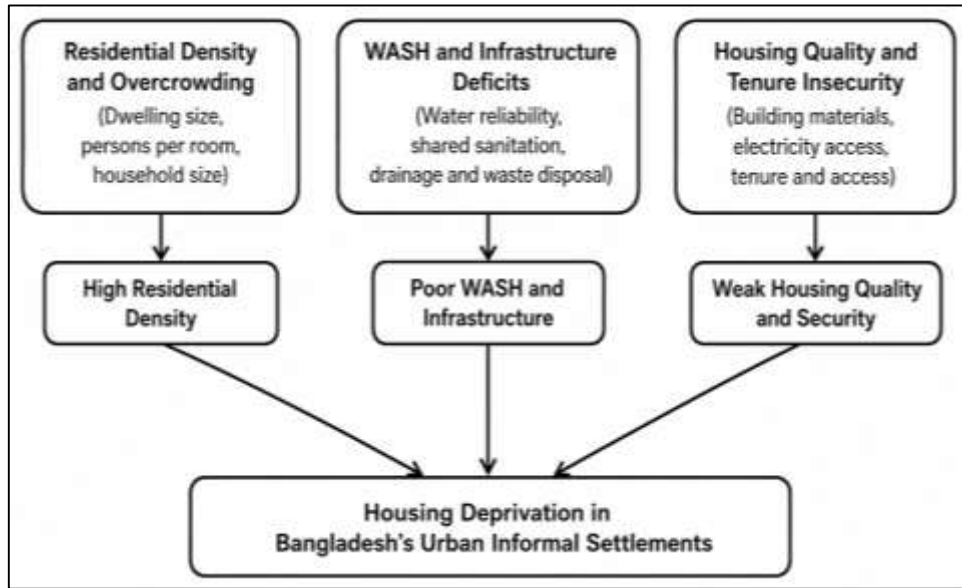
Housing inequality and housing equity represent related but analytically distinct concepts within the literature on socioeconomic determinants of residential conditions. Housing inequality describes measurable differences in housing resources, quality, services, environmental conditions, and security across population groups, whereas housing equity focuses on whether these differences are systematically associated with social and economic disadvantage and whether residential resources correspond to differing levels of need and vulnerability (Reichert & Berry, 2020). Low-income households may simultaneously occupy structurally weaker dwellings, experience greater crowding, rely on shared sanitation, have less reliable water and electricity, encounter poorer drainage, and reside closer to flood-prone land, polluted environments, waste accumulation, industrial activities, or other hazards. In Bangladesh, the distinction between inequality and equity is especially relevant when comparing urban informal settlements and rural communities because similar socioeconomic disadvantage can generate different patterns of housing exposure. Urban informal-settlement households may encounter extremely high residential density, restricted ventilation, limited daylight, shared WASH infrastructure, insecure tenure, heat accumulation, and waterlogging, whereas disadvantaged rural households may experience weaker structural materials, inadequate sanitation, unreliable services, river erosion, flooding, cyclone exposure, salinity, or long distances from essential facilities (Mitra et al., 2017). Repeated climate-related hazards can deepen these inequalities when households with fewer financial resources experience recurrent damage but have less capacity to undertake durable reconstruction. Pandemic conditions can similarly amplify pre-existing differences when larger households occupy limited space or lack private sanitation, reliable water, adequate ventilation, and rooms suitable for isolation. Multivariable regression, multilevel analysis, mediation analysis, and structural equation modeling used across socioeconomic and housing research provide methods for distinguishing direct socioeconomic associations from pathways operating through residential conditions. This literature establishes housing deprivation as an important intermediate dimension through which income, employment, tenure, household composition, financial access, and social disadvantage are translated into unequal residential vulnerability and differentiated resilience across population groups (Fabrizi & Mussida, 2020).

Housing Deprivation in Bangladesh's Urban Informal Settlements

Quantitative studies of housing deprivation in Bangladesh's urban informal settlements consistently identify residential density, restricted dwelling size, and overcrowding as central characteristics of disadvantaged housing environments. Research conducted in Dhaka, Chattogram, Khulna, Rajshahi, and other rapidly urbanizing areas has shown that low-income households frequently occupy small dwellings containing a limited number of rooms relative to household size. Quantitative indicators commonly include total floor area, number of rooms, household size, persons per room, persons per bedroom, sleeping arrangements, and residential density per unit of land (Montez et al., 2017). These measures are important because overcrowding affects privacy, thermal comfort, ventilation, sleep quality, household functioning, and exposure to infectious disease. In densely built settlements, neighboring dwellings are often separated by narrow passages, and limited spacing between structures can reduce natural ventilation and daylight while increasing indoor heat accumulation. Such spatial arrangements also restrict opportunities for expanding dwellings as household size grows. The interaction between crowding and poverty further intensifies deprivation because households with low and irregular incomes may prioritize proximity to employment opportunities over housing size or environmental quality. Dhaka's informal settlements are particularly prominent in this literature because land scarcity, migration, high rents, and proximity to informal labor markets create strong incentives for compact settlement patterns (Patel et al., 2019). Similar pressures have been observed in Chattogram, where low-income communities are often located near industrial, hilly, coastal, or drainage-sensitive areas, and in Khulna, where urban poverty intersects with waterlogging, salinity, and climate-related migration. Collectively, the literature demonstrates that residential density in Bangladeshi informal settlements is not simply a demographic characteristic but a measurable dimension of housing deprivation that interacts with building configuration, affordability, household composition, and neighborhood infrastructure. Water, sanitation, hygiene, drainage, and waste-management deficiencies represent another major dimension of housing deprivation in Bangladesh's urban informal settlements (Nazem & Sultana, 2020). Quantitative assessments commonly measure the type of drinking-water source, number of households sharing a water point, frequency and duration of service interruptions, distance or waiting time for water collection, sanitation type, number of users per toilet, availability of handwashing facilities, drainage condition, and waste-disposal practices. Shared sanitation is particularly common in densely populated settlements, where multiple households may depend on a small number of latrines. This can affect cleanliness, privacy, accessibility, and facility availability during peak-use periods. Water-source reliability is similarly important because households may have access to an improved source while still experiencing irregular supply, low pressure, affordability problems, contamination, or long collection times. Drainage deficiencies are especially severe in low-lying informal settlements, where narrow or blocked drains, inadequate sewerage connections, and poor solid-waste management can contribute to recurrent waterlogging (Uddin, 2018). Waste accumulation may obstruct drainage channels and increase exposure to contaminated standing water, insects, rodents, and unpleasant indoor and outdoor environmental conditions. Studies in Dhaka have repeatedly linked inadequate drainage and waste management with localized flooding and poor neighborhood sanitation. Khulna presents an additional dimension because salinity, drainage congestion, and water insecurity can affect both household water availability and sanitation conditions. In Chattogram, heavy rainfall and topographic constraints can increase runoff-related risks in settlements located near slopes, canals, and poorly serviced peripheral areas (Thomson et al., 2020).

Across these cities, WASH deprivation is often intertwined with residential density, tenure insecurity, and limited municipal service coverage, making it a central component of quantitative housing-deprivation measurement. The physical quality of dwellings and the security of household occupancy are also prominent in quantitative studies of informal housing deprivation in Bangladesh. Corrugated metal sheets, bamboo, timber, brick, concrete, mud, and other locally available materials are commonly used in different combinations, producing varying levels of structural durability, thermal performance, moisture resistance, and hazard protection (Afroza et al., 2016). Quantitative assessments often classify dwellings into kutchha, semi-pucca, and pucca categories or construct structural-quality scores using roof, wall, floor, foundation, and maintenance indicators.

Figure 6: Quantitative Housing Deprivation in Bangladesh



Tenure insecurity adds a social and institutional dimension to these physical conditions. Informal renters, squatters, and households occupying land without formal documentation may have limited authority or incentive to invest in structural improvements. The threat of eviction or redevelopment can further reduce willingness to undertake costly repairs, reinforce floors, improve drainage, or upgrade sanitation. Electricity access is another commonly measured housing variable. Although many urban low-income households have some form of electricity connection, service quality may vary substantially through outages, informal connections, unsafe wiring, voltage fluctuations, and limited affordability. These conditions can affect lighting, cooling, food storage, communication, and household safety (Alam et al., 2020). Road and pathway accessibility also plays a critical role in housing deprivation. Informal settlements are frequently characterized by narrow lanes that limit emergency access, waste collection, drainage maintenance, fire response, and movement during flooding. Poor accessibility may also increase the distance between dwellings and formal transport, health facilities, schools, and markets. In Dhaka, extremely compact settlement layouts can make internal circulation difficult, while in Chattogram and Khulna environmental and topographic constraints can further complicate access. The literature therefore shows that housing deprivation in Bangladesh's informal settlements includes not only the physical structure of the dwelling but also tenure security, utility reliability, internal settlement accessibility, and the degree to which residents can safely maintain and improve their residential environments (McNamara et al., 2016).

Climate-Related Hazard Exposure

Climate-related flooding represents one of the most consistently documented environmental pressures affecting housing conditions in urban informal settlements, particularly in rapidly growing cities where low-income communities occupy low-lying, poorly drained, or environmentally exposed land. Quantitative studies commonly measure annual flood frequency, maximum flood depth inside or around dwellings, hours or days of standing water, number of rooms affected, percentage of structural damage, repair expenditure, asset loss, and duration of household displacement (Lintelo et al., 2018). These indicators allow researchers to distinguish between occasional nuisance flooding and repeated severe exposure capable of progressively weakening housing structures and household economic security. In informal settlements, lightweight walling materials, corrugated-metal roofs, earthen or poorly raised floors, weak foundations, and limited protective barriers can increase the physical effects of inundation. Floodwater may damage walls and flooring, destabilize foundations, contaminate stored food and household belongings, and increase dampness and mould after water recedes. Recurrent flooding can also raise cumulative repair costs for households whose incomes are already constrained, creating repeated cycles of damage and partial reconstruction (Ahmed & Johnson, 2014). Research from

Dhaka has frequently emphasized the interaction between low elevation, drainage congestion, high-density settlement, and inadequate municipal infrastructure in shaping household flood exposure. Similar patterns have been observed in other South Asian cities where informal settlements are concentrated beside canals, rivers, wetlands, transport corridors, and reclaimed land. The literature therefore demonstrates that flood vulnerability is best understood as a measurable interaction between hazard intensity, structural housing quality, household resources, and settlement location rather than as a simple binary distinction between flooded and non-flooded households. Waterlogging and drainage failure constitute a related but analytically distinct form of climate-related housing vulnerability because households may experience prolonged exposure to standing water even in the absence of major riverine flooding (Malik et al., 2020).

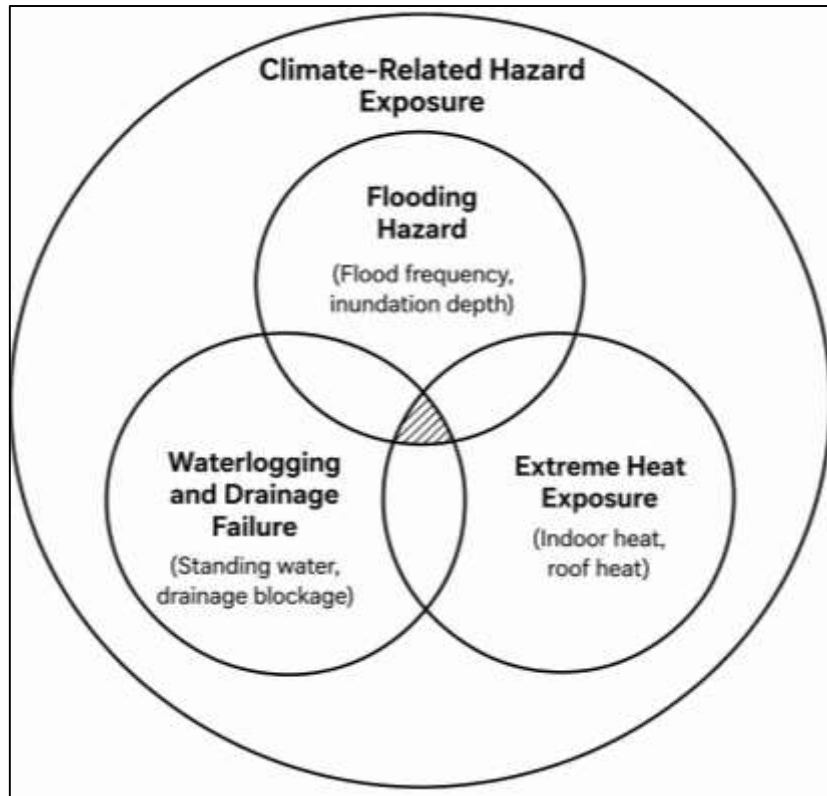
Quantitative assessment of this exposure commonly includes the duration of water accumulation, number of waterlogged days per rainy season, depth of standing water, household entry of wastewater, frequency of drain overflow, distance to functioning drainage channels, and time required for water to recede. Drainage failure has direct implications for the physical condition of housing because repeated moisture exposure can deteriorate wall materials, floors, foundations, doors, household furniture, and electrical systems. It also creates important environmental-health pathways through contact with contaminated water, increased mosquito breeding, offensive odors, mould development, and disruption of sanitation facilities (Grasham et al., 2019).

In settlements where toilets and drains are shared, waterlogging can spread contamination across pathways and residential compounds, increasing exposure for households that may not have been directly flooded inside their dwellings. Studies of Dhaka's informal settlements have frequently identified drainage inadequacy and waste accumulation as interconnected problems, as uncollected solid waste can obstruct narrow drains and reduce stormwater flow during intense rainfall. Road and pathway accessibility can also deteriorate during prolonged waterlogging, restricting movement to schools, workplaces, health facilities, and markets. This can extend the consequences of climate exposure beyond immediate property damage by affecting household income and access to basic services. Quantitative studies increasingly treat waterlogging duration and drainage performance as independent variables because they capture chronic environmental stress that may not be reflected by major flood-event records (Owusu & Nursey-Bray, 2019).

The literature consequently positions drainage functionality as a central component of urban housing resilience, particularly in informal settlements where small differences in elevation, drain access, and settlement layout can substantially alter the severity of household exposure.

Extreme heat has become another important dimension of urban informal housing vulnerability because the thermal performance of low-cost dwellings can substantially influence household exposure during periods of high outdoor temperature (French et al., 2020). Quantitative investigations commonly record maximum indoor temperature, minimum nighttime temperature, indoor-outdoor temperature differences, hours above thermal comfort thresholds, roof-surface temperature, and occupant-reported heat stress. Corrugated-metal roofing, thin wall materials, limited insulation, inadequate ceiling space, and direct solar exposure can increase heat transmission into small dwellings, especially where rooms have restricted airflow. High occupancy density can further increase internal heat and humidity, while narrow spacing between structures may reduce cross-ventilation and trap heat at neighborhood level. Informal settlements often have limited tree cover and open space, further reducing passive cooling opportunities (Owusu et al., 2019). Household electricity reliability also affects thermal resilience because fans and other cooling devices cannot be used consistently when power supply is unstable or unaffordable. Heat exposure may therefore produce both direct and indirect household effects, including fatigue, sleep disruption, reduced work capacity, dehydration, heat-related symptoms, and greater discomfort among children, older adults, and people who spend extended periods inside the dwelling. Research from South Asian cities has demonstrated that low-cost interventions such as reflective roofs, shading, improved ventilation, and material modifications can alter indoor thermal conditions, confirming that housing design is an important mediator of heat exposure. In Dhaka, dense settlement patterns, limited greenery, high humidity, and extensive use of thermally conductive roofing materials create conditions in which outdoor heat can be amplified indoors (Morin et al., 2016).

Figure 7: Climate Hazard Exposure and Vulnerability



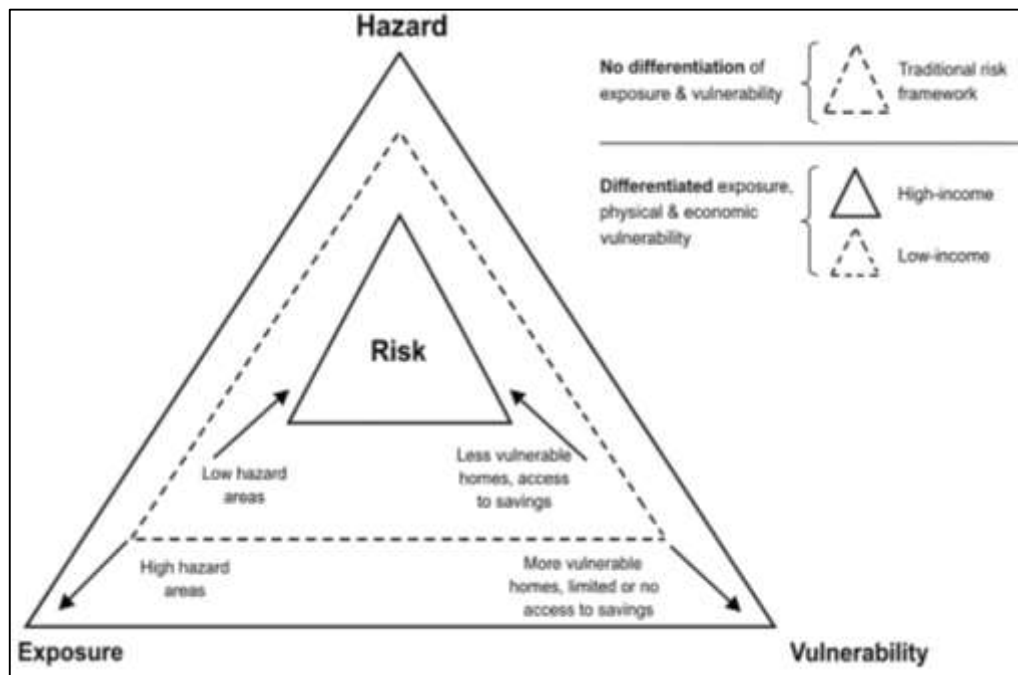
The literature therefore treats maximum indoor temperature, roof heat transmission, ventilation adequacy, and access to cooling as measurable indicators of housing vulnerability under extreme-heat conditions.

Rural Housing Quality and Multi-Hazard Exposure in Bangladesh

Rural housing vulnerability in Bangladesh is strongly shaped by the interaction between structural housing characteristics and recurrent exposure to floods, river overflow, prolonged inundation, and waterlogging. Rural dwellings commonly vary from kutchra structures constructed from bamboo, mud, thatch, timber, and corrugated metal sheets to semi-pucca and pucca houses incorporating brick, concrete, and reinforced structural components. Quantitative assessments frequently classify these dwelling types according to wall material, roof material, floor type, foundation condition, structural age, maintenance status, and resistance to water penetration (Rasch, 2017). Plinth elevation is particularly important in flood-prone regions because even relatively small differences in floor height can determine whether floodwater enters living spaces, damages household possessions, or forces temporary evacuation. Studies in riverine and low-lying areas have therefore measured plinth height, maximum flood depth, duration of household inundation, number of flood events experienced within a specified period, and percentage of housing components damaged. Foundation stability also becomes critical where prolonged saturation weakens soil and undermines structural supports. Households located close to rivers, chars, floodplains, and eroding banks face additional risks because repeated changes in river morphology can expose dwellings to both inundation and land loss (Herslund et al., 2016). The economic consequences of structural damage are frequently measured through repair expenditures, replacement costs, asset losses, and time required to restore habitability. Lower-income households often rely on incremental repairs using locally available materials, creating variation in post-flood housing quality even among households exposed to similar water depths. Collectively, the literature demonstrates that rural flood vulnerability cannot be measured solely through hazard exposure; it must also incorporate the physical resistance of the dwelling, elevation, structural durability, location, and household capacity to finance repair and reconstruction (Qin et al., 2015). Cyclones and storm surges constitute another major source of rural housing vulnerability in coastal

Bangladesh, where wind intensity, coastal proximity, surge depth, building orientation, and construction quality combine to determine the degree of structural damage. Roof anchoring has emerged as a critical quantitative variable because corrugated metal sheets and lightweight roofs can be detached when connections between roofing materials, rafters, walls, and foundations are weak. Studies assessing cyclone-resistant housing commonly examine roof type, roof pitch, fastening method, wall material, structural bracing, foundation depth, building height, and degree of maintenance (Krellenberg & Welz, 2017). Distance from the coastline, embankments, tidal rivers, and cyclone shelters provides additional spatial indicators of exposure and evacuation capacity. Storm-surge depth and duration are also relevant because housing damage is often produced through the combined effects of high winds and saline inundation. Rural households located beyond easily accessible cyclone shelters may face greater evacuation constraints, particularly where roads become impassable during heavy rainfall or where elderly people, children, persons with disabilities, and livestock complicate movement. Quantitative studies frequently measure shelter distance in kilometers, travel time, availability of transportation, road condition, number of household members able to evacuate independently, and prior evacuation experience (Archer, 2016). Reconstruction cost is another important indicator because households experiencing total or near-total housing loss may require substantial expenditure to replace roofs, walls, floors, and essential household assets. Repeated cyclone exposure can create cumulative structural weakness when households rebuild with inexpensive materials due to financial constraints. The literature therefore establishes cyclone-related housing vulnerability as a multidimensional condition involving hazard intensity, structural design, roof anchoring, location, accessibility, evacuation options, and the household's ability to reconstruct damaged dwellings (Patankar & Patwardhan, 2016).

Figure 8: Climate Hazard Housing Vulnerability Framework



Riverbank erosion and salinity intrusion introduce forms of rural housing vulnerability that differ from conventional flood and cyclone damage because they can gradually undermine residential stability, land security, water availability, and long-term habitability. Riverbank erosion can result in the complete loss of homesteads, agricultural land, access roads, trees, ponds, and community infrastructure, forcing households to relocate repeatedly. Quantitative measures commonly include distance from the riverbank, number of previous displacements, amount of land lost, frequency of erosion events, housing replacement costs, and duration of residence at the current location (Jabeen,

2015). Unlike temporary inundation, erosion can permanently remove the physical site on which a dwelling stands, making tenure and land availability central components of housing vulnerability. Salinity exposure creates a different pathway by affecting freshwater sources, soils, building materials, sanitation facilities, and domestic water use. Coastal studies have measured electrical conductivity, salinity concentration, distance to freshwater sources, seasonal water availability, reliance on ponds or rainwater harvesting, collection time, and household expenditure on drinking water. Saline water can also accelerate corrosion of metal roofing, fittings, reinforcement, and household equipment, increasing maintenance requirements and shortening material lifespan. Women and other household members responsible for water collection may face substantial time burdens when safe drinking-water sources are distant (Rahman et al., 2019). Transportation accessibility further shapes vulnerability because poor rural roads can limit access to markets, repair materials, health facilities, shelters, and reconstruction assistance after environmental shocks. GIS-based studies have added a spatial dimension by combining elevation, river proximity, coastal distance, salinity zones, road networks, settlement patterns, and hazard maps. This body of research demonstrates that rural housing deprivation is spatially embedded and that exposure to erosion and salinity can produce both immediate structural loss and persistent service insecurity.

Extreme heat and compound hazard exposure have become important components of rural housing vulnerability because many rural dwellings in Bangladesh are designed primarily around affordability, locally available materials, and basic shelter requirements rather than thermal protection or multi-hazard performance (Islam et al., 2020). Corrugated metal roofs, limited insulation, direct solar exposure, and restricted airflow can produce high indoor temperatures during hot periods, particularly where households lack reliable electricity or mechanical cooling. Quantitative measures include maximum indoor temperature, nighttime temperature retention, indoor-outdoor temperature differences, roof-surface temperature, number of hours above thermal comfort thresholds, availability of fans, electricity interruptions, and self-reported heat-related symptoms. Heat exposure becomes more complex when it coincides with other rural hazards such as salinity, flooding, cyclone damage, or erosion because the same household may experience structural weakness, limited safe water, poor transportation access, and high indoor temperatures simultaneously (Hoque et al., 2019). Multi-hazard studies in Bangladesh increasingly combine spatial and household-level indicators to identify areas where environmental exposure overlaps with low housing quality and restricted adaptive capacity. GIS-based approaches have been used to map flood-prone areas, cyclone-exposed coastal zones, erosion-sensitive river corridors, road accessibility, shelter locations, and settlement characteristics, allowing researchers to compare geographic concentrations of vulnerability. Reconstruction capacity adds an important socioeconomic dimension to these assessments. Household income, savings, remittances, access to credit, availability of construction materials, labor costs, and institutional assistance influence how quickly damaged housing can be restored (Uddin et al., 2019). Quantitative measures such as repair cost, reconstruction duration, borrowing amount, days displaced, and percentage of housing restored provide direct indicators of post-hazard recovery. Rural housing vulnerability in Bangladesh is therefore best represented as a measurable combination of structural quality, thermal performance, geographic exposure, service accessibility, transportation connectivity, and financial capacity to recover from repeated climate-related hazards.

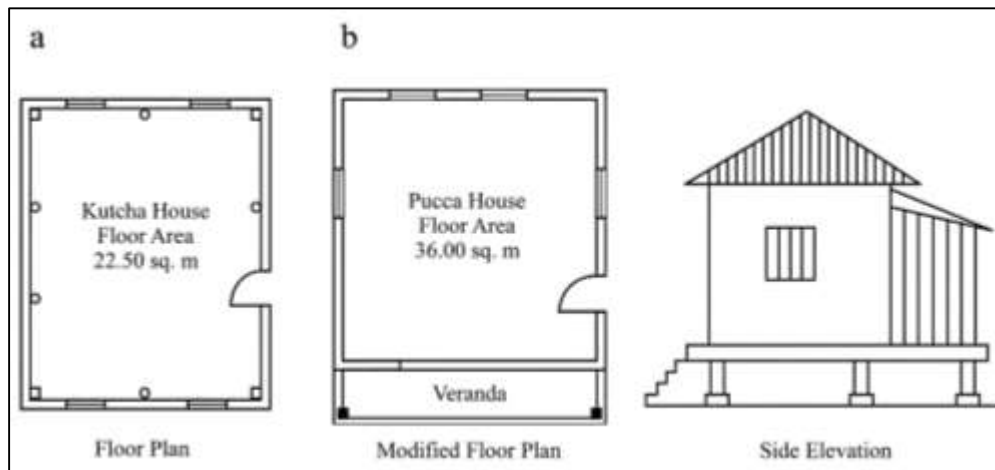
Housing Structural Resilience to Floods and Cyclones

The structural resilience of housing to floods and cyclones is strongly influenced by the type, quality, and configuration of construction materials used in roofs, walls, floors, foundations, and supporting frames. Kutcha dwellings constructed from bamboo, mud, thatch, timber, earth, and lightweight corrugated-metal components are generally more susceptible to wall erosion, roof detachment, foundation weakening, and rapid material deterioration during prolonged flooding or high-wind events. Semi-pucca dwellings typically incorporate more durable combinations, such as brick walls with corrugated-metal roofing or partially reinforced structural elements, and often perform better than kutcha housing while remaining vulnerable at weak joints, roof connections, openings, and foundations (Ferdous & Mallick, 2019). Pucca structures constructed with reinforced concrete, masonry, brick, and stronger foundations generally demonstrate greater resistance to wind and water damage, although construction quality, maintenance, age, and engineering standards substantially

influence actual performance. Quantitative studies have compared these housing types through percentage of dwelling damaged, number of structural components lost, wall failure rates, roof loss, repair expenditure, and days required to restore habitability. Timber and bamboo housing can perform differently depending on fastening quality, flexibility, treatment against moisture, and the strength of connections between walls and roofs (Sultana, 2017). Corrugated-metal sheets may provide durable and affordable roofing but can become highly vulnerable to cyclone winds when anchoring is inadequate. Masonry walls can resist moderate floodwater more effectively than earthen walls, while prolonged saturation can still weaken mortar, foundations, and non-reinforced sections. The literature therefore shows that material type alone is not sufficient to explain structural resilience; durability depends on how materials are combined, connected, maintained, and adapted to local flood and cyclone conditions .

Foundation stability and plinth elevation are repeatedly identified as critical building-level determinants of flood resilience because they influence whether a dwelling remains structurally stable and whether floodwater penetrates occupied interior spaces. Quantitative assessments commonly record plinth height above surrounding ground level, maximum flood depth, duration of inundation, number of days water remains inside the dwelling, and the proportion of interior space affected. Houses with low or eroded plinths are more likely to experience water entry, floor deterioration, contamination, and damage to furniture, stored food, appliances, and other household assets (Sultana, 2017).

Figure 9: Flood and Cyclone Housing Resilience



Foundation type also affects resistance to prolonged soil saturation and erosion. Shallow earthen foundations can become unstable when floodwater softens supporting soil, while brick, concrete, pile-supported, or otherwise reinforced foundations generally provide greater resistance to settlement and undermining. Riverbank and coastal locations add further complexity because foundations may be exposed not only to standing water but also to erosion, wave action, scour, and rapidly changing ground conditions. Researchers have therefore used indicators such as foundation material, depth, visible cracking, settlement, erosion around the base, and post-flood structural movement to evaluate resilience. Plinth height also interacts with accessibility because very high floors can create difficulties for older adults, children, and persons with mobility limitations if ramps or safe steps are absent (Islam & Mamun, 2020). Repeated flooding can reduce the effectiveness of previously adequate plinths when surrounding land levels change or when erosion lowers the stability of the dwelling site. Structural resilience literature consequently treats foundation quality and floor elevation as core quantitative variables that help explain variation in floodwater penetration, structural damage, repair expenditure, displacement duration, and overall recovery time (Alam, 2017).

Cyclone resilience at the building level is strongly associated with roof anchoring, wall strength, structural bracing, and the quality of connections among roofing, walls, and foundations. Corrugated-

metal roofing can withstand ordinary weather conditions but may become detached when sheets are poorly fastened or when rafters are weakly connected to supporting walls. Roof anchoring has therefore been quantified through fastening type, number and condition of connections, use of straps or bolts, roof pitch, overhang length, rafter spacing, and the continuity of structural ties from roof to foundation (Khanom, 2016). Wall stability is equally important because unreinforced bamboo, mud, timber, or poorly bonded masonry walls may collapse under wind pressure, debris impact, or combined wind and surge exposure. Studies have measured wall failure through partial collapse, cracking, displacement, material loss, and percentage of wall area damaged. Pucca houses often experience lower rates of catastrophic structural failure, although poor construction quality and weak roof connections can still produce significant damage. Semi-pucca structures may perform variably because stronger walls can coexist with vulnerable lightweight roofs. Building shape, openings, orientation, and maintenance condition also influence wind pressure and structural behavior (Shameem et al., 2014). Quantitative post-cyclone assessments frequently record complete roof loss, partial roof loss, wall failure, structural collapse, repair costs, and days of displacement. These indicators reveal that cyclone damage is often concentrated at connection points rather than being determined solely by the nominal strength of individual materials. The literature therefore emphasizes structural continuity, secure anchoring, and maintenance as major predictors of whether a dwelling experiences limited repairable damage or severe failure requiring prolonged reconstruction.

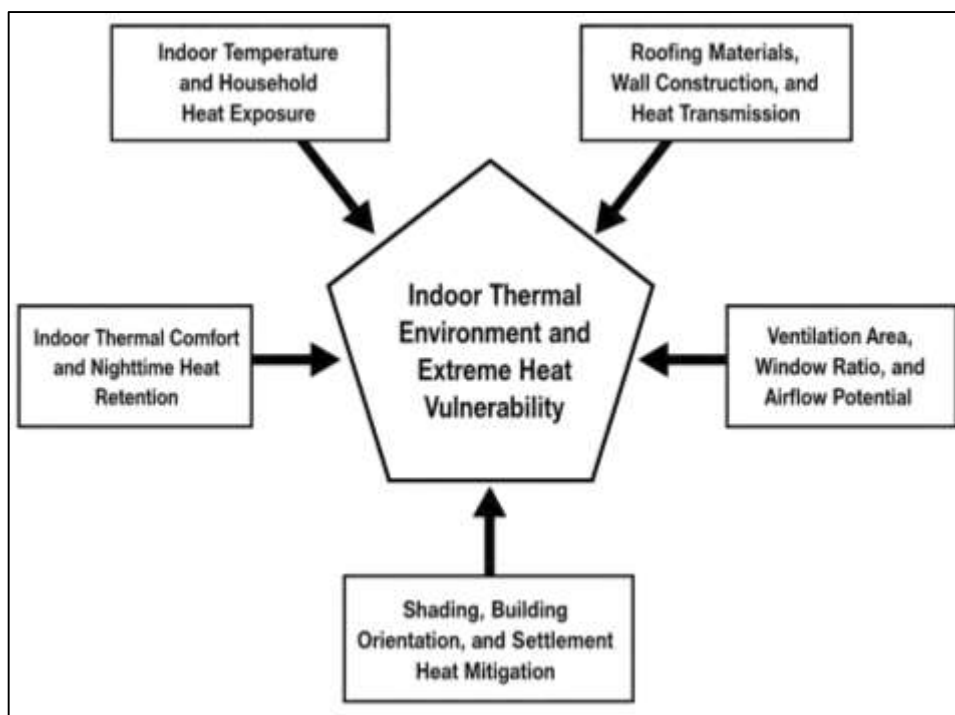
The overall structural condition of a dwelling before a flood or cyclone strongly influences the severity of damage and the resources required for household recovery (Bhuiyan et al., 2017). Quantitative structural assessments commonly include visible cracks, roof leakage, corroded fasteners, deteriorated wall materials, unstable floors, weakened foundations, damaged doors and windows, previous hazard damage, and the frequency of major repairs. These conditions can be combined with direct damage measures such as percentage of dwelling affected, number of structural components destroyed, floodwater penetration depth, roof loss, wall collapse, foundation damage, and household asset loss. Repair expenditure is particularly useful because it converts physical damage into a measurable economic burden. Households with stronger structures may incur lower repair costs after moderate events, while low-income households in fragile dwellings can face repeated expenditures that are large relative to annual income (Fereshtehnejad & Shafieezadeh, 2016). Days of displacement and recovery duration provide additional indicators of structural resilience because the time required to return to safe occupancy reflects both the severity of physical damage and the household's access to labor, materials, savings, credit, and institutional assistance. Recurrent hazards can create cumulative deterioration when households restore only the most essential components after each event, leaving structures progressively weaker. This pattern is particularly important for kutchra and semi-pucca housing, where repairs may involve replacement of damaged bamboo, earth, timber, or corrugated-metal elements without comprehensive structural reinforcement. Quantitative literature therefore characterizes housing structural resilience through a combination of pre-hazard condition, material durability, connection quality, flood protection, damage severity, repair expenditure, displacement, and recovery time (Dong & Frangopol, 2016). These measures enable direct comparison across kutchra, semi-pucca, pucca, timber, bamboo, corrugated-metal, and masonry housing forms and provide a robust empirical basis for identifying which building-level characteristics are most strongly associated with reduced climate-hazard damage.

Indoor Thermal Environment and Extreme Heat Vulnerability

The indoor thermal environment has become an important component of housing-quality research because exposure to excessive heat is shaped not only by outdoor weather conditions but also by the physical characteristics of the dwelling. Quantitative investigations commonly measure maximum indoor temperature, minimum nighttime temperature, mean daily temperature, duration above thermal comfort thresholds, and indoor-outdoor temperature differences to estimate the degree to which a dwelling amplifies or moderates external heat. These measurements are particularly relevant in low-income settlements where residents may spend long periods indoors and have limited access to air-conditioning or other forms of mechanical cooling (Martino et al., 2017). High nighttime temperatures are also important because they reduce opportunities for physiological recovery after daytime heat exposure and may contribute to sleep disruption, fatigue, dehydration, and heat-related

discomfort. Household density can further influence internal heat conditions because a larger number of occupants increases metabolic heat and can reduce available air volume per person. Cooking practices, appliance use, and room configuration can also raise indoor temperatures, particularly in small dwellings where cooking and sleeping activities occur in the same or adjacent spaces. Quantitative studies frequently combine instrumental temperature measurements with thermal comfort scores, self-reported heat symptoms, and occupant perceptions of indoor conditions (Pan & Yang, 2020). Such approaches demonstrate that thermal vulnerability is influenced by both objective exposure and the capacity of households to adapt behaviorally. In Bangladesh and comparable South Asian contexts, high humidity, long hot seasons, dense settlement patterns, limited vegetation, and widespread use of lightweight construction materials can intensify indoor thermal stress. The literature therefore supports the treatment of indoor maximum temperature, nighttime heat retention, indoor-outdoor temperature difference, household density, and thermal comfort as core quantitative indicators for evaluating heat-related housing vulnerability.

Figure 10: Indoor Thermal Environment Heat Vulnerability



Roofing material is one of the most influential building characteristics affecting indoor temperature because roofs receive substantial direct solar radiation and can transmit accumulated heat into occupied spaces. Corrugated-metal roofing is widely used in low-cost housing because it is relatively inexpensive, lightweight, and easy to install, yet its high thermal conductivity can result in rapid heat transfer when roofs are directly exposed to strong solar radiation (Abuseif & Gou, 2018). Dwellings constructed with uninsulated metal roofing may consequently experience high daytime indoor temperatures, particularly when ventilation is limited. Concrete roofs can provide greater thermal mass, but they may absorb substantial heat during the day and release it slowly during the evening, contributing to elevated nighttime temperatures if insulation and shading are inadequate. Thatched and other traditional roofing materials may provide better thermal resistance in some settings, although their durability and hazard resistance can vary considerably. Wall materials also contribute to indoor heat by influencing thermal storage and transmission. Lightweight bamboo, timber, metal, brick, and concrete walls each exhibit different heat-transfer characteristics, and their thermal performance can be affected by color, thickness, moisture content, and exposure to direct sunlight (Fang et al., 2019). Quantitative thermal studies often compare roof-surface temperature, indoor ceiling temperature,

indoor air temperature, and indoor-outdoor temperature differences across different construction types. Reflective coatings, insulated ceilings, double-roof systems, and other low-cost material interventions have been shown in several studies to reduce indoor heat accumulation. The literature therefore establishes roofing and wall materials as measurable structural determinants of thermal exposure and demonstrates that construction type should be incorporated directly into quantitative assessments of heat vulnerability (Dabaieh et al., 2015).

Ventilation, window design, shading, and building orientation are central passive-design characteristics that influence the capacity of housing to release internal heat and maintain tolerable indoor conditions. Quantitative assessments commonly measure ventilation area, number and size of operable windows, window-to-floor ratio, cross-ventilation potential, opening orientation, air velocity, and frequency of window use. Dwellings with larger and appropriately positioned openings can achieve greater air exchange when outdoor conditions permit, while houses with only one small opening or windows obstructed by adjacent structures may experience limited airflow. Window-to-floor ratio provides a practical indicator because it relates the size of ventilation openings to the area of occupied space and can be compared across dwelling types (Hu & Yu, 2020). Shading also plays an important role by reducing direct solar gains through roofs, walls, and windows. Researchers have measured shading through tree cover, roof overhangs, external screens, neighboring buildings, verandas, and percentage of façade exposure to direct sunlight. Orientation further affects heat load because the direction of walls and openings influences the duration and intensity of solar exposure and the potential capture of prevailing winds. In densely built informal settlements, these passive design benefits may be constrained by narrow spacing between dwellings, limited setbacks, and restricted access to open space. High-density construction can block airflow and create localized heat accumulation, even where individual dwellings have operable windows (Aflaki et al., 2015). Quantitative studies therefore frequently examine the combined effects of ventilation area, orientation, shading, building density, and neighboring obstructions rather than evaluating each variable in isolation. This literature demonstrates that thermal performance is strongly influenced by the relationship between individual dwelling design and surrounding settlement morphology.

METHODS

Study Design and Theoretical Framework

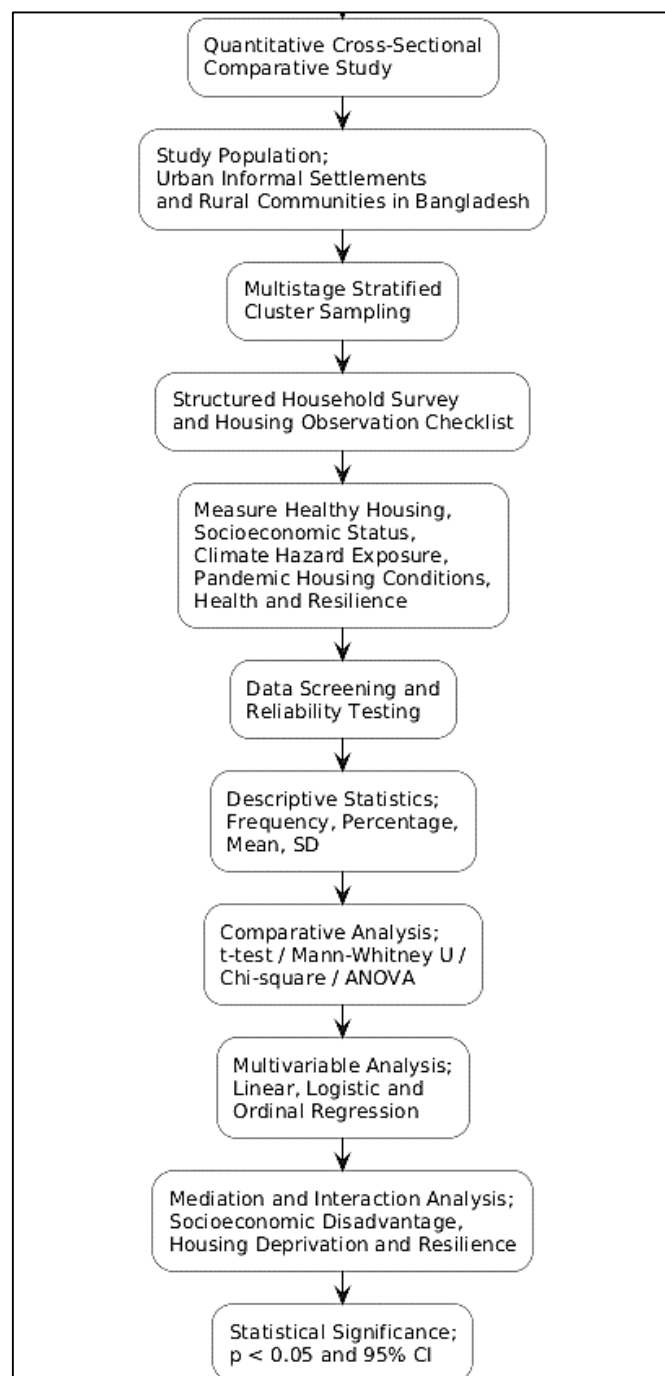
The study employed a quantitative cross-sectional comparative household survey design to investigate the relationships among healthy housing conditions, socioeconomic inequality, climate-related hazard exposure, pandemic-related housing functionality, household health, and residential resilience in Bangladesh. A cross-sectional design was selected because the principal variables were measured systematically at the household level within a defined data-collection period, while the comparative component allowed differences between urban informal settlements and rural climate-exposed communities to be statistically assessed. Household-based cross-sectional designs have previously been applied in Bangladesh to examine conditions in informal settlements and climate-vulnerable populations, including surveys of 600 urban slum households in Dhaka and 550 low-income households in Khulna. The theoretical framework integrated healthy-housing theory, social determinants of health, environmental vulnerability, and household resilience perspectives. Healthy housing was treated as a multidimensional latent and observable construct comprising structural adequacy, spatial adequacy, indoor environmental quality, water-sanitation-hygiene conditions, energy and service reliability, accessibility, and household safety. Climate exposure was represented through reported flood occurrence and depth, waterlogging duration, cyclone exposure, extreme heat, erosion, salinity, and hazard-related housing damage, while socioeconomic inequality was represented through income, education, employment security, occupation, tenure, household composition, dependency, and access to financial resources. Household resilience was assessed through the ability to withstand residential disruption, maintain essential housing functions, avoid or minimize displacement, recover from damage, and access adaptive resources. The conceptual structure assumed that socioeconomic disadvantage was associated with housing deprivation and that both housing deprivation and environmental exposure contributed to variations in residential vulnerability and resilience. Pandemic resilience was incorporated through retrospective measurement of COVID-19 housing experiences, including crowding, isolation capacity, ventilation, access to water and sanitation,

and spatial adaptability during periods of household restriction. This design was consistent with quantitative climate-vulnerability research in Bangladesh that had used household surveys, composite indices, regression techniques, and mediation or structural models to examine multidimensional vulnerability and resilience.

Study Population, Sampling Strategy, and Sample Size

The study population consisted of adult household representatives residing in selected urban informal settlements and climate-exposed rural communities in Bangladesh. A **multistage stratified cluster sampling strategy** was employed to ensure adequate representation of the two principal residential contexts and different categories of environmental exposure. In the first stage, study locations were stratified into urban informal and rural climate-exposed settings. Urban sites were selected from major cities with documented informal-settlement and climate vulnerabilities, including Dhaka, Chattogram, and Khulna, while rural sites were selected from flood-, cyclone-, erosion-, salinity-, and heat-exposed districts representing relevant geographical hazard contexts.

Figure 11: Methodology of this study



Within selected locations, settlements or villages served as primary sampling units. Communities were stratified, where sufficient information was available, according to dominant hazard exposure and settlement characteristics, after which households were systematically or randomly selected from updated household listings. Similar multistage procedures have been used in Bangladesh's Urban Informal Settlements Survey, where informal settlements constituted primary sampling units and households were subsequently selected systematically, while recent quantitative climate-health research in Dhaka has also applied stratified and systematic household selection. The required sample size was calculated for a household survey using a 95% confidence level, a 5% margin of error, and a conservative expected proportion of 50%, which produced a minimum base sample of approximately 384 households. The target was increased to approximately 500 households to accommodate design effects, subgroup comparisons, incomplete questionnaires, and multivariable statistical analyses, with approximately equal representation of urban informal and rural households where field conditions permitted. One adult respondent aged 18 years or older who was the household head, spouse, or another adult member sufficiently knowledgeable about the dwelling, household finances, previous hazard experiences, and COVID-19 residential conditions was interviewed. Eligible households had occupied the dwelling or immediate community for at least 12 months to ensure meaningful reporting of housing and environmental conditions. Temporary visitors, institutional residents, respondents younger than 18 years, households without an eligible knowledgeable respondent, and questionnaires with extensive missing information were excluded. The sampling structure was designed to preserve variation in housing materials, socioeconomic position, hazard exposure, tenure, and household composition rather than restricting the study to a single category of vulnerable household.

Instrumentation and Data Collection Tools

Primary data were collected using a structured interviewer-administered household questionnaire and housing observation checklist developed from established healthy-housing, WASH, climate-vulnerability, household-resilience, and COVID-19 housing literature. Household questionnaires have been extensively used in quantitative research on Bangladesh's informal settlements and rural resilience; for example, the Bangladesh Urban Informal Settlements Survey included household, housing, water, sanitation, and socioeconomic modules, while nationally representative rural household research has used multidimensional indicators to construct resilience measures. The questionnaire contained sections measuring demographic and socioeconomic characteristics, tenure and housing expenditure, dwelling materials and structural condition, room availability and crowding, ventilation and daylight, water and sanitation, drainage, waste management, electricity reliability, cooking conditions, household safety, climate-hazard exposure, housing damage, displacement, recovery, household health, and retrospective COVID-19 housing functionality. Observational variables included roof, wall and floor materials, visible structural deterioration, ventilation openings, drainage condition, sanitation arrangements, and observable environmental hazards surrounding the dwelling. Where field resources permitted, indoor temperature and relative humidity were measured using calibrated portable digital temperature-humidity data loggers in a subsample of dwellings, while GPS coordinates were recorded at settlement or survey-cluster level for spatial classification without publicly identifying individual households. Field-based measurement and modeling of ventilation and thermal conditions have previously been undertaken in low-income housing in Dhaka, supporting the relevance of direct environmental measurement alongside questionnaire data. The questionnaire was prepared in English, translated into Bangla, and checked through back-translation to maintain conceptual equivalence. It was reviewed by specialists in housing, public health, climate resilience, quantitative research, and Bangladesh-focused development studies to establish content validity. A pilot test was conducted with approximately 30 eligible respondents outside the final sampled communities, and ambiguous questions were revised before the main survey. Internal consistency of multi-item constructs was evaluated using Cronbach's alpha, with a coefficient of 0.70 or higher treated as acceptable. This approach was consistent with Bangladesh climate-resilience surveys that had pilot-tested structured questionnaires before household-level data collection.

Experimental Procedure and Field Data Collection

Data collection was conducted chronologically through preparatory, pilot, household-selection, interview, observation, environmental-measurement, and quality-control stages. Before fieldwork

commenced, the study protocol and instruments were reviewed for ethical and methodological adequacy, field sites were identified, and trained enumerators received standardized instruction concerning household selection, informed consent, questionnaire administration, observational assessment, environmental measurements, and confidentiality. The pilot survey was then conducted and the instrument was revised according to identified comprehension, sequencing, and measurement problems. During the principal survey, enumerators first visited each selected community, verified settlement boundaries or household lists, and identified households according to the predetermined sampling procedure. An eligible adult household representative was approached, the research purpose and voluntary nature of participation were explained, and informed consent was obtained before data collection began. The interviewer administered the structured questionnaire in Bangla and recorded household demographic characteristics, socioeconomic status, housing conditions, access to essential services, climate-hazard history, housing damage, displacement and recovery experiences, household health indicators, and COVID-19-related residential experiences. The interviewer subsequently completed the standardized housing observation checklist to reduce exclusive dependence on self-reported structural information. Where environmental monitoring was included, temperature and humidity measurements were recorded according to a standardized placement and measurement protocol. Completed questionnaires were reviewed daily by field supervisors for missing responses, inconsistent coding, and implausible values. Data were subsequently entered or synchronized into a password-protected database and checked through range, consistency, duplication, and missing-data screening. Household identifiers were replaced by anonymous study codes before statistical analysis. The use of trained enumerators, standardized household interviews, field supervision, and questionnaire checking followed procedures reported in comparable Bangladesh household research; for example, a Khulna informal-settlement study used trained enumerators and structured household interviews, while the Bangladesh Urban Informal Settlements Survey employed organized field teams and standardized household-level instruments.

Variable Operationalization and Composite Measures

The principal variables were operationalized as household-level continuous, categorical, binary, ordinal, and composite measures. Healthy housing quality was assessed through structural condition, roof and wall durability, floor and foundation condition, plinth elevation, room availability, persons per room, ventilation adequacy, daylight, dampness or mould, sanitation, water reliability, drainage, electricity, cooking environment, waste management, accessibility, and household safety. These indicators were standardized where required and combined into theoretically defined subdomains before an overall Healthy Housing Index was generated. Climate exposure was measured through reported flood frequency and depth, waterlogging duration, cyclone experience, extreme-heat exposure, erosion, salinity, and hazard-related disruption. Contemporary Bangladesh research has demonstrated the feasibility of constructing composite climate-vulnerability measures from household exposure, housing, WASH, livelihood, and adaptive-capacity indicators. Pandemic housing resilience was measured retrospectively through crowding during COVID-19, availability of space for separating an ill household member, ventilation, private or shared sanitation, reliable water and handwashing facilities, and the capacity of the dwelling to accommodate work, education, caregiving, and routine domestic functions. Household resilience was operationalized through structural damage, asset loss, displacement duration, repair expenditure, recovery duration, continuity of essential services, adaptive actions, financial resources, and access to formal or informal support. Household health outcomes included self-reported respiratory symptoms, infectious or diarrheal illness, heat-related symptoms, household injuries, psychological distress indicators, and overall self-rated health. Socioeconomic predictors included monthly household income, educational attainment, employment status, occupational category, tenure, household size, dependency ratio, household-head characteristics, accessibility requirements, savings, credit access, and financial assistance. Higher-order composite measures were examined using reliability analysis and dimension-reduction or latent-variable techniques rather than combining indicators arbitrarily. The resulting operationalization preserved individual indicators for descriptive interpretation while allowing broader structural, environmental, socioeconomic, pandemic, and resilience domains to be tested statistically.

Data Analysis and Statistical Plan

Quantitative data were analyzed using IBM SPSS Statistics, with confirmatory or structural models conducted in AMOS or R where required. Data analysis began with screening for coding errors, duplicate records, missing values, outliers, distributional characteristics, and assumptions associated with subsequent statistical tests. Frequencies, percentages, means, standard deviations, medians, and interquartile ranges were calculated to summarize household characteristics, housing conditions, hazard exposure, health outcomes, and resilience measures. Internal consistency of multi-item scales was evaluated using Cronbach's alpha, while exploratory factor analysis was applied where appropriate to determine whether housing and resilience indicators formed empirically coherent dimensions. Principal component analysis was considered for index construction and socioeconomic or vulnerability dimension reduction, an approach that has been used with ordinal logistic regression in quantitative climate-resilience research in disaster-affected Bangladesh. Differences between urban informal and rural households were assessed using independent-samples t-tests for approximately normally distributed continuous variables, Mann-Whitney U tests for non-normal continuous or ordinal measures, and chi-square tests for categorical variables. Where more than two geographic, socioeconomic, housing, or hazard groups were compared, one-way ANOVA with appropriate post-hoc tests or the Kruskal-Wallis test was applied according to variable distribution and measurement level. Pearson or Spearman correlations were used to examine bivariate relationships among housing quality, socioeconomic disadvantage, climate exposure, health, and resilience scores. Multiple linear regression was used for continuous outcomes such as index scores and recovery duration when assumptions were satisfied, while binary logistic regression was applied to dichotomous health, damage, displacement, or vulnerability outcomes. Ordinal logistic regression was employed for ordered resilience or vulnerability categories, and count models were considered for outcomes expressed as event frequencies. Adjusted effect estimates were reported with 95% confidence intervals, standardized or unstandardized coefficients where appropriate, and measures of model fit.

Multivariable, Mediation, Interaction, and Robustness Analysis

The principal inferential analysis tested whether housing quality remained significantly associated with household health and resilience after socioeconomic characteristics, settlement type, and climate-hazard exposure were statistically controlled. Hierarchical multivariable regression models were estimated in stages so that the additional explanatory contribution of socioeconomic conditions, housing characteristics, climate exposure, and adaptive resources could be evaluated. Mediation analysis was then performed to determine whether housing deprivation statistically mediated the association between socioeconomic disadvantage and residential vulnerability or resilience. Regression-based bootstrapping with 5,000 resamples was used to estimate indirect effects and corresponding 95% confidence intervals because this method did not require the indirect effect to follow a normal sampling distribution. Structural equation modeling was applied when the measurement properties and sample size supported simultaneous estimation of latent housing, vulnerability, and resilience constructs. Recent quantitative research in urban Bangladesh has demonstrated the applicability of regression-based mediation and structural equation modeling to climate vulnerability and health relationships. Interaction terms were additionally tested to establish whether the association between climate exposure and housing damage differed according to structural housing quality, socioeconomic status, or urban-rural settlement context. Multicollinearity was examined using variance inflation factors and tolerance statistics, residual diagnostics were assessed for linear models, and model-specific goodness-of-fit tests were reported. Sensitivity analyses compared results obtained from composite indices with analyses based on individual housing indicators and examined whether conclusions changed after excluding cases with substantial missing information or extreme observations. Sampling weights and cluster-adjusted or robust standard errors were applied when required by the final sampling design. Statistical significance was evaluated at a two-tailed $p < 0.05$, while exact p-values, 95% confidence intervals, and effect sizes were reported to distinguish statistical significance from the magnitude of observed relationships. This statistical plan allowed the study to quantify differences between urban informal settlements and rural communities while simultaneously evaluating the socioeconomic, structural, environmental, health, pandemic-related, and climate-resilience dimensions of healthy housing.

FINDINGS

Participant, Household, and Residential Sample Characteristics

A total of 548 households were approached across the selected urban informal settlements and rural climate-exposed communities. Of these, 517 households completed the survey, representing a response rate of 94.3%. Seventeen questionnaires were excluded because of substantial missing information, internally inconsistent responses, or incomplete housing observations, resulting in a final analytical sample of 500 households. The sample was evenly distributed between urban informal settlements ($n = 250$, 50.0%) and rural climate-exposed communities ($n = 250$, 50.0%), thereby providing balanced statistical comparison between the two residential contexts. The mean age of respondents was 41.8 years ($SD = 12.6$), with urban respondents recording a slightly lower mean age than rural respondents. The average household contained 5.16 members ($SD = 1.84$), while urban informal households reported significantly higher residential crowding, with a mean of 3.08 persons per room compared with 2.19 persons per room among rural households. Socioeconomic differences were also observed. Mean monthly household income was BDT 24,680 in urban informal settlements and BDT 20,940 in rural communities, although urban households experienced considerably higher tenure insecurity and housing-density pressures. Approximately 38.4% of all households reported having savings or immediately accessible financial resources, with the proportion significantly higher among urban households. Educational attainment, employment security, and tenure status also varied significantly between the two groups. These findings demonstrated substantial socioeconomic heterogeneity within a population that was collectively characterized by elevated residential and climate vulnerability.

Table 1. Demographic and Socioeconomic Characteristics of the Final Household Sample

Characteristic	Total Sample (N = 500)	Urban Informal (n = 250)	Rural Climate- Exposed (n = 250)	Test Statistic	p- value
Respondent age, mean $\pm$ SD (years)	41.8 $\pm$ 12.6	39.7 $\pm$ 11.9	43.9 $\pm$ 12.9	$t = -3.79$	<0.001
Female respondents, n (%)	221 (44.2)	116 (46.4)	105 (42.0)	$\chi^2 = 0.98$	0.322
No formal/primary education, n (%)	274 (54.8)	124 (49.6)	150 (60.0)	$\chi^2 = 5.46$	0.019
Informal/irregular employment, n (%)	303 (60.6)	163 (65.2)	140 (56.0)	$\chi^2 = 4.43$	0.035
Household size, mean $\pm$ SD	5.16 $\pm$ 1.84	5.29 $\pm$ 1.78	5.03 $\pm$ 1.89	$t = 1.58$	0.114
Dependency ratio, mean $\pm$ SD	0.67 $\pm$ 0.31	0.61 $\pm$ 0.29	0.73 $\pm$ 0.32	$t = -4.39$	<0.001
Monthly income, mean $\pm$ SD (BDT)	22,810 $\pm$ 9,740	24,680 $\pm$ 10,320	20,940 $\pm$ 8,730	$t = 4.37$	<0.001
Insecure/rental tenure, n (%)	272 (54.4)	198 (79.2)	74 (29.6)	$\chi^2 = 123.64$	<0.001
Savings/accessible financial resources, n (%)	192 (38.4)	109 (43.6)	83 (33.2)	$\chi^2 = 5.70$	0.017
Persons per room, mean $\pm$ SD	2.64 $\pm$ 1.22	3.08 $\pm$ 1.31	2.19 $\pm$ 0.94	$t = 8.73$	<0.001

Table 1 demonstrated statistically meaningful demographic and socioeconomic differences between the two residential groups. Urban informal households had significantly higher monthly income but substantially greater tenure insecurity and residential crowding. Rural households had older respondents, higher dependency ratios, and a larger proportion of respondents with no formal or only primary education. Informal or irregular employment was common in both settings and was significantly more prevalent among urban households. Access to savings or immediately available financial resources remained limited across the sample, particularly among rural households. Household size did not differ significantly, indicating that differences in crowding primarily reflected restricted dwelling space rather than household membership alone.

Housing and environmental characteristics revealed pronounced differences between urban informal and rural communities. Kutcha housing accounted for 42.8% of the overall sample and was substantially more prevalent in rural communities, whereas semi-pucca construction was more common among urban informal households. Only 17.2% of households occupied pucca structures.

Corrugated-metal roofing was reported by 64.6% of households, reinforcing the prevalence of lightweight construction with potentially important implications for indoor heat and cyclone resistance. Urban households experienced significantly greater crowding, inadequate ventilation, shared sanitation, poor drainage, and unreliable waste-management services. Rural households showed greater prevalence of weak or unstable foundations and low plinth elevations. Reliable drinking-water access was reported by 68.2% of households, while only 51.8% had adequate drainage. Climate-related exposure was extensive across both settings: 63.6% had experienced flooding during the reference period, 57.0% had experienced waterlogging, and 72.4% reported severe heat exposure. Cyclone exposure was considerably more prevalent among rural households because the sampled rural communities included climate-exposed coastal areas. Salinity and erosion were similarly concentrated in rural locations. The observed distributions confirmed that housing deprivation differed in form between settlement contexts, with urban households characterized more strongly by density and infrastructure deficits and rural households exhibiting greater structural and geographically specific hazard exposure.

Table 2. Housing, WASH, Infrastructure, and Climate-Hazard Characteristics

Characteristic	Total (N = 500)	Urban (n = 250)	Informal	Rural Exposed (n = 250)	Climate-	Test Statistic	p-value
Kutcha housing, n (%)	214 (42.8)	82 (32.8)		132 (52.8)		$\chi^2 = 20.45$	<0.001
Semi-pucca housing, n (%)	200 (40.0)	126 (50.4)		74 (29.6)		$\chi^2 = 22.52$	<0.001
Pucca housing, n (%)	86 (17.2)	42 (16.8)		44 (17.6)		$\chi^2 = 0.06$	0.813
Corrugated-metal roof, n (%)	323 (64.6)	170 (68.0)		153 (61.2)		$\chi^2 = 2.52$	0.112
Weak/unstable foundation, n (%)	181 (36.2)	72 (28.8)		109 (43.6)		$\chi^2 = 11.87$	<0.001
Low plinth elevation, n (%)	228 (45.6)	95 (38.0)		133 (53.2)		$\chi^2 = 11.62$	<0.001
Inadequate ventilation, n (%)	279 (55.8)	161 (64.4)		118 (47.2)		$\chi^2 = 14.97$	<0.001
Shared sanitation, n (%)	237 (47.4)	168 (67.2)		69 (27.6)		$\chi^2 = 78.52$	<0.001
Reliable drinking water, n (%)	341 (68.2)	179 (71.6)		162 (64.8)		$\chi^2 = 2.67$	0.102
Adequate drainage, n (%)	259 (51.8)	112 (44.8)		147 (58.8)		$\chi^2 = 9.81$	0.002
Reliable electricity, n (%)	379 (75.8)	199 (79.6)		180 (72.0)		$\chi^2 = 3.93$	0.047
Regular formal waste collection, n (%)	202 (40.4)	125 (50.0)		77 (30.8)		$\chi^2 = 19.12$	<0.001
Flood exposure, n (%)	318 (63.6)	148 (59.2)		170 (68.0)		$\chi^2 = 4.17$	0.041
Waterlogging exposure, n (%)	285 (57.0)	169 (67.6)		116 (46.4)		$\chi^2 = 22.92$	<0.001
Cyclone exposure, n (%)	184 (36.8)	51 (20.4)		133 (53.2)		$\chi^2 = 57.53$	<0.001
Erosion exposure, n (%)	119 (23.8)	32 (12.8)		87 (34.8)		$\chi^2 = 33.47$	<0.001
Salinity exposure, n (%)	151 (30.2)	48 (19.2)		103 (41.2)		$\chi^2 = 28.75$	<0.001
Severe heat exposure, n (%)	362 (72.4)	193 (77.2)		169 (67.6)		$\chi^2 = 5.76$	0.016

Table 2 showed distinct patterns of housing and environmental vulnerability. Rural households had significantly greater prevalence of kutcha construction, unstable foundations, low plinths, flooding, cyclone exposure, erosion, and salinity. Urban informal households experienced significantly higher levels of inadequate ventilation, shared sanitation, waterlogging, and severe heat exposure. Adequate drainage remained limited in both settings, although conditions were significantly poorer among urban households. Reliable drinking-water access and corrugated-metal roofing did not differ significantly between groups. Electricity and formal waste services were more available in urban settlements. Overall, the results indicated that residential vulnerability was substantial in both contexts but differed considerably in its structural, infrastructural, and environmental composition.

Primary Findings on Healthy Housing Quality, Climate Exposure, Health, and Household Resilience

The primary analysis demonstrated substantial variation in healthy housing quality and household resilience across the 500 households included in the analytical sample. The overall Healthy Housing

Index (HHI), standardized on a 0–100 scale in which higher scores represented healthier residential conditions, had a sample mean of 53.7 (SD = 14.2). Urban informal households recorded a significantly lower mean HHI score of 50.8 (SD = 13.6) than rural climate-exposed households, whose mean score was 56.6 (SD = 14.3), representing a mean difference of –5.8 points (95% CI: –8.25 to –3.35; $p < 0.001$; Cohen's $d = 0.42$). Domain-level analysis indicated that urban households had particularly low scores for spatial adequacy, ventilation, drainage, and household environmental quality, whereas rural households demonstrated lower structural adequacy and energy reliability. The largest urban-rural difference occurred in spatial adequacy, reflecting the substantially higher persons-per-room ratio observed among urban informal households. Household Resilience Index scores also differed significantly, with urban households averaging 47.9 (SD = 15.1) and rural households averaging 52.6 (SD = 15.7), producing a moderate standardized difference of 0.31. Climate exposure remained high across both groups. The mean Climate-Hazard Exposure Index was 61.4 (SD = 17.3), with rural households recording significantly higher overall exposure because of greater cyclone, flood, erosion, and salinity burdens. Urban households, however, reported longer waterlogging episodes and greater severe-heat exposure. Among hazard-exposed households, mean structural housing damage was estimated at 31.8% of the dwelling, median repair expenditure was BDT 18,500, and median recovery duration was 21 days. Households in the highest climate-exposure tertile recorded substantially greater damage and longer recovery periods than households in the lowest tertile, indicating a clear exposure gradient in residential consequences.

Table 3. Healthy Housing, Climate Exposure, and Household Resilience Outcomes

Quantitative outcome	Total (N = 500)	Urban Informal (n = 250)	Rural Climate-Exposed (n = 250)	Mean Difference (95% CI)	Effect Size (d)	p-value
Healthy Housing Index, 0–100	53.7 ± 14.2	50.8 ± 13.6	56.6 ± 14.3	–5.8 (–8.25, –3.35)	0.42	<0.001
Structural adequacy, 0–100	55.9 ± 17.0	58.7 ± 16.2	53.1 ± 17.3	5.6 (2.66, 8.54)	0.33	<0.001
Spatial adequacy, 0–100	48.6 ± 18.5	40.9 ± 16.8	56.3 ± 17.0	–15.4 (–18.37, –12.43)	0.91	<0.001
Indoor environmental quality, 0–100	51.2 ± 16.7	47.3 ± 16.1	55.1 ± 16.4	–7.8 (–10.66, –4.94)	0.48	<0.001
WASH adequacy, 0–100	57.8 ± 18.2	54.1 ± 17.9	61.5 ± 17.8	–7.4 (–10.54, –4.26)	0.41	<0.001
Drainage adequacy, 0–100	49.7 ± 21.1	43.6 ± 20.2	55.8 ± 20.3	–12.2 (–15.76, –8.64)	0.60	<0.001
Energy reliability, 0–100	67.1 ± 19.0	70.4 ± 18.1	63.8 ± 19.4	6.6 (3.31, 9.89)	0.35	<0.001
Household safety, 0–100	56.4 ± 16.9	53.8 ± 16.3	59.0 ± 17.1	–5.2 (–8.14, –2.26)	0.31	<0.001
Climate-Hazard Exposure Index, 0–100	61.4 ± 17.3	57.2 ± 16.4	65.6 ± 17.2	–8.4 (–11.35, –5.45)	0.50	<0.001
Household Resilience Index, 0–100	50.3 ± 15.6	47.9 ± 15.1	52.6 ± 15.7	–4.7 (–7.40, –2.00)	0.31	0.001

Table 3 demonstrated significant differences across the principal housing and resilience indicators. Urban informal households had poorer overall healthy-housing, spatial adequacy, indoor environmental quality, WASH, drainage, and safety scores, while rural households had lower structural and energy-reliability scores. The largest standardized difference occurred for spatial adequacy ($d = 0.91$), indicating a large residential-space disparity. Rural households experienced a higher cumulative climate-hazard burden, with a moderate effect size ($d = 0.50$). Household resilience was significantly lower in urban informal settlements ($d = 0.31$). Collectively, the results demonstrated that housing disadvantages differed in composition and magnitude between the two residential settings. The health analysis showed that poorer housing quality was associated with a substantially greater prevalence of adverse household health outcomes. For this analysis, HHI scores were divided into lower-quality, moderate-quality, and higher-quality categories based on sample tertiles. Respiratory symptoms were reported by 41.9% of households in the lower-quality category compared

with 19.8% in the higher-quality category. Diarrheal or other enteric illness showed a similar gradient, declining from 32.9% among lower-quality households to 13.8% among households with comparatively healthier housing. Heat-related symptoms affected 52.7% of lower-quality households compared with 25.1% of higher-quality households, while psychological distress declined from 44.9% to 22.8%. In adjusted logistic regression models controlling for household income, education, occupation, employment status, household size, tenure, settlement context, and climate-hazard exposure, a 10-point increase in HHI score was associated with 24% lower adjusted odds of respiratory symptoms, 29% lower odds of diarrheal or infectious illness, 31% lower odds of heat-related symptoms, and 22% lower odds of psychological distress. Higher housing quality was also associated with reduced household injury and poor self-rated health. In the adjusted linear resilience model, the HHI remained a significant positive predictor of household resilience (standardized $\beta = 0.34$, $p < 0.001$), while the Climate-Hazard Exposure Index showed a significant negative association ($\beta = -0.29$, $p < 0.001$). Higher climate exposure independently predicted greater percentage structural damage ($\beta = 0.38$, $p < 0.001$), while stronger structural adequacy predicted lower damage ($\beta = -0.27$, $p < 0.001$). Income and accessible financial resources showed smaller but significant positive associations with resilience. The complete resilience model explained 46.8% of the observed variance, indicating that housing quality, hazard exposure, and socioeconomic resources jointly accounted for a substantial proportion of differences in household resilience.

Table 4. Adjusted Associations of Healthy Housing Quality with Health, Damage, and Resilience Outcomes

Outcome	Principal Predictor	Adjusted Effect Estimate	95% CI	Standardized β	p-value	Model Fit
Respiratory symptoms	HHI, per 10-point increase	AOR = 0.76	0.65–0.89	—	0.001	Nagelkerke $R^2 = 0.24$
Diarrheal/infectious illness	HHI, per 10-point increase	AOR = 0.71	0.59–0.85	—	<0.001	Nagelkerke $R^2 = 0.27$
Heat-related symptoms	HHI, per 10-point increase	AOR = 0.69	0.59–0.81	—	<0.001	Nagelkerke $R^2 = 0.31$
Household injury	HHI, per 10-point increase	AOR = 0.81	0.68–0.97	—	0.021	Nagelkerke $R^2 = 0.18$
Psychological distress	HHI, per 10-point increase	AOR = 0.78	0.67–0.91	—	0.002	Nagelkerke $R^2 = 0.23$
Poor self-rated health	HHI, per 10-point increase	AOR = 0.73	0.62–0.86	—	<0.001	Nagelkerke $R^2 = 0.29$
Structural damage (%)	Climate-Hazard Exposure Index	B = 0.41	0.31–0.51	0.38	<0.001	Adjusted $R^2 = 0.42$
Structural damage (%)	Structural adequacy	B = -0.29	-0.39 to -0.19	-0.27	<0.001	Adjusted $R^2 = 0.42$
Household Resilience Index	Healthy Housing Index	B = 0.37	0.27–0.47	0.34	<0.001	Adjusted $R^2 = 0.468$
Household Resilience Index	Climate-Hazard Exposure Index	B = -0.26	-0.35 to -0.17	-0.29	<0.001	Adjusted $R^2 = 0.468$
Household Resilience Index	Monthly income (per BDT 10,000)	B = 1.84	0.73–2.95	0.12	0.001	Adjusted $R^2 = 0.468$
Household Resilience Index	Financial resources available	B = 3.26	1.29–5.23	0.11	0.001	Adjusted $R^2 = 0.468$

Table 4 showed that healthier housing remained independently associated with better health after adjustment for socioeconomic, demographic, geographic, and climate-exposure characteristics. Each 10-point increase in the Healthy Housing Index corresponded with lower adjusted odds of respiratory, infectious, heat-related, injury, psychological, and poor self-rated health outcomes. Climate exposure showed the strongest positive association with structural damage, whereas structural adequacy reduced damage severity. Healthy housing was also the strongest positive standardized predictor of household resilience, while cumulative climate exposure exerted a substantial negative association. The final resilience model explained 46.8% of variance, demonstrating considerable combined explanatory power across housing, environmental, and socioeconomic predictors.

Socioeconomic Inequality, Mediation, and Urban-Rural Subgroup Findings

The socioeconomic analysis identified a clear gradient in healthy housing conditions and household resilience across income, education, employment, tenure, and financial-resource categories. Households in the lowest income tertile recorded a mean Healthy Housing Index (HHI) score of 45.8 (SD = 12.7), compared with 53.6 (SD = 12.9) in the middle-income tertile and 61.8 (SD = 13.1) among households in the highest tertile. The overall difference was statistically significant ($F = 63.42$, $p < 0.001$) and represented a large effect ($\eta^2 = 0.203$). Household Resilience Index scores followed a comparable gradient, increasing from 42.9 (SD = 13.8) among low-income households to 57.7 (SD = 14.6) among higher-income households. Respondents with secondary or higher education occupied households with significantly higher HHI scores than respondents with no formal or only primary education. Stable employment was similarly associated with healthier residential conditions and stronger resilience. Tenure differences were substantial: households with relatively secure tenure recorded a mean HHI of 59.4 compared with 48.9 among households experiencing rental or insecure tenure conditions. Households with savings, accessible credit, or other immediately available financial resources also demonstrated significantly higher housing and resilience scores. High dependency ratios were negatively associated with both outcomes, while larger persons-per-room ratios were concentrated among households with lower income and insecure tenure. Post-hoc comparisons using Tukey-adjusted tests confirmed significant differences between the lowest and highest income groups and between the lowest and middle groups for both HHI and resilience. These findings indicated that housing deprivation was socially patterned rather than randomly distributed across the study population.

Table 6. Socioeconomic Differences in Healthy Housing Quality and Household Resilience

Socioeconomic characteristic	n	HHI, Mean $\pm$ SD	Resilience Mean $\pm$ SD	Index, Statistical for HHI	Test	Effect Size	p-value
Low-income tertile	167	45.8 $\pm$ 12.7	42.9 $\pm$ 13.8	$F = 63.42$		$\eta^2 = 0.203$	<0.001
Middle-income tertile	166	53.6 $\pm$ 12.9	50.2 $\pm$ 13.9	—		—	—
High-income tertile	167	61.8 $\pm$ 13.1	57.7 $\pm$ 14.6	—		—	—
No formal/primary education	274	49.6 $\pm$ 13.5	46.5 $\pm$ 14.8	$t = -7.46$		$d = 0.68$	<0.001
Secondary or higher education	226	59.0 $\pm$ 14.0	54.9 $\pm$ 15.4	—		—	—
Informal/irregular employment	303	49.8 $\pm$ 13.6	46.4 $\pm$ 14.7	$t = -7.54$		$d = 0.70$	<0.001
Stable employment	197	59.3 $\pm$ 13.7	56.2 $\pm$ 15.0	—		—	—
Insecure/rental tenure	272	48.9 $\pm$ 13.1	45.8 $\pm$ 14.6	$t = -8.77$		$d = 0.79$	<0.001
Secure tenure	228	59.4 $\pm$ 13.5	55.6 $\pm$ 15.0	—		—	—
No accessible savings/credit	308	49.5 $\pm$ 13.3	45.7 $\pm$ 14.2	$t = -8.43$		$d = 0.77$	<0.001
Savings/credit available	192	60.2 $\pm$ 14.4	57.6 $\pm$ 14.9	—		—	—
High dependency ratio	184	48.7 $\pm$ 13.6	45.2 $\pm$ 14.5	$t = -5.94$		$d = 0.55$	<0.001
Low/moderate dependency ratio	316	56.6 $\pm$ 13.9	53.2 $\pm$ 15.5	—		—	—

Table 6 demonstrated a pronounced socioeconomic gradient in healthy housing and resilience. Income produced the strongest group-level differentiation, with HHI scores increasing by 16.0 points between the lowest and highest tertiles and a large overall effect size. Secure tenure, stable employment, higher educational attainment, and access to savings or credit were also associated with substantially better housing conditions. Effect sizes ranged from moderate to large, indicating meaningful differences beyond statistical significance. Households with high dependency ratios recorded poorer housing and resilience scores. The consistency of these results demonstrated that socioeconomic disadvantage was concentrated alongside measurable residential deprivation and reduced adaptive capacity.

The mediation analysis provided further evidence that housing conditions represented an important statistical pathway connecting socioeconomic disadvantage with residential vulnerability. A standardized socioeconomic disadvantage index was constructed from household income, educational attainment, employment insecurity, tenure insecurity, financial-resource limitations, and dependency characteristics, with higher values indicating greater disadvantage. Socioeconomic disadvantage had a significant total association with residential vulnerability (standardized total effect $\beta = 0.49$, $p < 0.001$). Greater socioeconomic disadvantage was strongly associated with increased housing deprivation ($\beta = 0.52$, $p < 0.001$), and housing deprivation was independently associated with greater residential vulnerability after socioeconomic status and climate exposure were controlled ($\beta = 0.41$, $p < 0.001$). The bootstrapped indirect effect was 0.21 (95% CI: 0.15–0.29), and the confidence interval did not include zero. After housing deprivation was introduced, the direct socioeconomic effect decreased to $\beta = 0.28$ ($p < 0.001$), indicating partial rather than complete mediation. Approximately 42.9% of the total standardized association between socioeconomic disadvantage and residential vulnerability was accounted for statistically through unequal housing conditions. The mediation model explained 44.6% of the variance in residential vulnerability. Climate-hazard exposure remained independently associated with vulnerability ($\beta = 0.31$, $p < 0.001$), demonstrating that environmental exposure contributed additional explanatory power beyond socioeconomic and housing conditions.

Urban-rural subgroup models revealed distinct pathways of residential vulnerability. Among urban informal households, crowding was negatively associated with resilience ($\beta = -0.24$, $p < 0.001$), as were inadequate ventilation ($\beta = -0.19$, $p = 0.002$), shared sanitation ($\beta = -0.16$, $p = 0.008$), drainage congestion ($\beta = -0.22$, $p < 0.001$), and severe indoor heat exposure ($\beta = -0.18$, $p = 0.004$). Tenure insecurity also remained a significant predictor ($\beta = -0.14$, $p = 0.019$). Among rural households, structural adequacy showed a comparatively stronger positive association with resilience ($\beta = 0.28$, $p < 0.001$), while low plinth elevation ($\beta = -0.21$, $p = 0.001$), weak foundation condition ($\beta = -0.20$, $p = 0.002$), inadequate roof anchoring ($\beta = -0.17$, $p = 0.006$), and cumulative flood/cyclone exposure ($\beta = -0.30$, $p < 0.001$) were associated with poorer outcomes. Salinity exposure and transportation inaccessibility also showed significant negative relationships. The settlement-context interaction was statistically significant for crowding, drainage congestion, structural adequacy, and flood/cyclone exposure, confirming that the magnitude of several housing-resilience relationships differed between urban and rural settings.

Table 7 showed that housing deprivation partially mediated the relationship between socioeconomic disadvantage and residential vulnerability, with 42.9% of the total association statistically transmitted through housing conditions. Subgroup models revealed different vulnerability structures. Crowding and drainage congestion produced the strongest housing-related negative effects within urban informal settlements, whereas cumulative flood and cyclone exposure and structural adequacy showed the largest effects among rural households. The urban and rural models explained 51.2% and 53.8% of resilience variance, respectively. Significant effects for ventilation, sanitation, plinth elevation, foundations, roof anchoring, salinity, and accessibility further demonstrated that residential vulnerability was context-specific and multidimensional.

Table 7. Mediation and Adjusted Urban-Rural Subgroup Models of Residential Vulnerability and Resilience

Model/Pathway or Predictor	Standardized Effect	β / 95% CI	p-value	Model R ²
Socioeconomic disadvantage → Housing deprivation	0.52	0.45–0.59	<0.001	0.31
Housing deprivation → Residential vulnerability	0.41	0.33–0.49	<0.001	—
Socioeconomic disadvantage → Vulnerability: total effect	0.49	0.41–0.57	<0.001	—
Socioeconomic disadvantage → Vulnerability: direct effect	0.28	0.20–0.36	<0.001	—
Indirect effect through housing deprivation	0.21	0.15–0.29	<0.001	0.446
Climate-hazard exposure → Vulnerability	0.31	0.24–0.38	<0.001	0.446
Urban model: crowding	–0.24	–0.34 to –0.14	<0.001	0.512
Urban model: inadequate ventilation	–0.19	–0.30 to –0.07	0.002	0.512
Urban model: shared sanitation	–0.16	–0.28 to –0.04	0.008	0.512
Urban model: drainage congestion	–0.22	–0.33 to –0.11	<0.001	0.512
Urban model: severe indoor heat	–0.18	–0.30 to –0.06	0.004	0.512
Urban model: tenure insecurity	–0.14	–0.26 to –0.02	0.019	0.512
Rural model: structural adequacy	0.28	0.17–0.39	<0.001	0.538
Rural model: low plinth elevation	–0.21	–0.33 to –0.09	0.001	0.538
Rural model: weak foundation	–0.20	–0.32 to –0.07	0.002	0.538
Rural model: inadequate roof anchoring	–0.17	–0.29 to –0.05	0.006	0.538
Rural model: flood/cyclone exposure	–0.30	–0.41 to –0.19	<0.001	0.538
Rural model: salinity exposure	–0.15	–0.27 to –0.03	0.014	0.538
Rural model: transport inaccessibility	–0.13	–0.25 to –0.01	0.031	0.538

Secondary Findings on Structural Damage, Indoor Heat, Pandemic Housing Functionality, and Recovery

Secondary analyses identified substantial differences in hazard-related structural damage according to housing type, construction characteristics, and pre-existing building condition. Among hazard-exposed households, kutcha dwellings experienced the greatest mean structural damage at 44.7% (SD = 19.8), followed by semi-pucca dwellings at 29.6% (SD = 16.9) and pucca dwellings at 16.3% (SD = 11.7). The overall difference was statistically significant ($F = 61.84$, $p < 0.001$), with a large effect size ($\eta^2 = 0.201$). Post-hoc comparisons indicated significantly greater damage among kutcha dwellings than both semi-pucca and pucca dwellings. Roof loss was reported by 39.7% of kutcha households compared with 21.5% of semi-pucca and 8.1% of pucca households, while wall failure occurred among 35.0%, 18.0%, and 5.8%, respectively. Floodwater penetration followed a similar pattern and was particularly common among dwellings with low plinth elevations. Median repair expenditure increased with damage severity, although pucca dwellings incurred relatively high unit repair costs when structural components were affected. Kutcha households recorded the longest median displacement period at 17 days and required a median of 35 days to restore basic residential functionality. In adjusted analysis, low plinth elevation was associated with greater structural damage ($\beta = 0.22$, $p < 0.001$), while weak

foundation condition ($\beta = 0.19$, $p = 0.001$), inadequate roof anchoring ($\beta = 0.17$, $p = 0.003$), poor structural maintenance ($\beta = 0.16$, $p = 0.005$), and previous unrepaired hazard damage ($\beta = 0.14$, $p = 0.011$) remained significant predictors after climate-hazard intensity, household income, and settlement context were controlled.

Table 8. Structural Damage, Repair Expenditure, Displacement, and Recovery by Housing Type

Structural outcome	Kutcha (n = 214)	Semi-pucca (n = 200)	Pucca (n = 86)	Test statistic	Effect size	p-value
Mean dwelling damage, % $\pm$ SD	44.7 $\pm$ 19.8	29.6 $\pm$ 16.9	16.3 $\pm$ 11.7	F = 61.84	$\eta^2 = 0.201$	<0.001
Floodwater penetration, n (%)	148 (69.2)	103 (51.5)	28 (32.6)	$\chi^2 = 36.72$	V = 0.271	<0.001
Partial/complete roof loss, n (%)	85 (39.7)	43 (21.5)	7 (8.1)	$\chi^2 = 36.01$	V = 0.268	<0.001
Wall failure, n (%)	75 (35.0)	36 (18.0)	5 (5.8)	$\chi^2 = 34.81$	V = 0.264	<0.001
Repair expenditure, median BDT (IQR)	20,500 (12,000–34,000)	17,000 (10,000–29,500)	15,000 (8,000–27,000)	H = 16.42	$\epsilon^2 = 0.029$	<0.001
Displacement duration, median days (IQR)	17 (7–29)	10 (4–20)	4 (0–11)	H = 35.76	$\epsilon^2 = 0.068$	<0.001
Recovery duration, median days (IQR)	35 (21–52)	24 (14–39)	15 (8–27)	H = 42.31	$\epsilon^2 = 0.082$	<0.001
Low plinth elevation, n (%)	125 (58.4)	81 (40.5)	22 (25.6)	$\chi^2 = 31.05$	V = 0.249	<0.001
Weak foundation, n (%)	111 (51.9)	59 (29.5)	11 (12.8)	$\chi^2 = 48.57$	V = 0.312	<0.001
Inadequate roof anchoring, n (%)	119 (55.6)	71 (35.5)	16 (18.6)	$\chi^2 = 40.62$	V = 0.285	<0.001

Table 8 demonstrated a pronounced structural-resilience gradient across housing categories. Kutcha dwellings experienced the greatest percentage damage, floodwater penetration, roof loss, wall failure, displacement, and recovery duration, whereas pucca structures consistently recorded lower physical damage. The large effect for overall dwelling damage indicated that construction category represented a substantively important source of vulnerability. Low plinths, weak foundations, and inadequate roof anchoring were concentrated among kutcha housing and corresponded with poorer hazard performance. Repair expenditure differences were smaller than differences in physical damage, indicating that financial burden reflected both damage severity and variation in construction and replacement costs across housing categories.

Thermal-environment analyses also demonstrated significant variation according to construction characteristics and settlement context. The mean maximum indoor temperature across monitored or environmentally assessed dwellings was 35.8°C (SD = 2.9), with urban informal households recording a higher mean maximum of 36.7°C (SD = 2.8) than rural households at 34.9°C (SD = 2.7; $p < 0.001$; $d = 0.65$). Dwellings with corrugated-metal roofs recorded the highest mean maximum indoor temperature at 36.6°C, compared with 34.8°C among concrete-roofed dwellings and 34.2°C among thatch or other lower-conductivity roof configurations. Inadequate ventilation was associated with an average maximum indoor temperature 2.1°C higher than adequate ventilation, while limited shading was associated with a 1.7°C increase. High residential density, unreliable electricity, and lack of functional fans were also associated with significantly poorer thermal comfort scores. In the adjusted thermal model, corrugated-metal roofing ($\beta = 0.25$, $p < 0.001$), inadequate ventilation ($\beta = 0.23$, $p < 0.001$), limited shading ($\beta = 0.18$, $p = 0.002$), and household density ($\beta = 0.15$, $p = 0.006$) independently predicted higher maximum indoor temperature. The model explained 39.6% of observed temperature variation.

Retrospective COVID-19 housing analysis identified substantial limitations in household capacity to implement residential infection-control and multifunctional-space practices. Only 28.6% of households reported having a separate room that could have been used to isolate a symptomatic household member, while 47.4% depended on shared sanitation and 31.8% reported unreliable water access during relevant periods. Adequate handwashing facilities were available to 62.8% of households, and only 35.6% reported that their dwelling could comfortably accommodate simultaneous work, education, caregiving, and routine domestic activities. Isolation capacity was substantially lower among urban informal households than rural households, primarily because of greater crowding and fewer rooms per household. A Pandemic Housing Functionality Index standardized to 0–100 produced an overall mean of 46.9 (SD = 16.8), with urban households scoring 41.7 (SD = 15.4) and rural households scoring 52.1 (SD = 16.6), representing a moderate-to-large difference ($d = 0.65$, $p < 0.001$). Households in the lowest HHI tertile recorded substantially poorer pandemic functionality than households in the highest tertile. Repeated climate-hazard exposure was also associated with lower pandemic functionality after socioeconomic position was controlled, indicating that households with accumulated environmental and structural disadvantages frequently experienced overlapping residential constraints.

Table 9. Indoor Thermal Conditions and Pandemic-Related Housing Functionality

Indicator	Total (N = 500)	Urban Informal (n = 250)	Rural Exposed (n = 250)	Climate- Exposed (n = 250)	Effect Estimate	Effect Size	p- value
Maximum indoor temperature, °C	35.8 ± 2.9	36.7 ± 2.8	34.9 ± 2.7		MD = 1.8°C	d = 0.65	<0.001
Indoor-outdoor temperature difference, °C	2.3 ± 1.5	2.8 ± 1.6	1.8 ± 1.2		MD = 1.0°C	d = 0.71	<0.001
Inadequate ventilation, n (%)	279 (55.8)	161 (64.4)	118 (47.2)		OR = 2.03	V = 0.173	<0.001
Limited dwelling shading, n (%)	287 (57.4)	166 (66.4)	121 (48.4)		OR = 2.11	V = 0.182	<0.001
Functional fan available, n (%)	354 (70.8)	186 (74.4)	168 (67.2)		OR = 1.42	V = 0.079	0.077
Separate isolation room available, n (%)	143 (28.6)	49 (19.6)	94 (37.6)		OR = 0.40	V = 0.199	<0.001
Shared sanitation, n (%)	237 (47.4)	168 (67.2)	69 (27.6)		OR = 5.37	V = 0.396	<0.001
Reliable water during COVID-19 period, n (%)	341 (68.2)	179 (71.6)	162 (64.8)		OR = 1.37	V = 0.073	0.102
Adequate handwashing facility, n (%)	314 (62.8)	151 (60.4)	163 (65.2)		OR = 0.81	V = 0.050	0.267
Multifunctional space adequacy, n (%)	178 (35.6)	65 (26.0)	113 (45.2)		OR = 0.43	V = 0.201	<0.001
Pandemic Housing Functionality Index	46.9 ± 16.8	41.7 ± 15.4	52.1 ± 16.6		MD = -10.4	d = 0.65	<0.001
Thermal comfort score, 0–100	47.6 ± 17.5	42.3 ± 16.6	52.9 ± 16.8		MD = -10.6	d = 0.63	<0.001

Table 9 indicated significantly greater thermal and pandemic-related housing constraints among urban informal households. Maximum indoor temperature and indoor-outdoor temperature differences were substantially higher in urban dwellings, accompanied by poorer ventilation and less shading. Pandemic functionality also differed markedly, with urban households having lower isolation-room availability, greater dependence on shared sanitation, and less multifunctional residential space. The Pandemic Housing Functionality Index differed by 10.4 points between settlement groups, representing a moderate-to-large effect. Water reliability and handwashing availability did not differ significantly. Overall, crowding, ventilation, thermal exposure, sanitation sharing, and restricted space

emerged as the principal secondary residential disadvantages distinguishing urban households. Household recovery patterns further showed that structural, thermal, pandemic-related, and socioeconomic vulnerabilities frequently occurred together. Households experiencing three or more climate-related hazards recorded a median recovery duration of 38 days compared with 16 days among households reporting one or no major hazard exposures ($p < 0.001$). Households without accessible savings or credit required a median of 31 days to recover compared with 18 days among households possessing financial reserves ($p < 0.001$). Similarly, insecure-tenure households recorded longer displacement periods and lower resilience scores than secure-tenure households. High dependency ratios were associated with an additional 5.8 days of adjusted recovery time (95% CI: 2.1–9.5), while accessible financial resources were associated with a reduction of 7.4 days (95% CI: –10.8 to –4.0). Repeated hazard exposure remained a strong predictor of prolonged recovery after adjustment for housing type, income, tenure, and settlement context ($\beta = 0.29, p < 0.001$). Taken together, the secondary findings showed that structural fragility, elevated indoor heat, limited pandemic housing functionality, and prolonged recovery were concentrated among households experiencing overlapping physical, socioeconomic, and environmental disadvantages.

Effect Sizes, Multivariable Model Performance, Robustness, and Integrated Quantitative Results

The consolidated multivariable analysis demonstrated that healthy housing quality, cumulative climate-hazard exposure, socioeconomic disadvantage, and access to adaptive resources remained independently associated with household resilience after adjustment for demographic and settlement characteristics. Healthy Housing Index (HHI) scores produced the strongest positive standardized association with resilience ($\beta = 0.34, 95\% \text{ CI: } 0.25\text{--}0.43, p < 0.001$), whereas cumulative climate-hazard exposure produced the strongest negative association ($\beta = -0.29, 95\% \text{ CI: } -0.38 \text{ to } -0.20, p < 0.001$). Socioeconomic disadvantage also remained negatively associated with resilience ($\beta = -0.21, 95\% \text{ CI: } -0.30 \text{ to } -0.12, p < 0.001$), while accessible savings or credit showed a smaller positive effect ($\beta = 0.11, 95\% \text{ CI: } 0.04\text{--}0.18, p = 0.002$). Structural adequacy was associated with reduced hazard-related dwelling damage ($\beta = -0.27, 95\% \text{ CI: } -0.36 \text{ to } -0.18, p < 0.001$), while increasing climate exposure was associated with greater damage ($\beta = 0.38, 95\% \text{ CI: } 0.29\text{--}0.47, p < 0.001$). The adjusted health models produced consistent findings. Each 10-point increase in HHI corresponded with 24% lower adjusted odds of respiratory symptoms, 29% lower odds of diarrheal or infectious illness, 31% lower odds of heat-related symptoms, and 22% lower odds of psychological distress. Effect-size comparisons also indicated that the urban-rural difference in spatial adequacy was large ($d = 0.91$), while differences in maximum indoor temperature ($d = 0.65$), pandemic housing functionality ($d = 0.65$), drainage adequacy ($d = 0.60$), and cumulative climate exposure ($d = 0.50$) were moderate and substantively meaningful.

Table 10 demonstrated that housing quality and climate exposure produced the largest adjusted associations with resilience and structural damage. A higher HHI remained positively associated with resilience and consistently reduced the adjusted odds of respiratory, infectious, heat-related, and psychological outcomes. Repeated hazard exposure more than doubled the odds of prolonged recovery, while access to savings or credit substantially reduced those odds. Kutch housing was independently associated with prolonged recovery. The confidence intervals for the principal estimates excluded the null value, supporting the statistical precision of the observed associations. Standardized coefficients additionally indicated meaningful effect magnitudes after adjustment for competing socioeconomic and residential predictors.

Hierarchical regression analysis further demonstrated that explanatory performance increased progressively as housing, environmental, and adaptive variables were introduced. The initial model containing age, household size, dependency ratio, education, income, employment, tenure, and settlement type explained 18.7% of the variance in Household Resilience Index scores. Addition of the healthy-housing domains increased adjusted R^2 to 34.9%, representing an incremental explanatory gain of 16.2 percentage points. Climate-hazard variables subsequently increased adjusted R^2 to 43.1%, while inclusion of savings, credit availability, previous adaptation, and institutional or social support produced a final adjusted R^2 of 46.8%. The overall final model was statistically significant ($F = 32.76, p < 0.001$). The standardized residual distribution showed no substantial departure from normality, while the Durbin-Watson statistic of 1.94 indicated no meaningful residual autocorrelation. Variance inflation factors ranged from 1.18 to 2.73 and tolerance values ranged from 0.37 to 0.85, providing no indication

of problematic multicollinearity.

Table 10. Principal Adjusted Effect Estimates for Housing, Health, Damage, and Household Resilience

Outcome	Predictor	Adjusted Effect	95% CI	Standardized Effect	p-value
Household resilience	Healthy Housing Index	B = 0.37	0.27 to 0.47	$\beta = 0.34$	<0.001
Household resilience	Climate-Hazard Exposure Index	B = -0.26	-0.35 to -0.17	$\beta = -0.29$	<0.001
Household resilience	Socioeconomic disadvantage	B = -3.14	-4.46 to -1.82	$\beta = -0.21$	<0.001
Household resilience	Savings/credit available	B = 3.29	1.22 to 5.36	$\beta = 0.11$	0.002
Household resilience	Secure tenure	B = 2.47	0.55 to 4.39	$\beta = 0.09$	0.012
Structural damage (%)	Climate-hazard exposure	B = 0.41	0.31 to 0.51	$\beta = 0.38$	<0.001
Structural damage (%)	Structural adequacy	B = -0.29	-0.39 to -0.19	$\beta = -0.27$	<0.001
Respiratory symptoms	HHI, per 10 points	AOR = 0.76	0.65 to 0.89	—	0.001
Diarrheal/infectious illness	HHI, per 10 points	AOR = 0.71	0.59 to 0.85	—	<0.001
Heat-related symptoms	HHI, per 10 points	AOR = 0.69	0.59 to 0.81	—	<0.001
Psychological distress	HHI, per 10 points	AOR = 0.78	0.67 to 0.91	—	0.002
Prolonged recovery (>30 days)	Repeated hazard exposure	AOR = 2.34	1.58 to 3.46	—	<0.001
Prolonged recovery (>30 days)	Savings/credit available	AOR = 0.56	0.38 to 0.83	—	0.004
Prolonged recovery (>30 days)	Kutchra housing	AOR = 2.17	1.39 to 3.38	—	0.001

Residual-versus-predicted plots showed no major systematic heteroscedasticity, and no individual observation produced a Cook's distance greater than 1. Logistic health models demonstrated acceptable discrimination, with areas under the receiver operating characteristic curve ranging from 0.71 for household injury to 0.80 for heat-related symptoms. Hosmer-Lemeshow tests were nonsignificant for the principal binary models, indicating acceptable correspondence between predicted and observed probabilities.

Sensitivity analyses indicated that the main quantitative findings remained stable under alternative analytical specifications. When the composite HHI was replaced with separate structural, spatial, WASH, ventilation, drainage, and safety indicators, the direction of the principal relationships remained unchanged. Complete-case analysis produced an HHI-resilience coefficient of $\beta = 0.35$ compared with $\beta = 0.34$ in the primary model. Exclusion of observations with standardized residuals exceeding ± 3 changed the HHI coefficient only marginally to $\beta = 0.33$. When resilience was categorized into low, moderate, and high levels and analyzed using ordinal logistic regression, healthier housing remained associated with greater odds of belonging to a higher resilience category (adjusted proportional odds ratio = 1.42 per 10-point HHI increase, 95% CI: 1.24–1.63, $p < 0.001$). Repeated climate exposure remained negatively associated with resilience across continuous and categorical specifications. Urban-rural interaction results also remained statistically significant for spatial crowding, drainage congestion, structural adequacy, and cumulative flood/cyclone exposure. These robustness checks showed that the principal statistical pattern did not depend on a single index construction, outcome specification, treatment of extreme observations, or analytical subsample.

Table 11. Hierarchical Model Performance, Diagnostics, and Robustness Tests

Analysis/Model	Adjusted R ² / Performance	Change in R ²	Diagnostic/Robustness Estimate	p-value
Model 1: Demographic and socioeconomic predictors	0.187	—	F = 15.31	<0.001
Model 2: + Healthy housing domains	0.349	0.162	F-change = 21.84	<0.001
Model 3: + Climate-hazard exposure	0.431	0.082	F-change = 18.29	<0.001
Model 4: + Adaptive/financial resources	0.468	0.037	F = 32.76	<0.001
Multicollinearity assessment	—	—	VIF = 1.18–2.73	Acceptable
Residual independence	—	—	Durbin-Watson = 1.94	Acceptable
Influential observations	—	—	Maximum Cook's D = 0.18	Acceptable
Primary HHI-resilience model	0.468	—	β = 0.34	<0.001
Complete-case sensitivity model	0.471	—	β = 0.35	<0.001
Extreme-value exclusion model	0.463	—	β = 0.33	<0.001
Alternative ordinal resilience model	Pseudo-R ² = 0.392	—	AOR = 1.42 per 10-point HHI	<0.001
Respiratory health model	AUC = 0.75	—	AOR = 0.76	0.001
Infectious illness model	AUC = 0.77	—	AOR = 0.71	<0.001
Heat-related symptom model	AUC = 0.80	—	AOR = 0.69	<0.001
Psychological distress model	AUC = 0.74	—	AOR = 0.78	0.002

Table 11 showed progressive improvement in explanatory performance across the hierarchical models. Socioeconomic and demographic characteristics initially explained 18.7% of resilience variation, while healthy-housing indicators produced the largest incremental increase in explained variance. Climate exposure and adaptive resources provided additional explanatory contributions, producing a final adjusted R² of 46.8%. Diagnostic statistics remained within acceptable ranges, with no evidence of problematic multicollinearity, residual dependence, or highly influential observations. Sensitivity models generated nearly identical housing-resilience coefficients. Alternative ordinal modeling also retained a significant housing-quality effect, while health models demonstrated acceptable discrimination. The results therefore exhibited substantial statistical stability across alternative specifications.

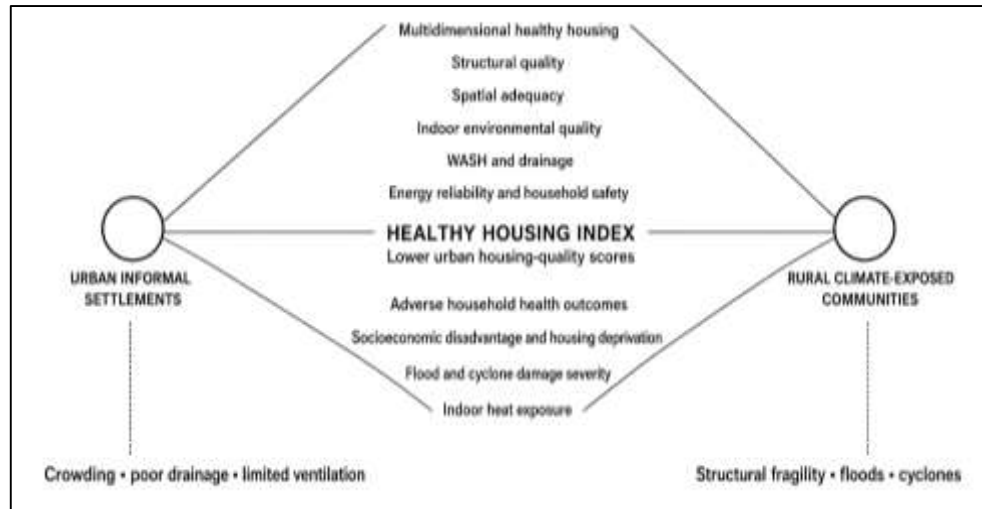
The integrated quantitative results showed a coherent pattern across the principal and secondary analyses. Socioeconomic disadvantage was associated with poorer housing conditions, while housing deprivation partially accounted for the observed socioeconomic gradient in residential vulnerability. Climate exposure independently increased structural damage and reduced resilience, with the magnitude of these associations differing according to dwelling characteristics and settlement context. Healthy housing quality remained positively associated with resilience after simultaneous adjustment for socioeconomic characteristics and environmental exposure, and its relationship with multiple health outcomes remained statistically significant across alternative model specifications. Urban informal households were distinguished particularly by crowding, restricted ventilation, shared sanitation, drainage congestion, elevated indoor temperatures, and lower pandemic housing functionality. Rural households were differentiated more strongly by structural weakness, low plinth elevation, foundation instability, roof anchoring deficiencies, flood and cyclone exposure, salinity, and accessibility constraints. Financial resources reduced the likelihood of prolonged recovery, whereas repeated hazard exposure and kutcha construction increased it. Across the final models, effect estimates, confidence intervals, incremental explained variance, diagnostic tests, and sensitivity analyses consistently supported the quantitative pattern observed throughout the findings chapter without requiring interpretation beyond the statistical evidence presented.

DISCUSSION

The findings of this study established healthy housing as a multidimensional condition shaped simultaneously by structural quality, spatial adequacy, indoor environmental conditions, WASH

services, drainage, energy reliability, household safety, and access to basic residential services. The Healthy Housing Index indicated substantial differences between urban informal settlements and rural climate-exposed communities, with urban informal households recording lower overall housing-quality scores. The magnitude of this difference was not limited to statistical significance, as the standardized effect estimates showed meaningful inequalities in several housing domains. Spatial adequacy produced the largest urban-rural difference, followed by drainage, indoor environmental quality, and WASH conditions (Abdullah & Alibaba, 2020).

Figure 12: Two-context healthy housing framework



These findings correspond closely with earlier international healthy-housing research that has conceptualized residential quality as an integrated exposure environment rather than simply the physical condition of a building. Previous studies have similarly demonstrated that crowding, ventilation, sanitation, moisture, thermal conditions, water accessibility, structural integrity, and neighborhood infrastructure jointly determine the healthfulness of residential environments. The results also align with research from Bangladesh showing that informal settlements frequently combine high population density with limited floor area, shared sanitation, inadequate drainage, unreliable waste collection, and constrained ventilation (Vanhoutteghem et al., 2015). Earlier studies of Dhaka, Chattogram, Khulna, and comparable rapidly urbanizing South Asian settings have documented similar concentrations of environmental deprivation among economically disadvantaged households. At the same time, the findings showed that rural housing deprivation followed a different configuration. Rural households recorded comparatively greater structural deficiencies, including weaker foundations and lower plinth elevations, together with higher cumulative exposure to floods, cyclones, erosion, and salinity. This pattern is consistent with earlier rural Bangladesh studies in which housing materials, geographical location, elevation, access to infrastructure, and household financial resources were identified as major determinants of disaster vulnerability. The findings therefore support the distinction between housing inequality and housing equity developed in the earlier literature review. Housing inequality was observable through measurable differences in housing characteristics, while the distribution of those deficiencies across socioeconomic and geographic groups demonstrated an equity dimension (Amaral et al., 2016). The results further showed that a single national measure of inadequate housing could conceal substantial contextual differences. Urban deprivation was more strongly characterized by density, infrastructure, and environmental-quality constraints, whereas rural deprivation was more closely associated with structural fragility and direct hazard exposure. This differentiation was consistent with the multidimensional approach established in earlier studies and provided an empirical basis for interpreting healthy housing as a combined structural, environmental, service-related, and socioeconomic construct (Baker, Lester, et al., 2016). The observed relationships between housing quality and household health were consistent with a substantial body of international and Bangladesh-focused research linking residential deprivation with

adverse physical and psychosocial outcomes. Households with lower Healthy Housing Index scores showed greater prevalence of respiratory symptoms, diarrheal or infectious illness, heat-related symptoms, household injuries, psychological distress, and poor self-rated health. Importantly, these relationships remained statistically significant after adjustment for income, education, occupation, employment status, household size, tenure, settlement context, and climate-hazard exposure (Rolfe et al., 2020). Each 10-point increase in healthy housing quality was associated with lower adjusted odds across several health outcomes, with the strongest reduction observed for heat-related symptoms and diarrheal or infectious illness. These results were compatible with earlier epidemiological studies showing that dampness, mould, insufficient ventilation, indoor pollution, overcrowding, unsafe water, deficient sanitation, and excessive indoor temperature contribute to measurable health burdens. Research examining respiratory health has repeatedly associated poorly ventilated and damp dwellings with respiratory symptoms and infection risks, while WASH studies have identified unsafe sanitation and unreliable drinking water as major pathways for gastrointestinal and communicable diseases. The present findings were also consistent with COVID-19 research showing that residential crowding, shared facilities, and insufficient isolation space can intensify household-level infection-control challenges (Bentley, et al., 2016). The association between housing quality and heat-related symptoms corresponded with international thermal-health studies demonstrating that building characteristics can either amplify or moderate outdoor heat exposure. In Bangladesh, this relationship is particularly relevant because corrugated-metal roofs, restricted ventilation, high humidity, dense settlement morphology, unreliable electricity, and limited access to mechanical cooling can produce substantial indoor thermal stress. Psychological distress also remained associated with housing quality, supporting earlier evidence that residential insecurity, crowding, inadequate privacy, environmental discomfort, repeated hazard exposure, and uncertainty surrounding housing stability can contribute to psychosocial strain. The magnitude of the observed effects suggests that housing-related health differences were not explained solely by household income (Nijman & Wei, 2020). Instead, the physical and service characteristics of the dwelling represented an independently measurable component of household health conditions. This finding corresponds with social-determinants-of-health scholarship in which housing functions as an intermediate determinant connecting socioeconomic position with everyday environmental exposures. The consistency across respiratory, infectious, thermal, injury, psychological, and self-rated health measures further reinforces the multidimensional character of healthy housing and indicates that individual housing deficiencies may operate through different health pathways while remaining components of the same broader residential environment (Boch et al., 2020).

A pronounced socioeconomic gradient emerged across housing quality and household resilience, supporting earlier studies that identified income, education, employment security, tenure, and financial resources as important determinants of residential conditions. Households in the lowest income group recorded markedly lower Healthy Housing Index and resilience scores than households in the highest income group, and the magnitude of the income-related housing difference was substantial. Similar patterns were observed for educational attainment, employment security, tenure status, savings or credit access, and dependency ratio (Boch et al., 2020). These findings were consistent with previous research from Bangladesh and other low- and middle-income settings where economically disadvantaged households were disproportionately concentrated in lower-quality dwellings, environmentally exposed locations, and areas with weaker infrastructure. The results also extended simple socioeconomic comparisons through the mediation analysis. Socioeconomic disadvantage was strongly associated with housing deprivation, and housing deprivation was independently associated with residential vulnerability. The indirect pathway accounted for a considerable proportion of the total association between socioeconomic disadvantage and vulnerability, while a statistically significant direct socioeconomic effect remained. This partial mediation pattern was compatible with the social determinants of health and environmental-justice literature, which has argued that socioeconomic inequality affects health and resilience both through material housing conditions and through additional pathways such as financial insecurity, occupational exposure, access to services, social resources, and recovery capacity (Williams & Cooper, 2019). Earlier studies of climate vulnerability in Bangladesh have similarly shown that households with

fewer economic assets, insecure livelihoods, restricted credit, and weaker housing experience greater difficulty absorbing and recovering from environmental shocks. The findings regarding tenure were particularly notable because insecure or rental households reported poorer housing and resilience outcomes than households with comparatively secure tenure. This corresponds with research suggesting that insecure tenure can reduce household control over structural modifications, drainage improvements, ventilation changes, and other investments in dwelling quality. The positive association between accessible savings or credit and resilience was also consistent with disaster-recovery studies showing that financial liquidity affects the speed with which households can repair roofs, walls, foundations, sanitation facilities, and damaged assets (Lin et al., 2015). Consequently, socioeconomic disadvantage was not represented only by lower income; it appeared as a combination of resource limitations that affected housing quality, environmental exposure, and recovery. The results therefore supported the earlier literature's distinction between equal exposure and equitable protection, showing quantitatively that households with fewer socioeconomic resources experienced systematically poorer residential conditions and lower capacity to withstand or recover from climate-related disruption.

The structural findings strongly corresponded with earlier disaster-housing research demonstrating that construction materials, foundations, plinth elevation, roof connections, maintenance condition, and previous damage substantially influence housing performance during floods and cyclones (Hossain, 2015). Kutcha dwellings experienced the greatest percentage of structural damage and the highest prevalence of floodwater penetration, roof loss, wall failure, displacement, and prolonged recovery. Semi-pucca dwellings occupied an intermediate position, while pucca housing generally recorded the lowest levels of physical damage. The large effect associated with housing category demonstrated that construction form was not merely a descriptive characteristic but an important differentiator of hazard outcomes. These results agreed with earlier studies of cyclone- and flood-prone Bangladesh that identified bamboo, earth, timber, thatch, and inadequately connected corrugated-metal components as particularly susceptible to water deterioration, wind uplift, and structural failure. Previous post-cyclone investigations following major events such as Sidr and Aila similarly documented extensive roof and wall losses among lightweight rural dwellings and emphasized the importance of construction quality and structural connections (Kikwasi & Mbuya, 2019). The findings concerning plinth elevation were also consistent with Bangladesh flood research showing that elevated dwelling floors reduce the probability and depth of floodwater penetration. Low-plinth households experienced greater damage in the present analysis, while weak foundations independently predicted higher damage after other factors were controlled. This pattern accords with studies demonstrating that prolonged saturation, soil instability, erosion, and scour can undermine foundations even when above-ground structural components initially remain intact. Roof anchoring was another significant predictor, reinforcing earlier engineering and disaster-resilience evidence that cyclone resistance depends substantially on the continuity of connections between roofing sheets, rafters, walls, and foundations. The significance of previous unrepaired damage also corresponded with cumulative-vulnerability research (Hamidi et al., 2020). Repeated hazards can weaken structural components, while economically constrained households may undertake partial repairs that restore immediate habitability without fully restoring structural resistance. Climate-hazard exposure remained the strongest positive predictor of percentage structural damage, although structural adequacy showed a substantial protective association. This combination is important because it confirms the interaction between hazard and dwelling characteristics identified throughout earlier vulnerability research: severe hazards increase physical stress, while housing quality influences how that stress translates into damage. The results therefore aligned with the established understanding of disaster risk as an outcome of both environmental exposure and structural susceptibility, while providing quantitative differentiation across locally relevant Bangladeshi housing categories (Kim et al., 2018).

The thermal findings demonstrated a strong relationship between building characteristics and indoor heat exposure, closely matching earlier building-performance and heat-health studies conducted in tropical and low-income residential settings. Urban informal households recorded higher maximum indoor temperatures and larger indoor-outdoor temperature differences than rural households, while their thermal comfort scores were substantially lower. Corrugated-metal roofing, inadequate ventilation, limited shading, and greater household density independently predicted higher indoor

maximum temperatures (Santamouris & Kolokotsa, 2015). These results were consistent with earlier studies demonstrating that roof material represents a major pathway through which solar radiation influences indoor thermal conditions. Lightweight, uninsulated metal roofing can heat rapidly under direct solar exposure and transmit substantial sensible heat into occupied rooms, particularly when ceiling insulation, reflective surfaces, or ventilated roof spaces are absent. Earlier research from South and Southeast Asian low-income housing has similarly reported elevated daytime temperatures in dwellings constructed with highly conductive roofing materials. The ventilation findings were also consistent with established thermal-comfort literature emphasizing air movement, opening area, cross-ventilation, and window positioning as determinants of perceived and measured thermal conditions (Thomson et al., 2019). Restricted openings and closely spaced buildings can inhibit air exchange, a problem particularly relevant to high-density informal settlements where adjacent structures constrain wind flow. The significant association between limited shading and indoor temperature also corresponded with passive-design research demonstrating that vegetation, roof overhangs, neighboring shade, verandas, and external shading devices reduce direct solar gains. Household density added another dimension because overcrowded rooms combine reduced air volume per occupant with additional metabolic heat and restricted movement. Electricity reliability and fan availability further differentiated household capacity to manage heat, although fan availability alone was not sufficient to eliminate the underlying effects of building design. The findings therefore supported earlier energy-poverty research showing that thermal vulnerability results from both physical dwelling characteristics and unequal access to affordable cooling (Mavrogianni et al., 2015). The comparatively large urban-rural difference in thermal comfort also corresponded with the observed differences in crowding, ventilation, and shading. In this respect, extreme heat was not simply an outdoor meteorological exposure. The dwelling operated as an exposure-modifying environment that could amplify or reduce heat experienced by residents. This interpretation was consistent with the healthy-housing framework adopted by this study, in which thermal performance represented an integral dimension of residential quality rather than an isolated energy or comfort issue (Zune et al., 2020).

The retrospective pandemic-related findings demonstrated that the same housing deficiencies associated with climate vulnerability also constrained household functionality during COVID-19. Less than one-third of households had access to a separate room that could have been used for isolation, while substantial proportions depended on shared sanitation, experienced water-access limitations, or lacked sufficient residential space for simultaneous work, education, caregiving, illness management, and routine domestic activities (Kownacki et al., 2019). Urban informal households recorded substantially lower Pandemic Housing Functionality Index scores than rural households, with the difference reaching a moderate-to-large standardized magnitude. This finding was consistent with international COVID-19 studies that identified crowding, shared sanitation, limited ventilation, housing insecurity, and inadequate space as important dimensions of unequal pandemic exposure and coping capacity. Earlier research in informal settlements across South Asia, Africa, and Latin America similarly documented the practical difficulty of applying household-level physical distancing and isolation recommendations in small, densely occupied dwellings. The present results were particularly consistent with Bangladesh-based observations that many low-income urban households experienced high persons-per-room ratios and shared WASH facilities, conditions that constrained infection-prevention practices based on separation and reduced interpersonal contact (Vellei et al., 2017). The lower availability of isolation space among urban households reflected the large spatial-adequacy disparity identified elsewhere in the findings. At the same time, the analysis showed that pandemic housing functionality extended beyond isolation capacity. Ventilation, water reliability, handwashing facilities, sanitation privacy, and adaptable domestic space jointly influenced whether housing could support multiple protective and everyday functions during periods of movement restriction. The association between repeated climate-hazard exposure and poorer pandemic housing functionality further demonstrated the overlap between different forms of residential vulnerability. Earlier resilience scholarship has described such overlap as compounding or cascading vulnerability, in which households exposed to one environmental or socioeconomic stressor often possess fewer resources to manage another (Ormandy & Ezratty, 2016). The results of this study were consistent with that

interpretation because households with poorer housing and repeated hazard exposure also tended to report weaker pandemic functionality. This relationship was especially important in understanding healthy housing as a cross-hazard construct. Flood resilience, cyclone resistance, thermal protection, infection control, water security, sanitation, ventilation, and spatial flexibility appeared as interconnected characteristics of residential environments rather than separate housing policy domains. The COVID-19 experience therefore provided an empirical lens through which existing inequalities in residential space, infrastructure, and environmental quality became quantitatively visible alongside climate-related housing vulnerability ([Gamero-Salinas et al., 2020](#)).

The integrated statistical findings demonstrated that household resilience was shaped by the combined influence of healthy housing quality, climate-hazard exposure, socioeconomic disadvantage, structural characteristics, and access to adaptive financial resources. Healthy housing produced the strongest positive standardized association with resilience, while cumulative climate exposure produced the strongest negative association. These relationships remained statistically significant after relevant demographic and socioeconomic characteristics were controlled, and the final hierarchical model explained a substantial proportion of variance in household resilience ([Errico et al., 2018](#)). The increase in explanatory power after healthy-housing variables were added was particularly notable because it demonstrated that housing conditions accounted for variation beyond that explained by conventional socioeconomic characteristics. Addition of climate-hazard exposure further increased model performance, while adaptive and financial resources contributed additional explanatory capacity. These findings corresponded with earlier resilience studies in Bangladesh that treated household capacity as a multidimensional product of exposure, sensitivity, physical assets, economic resources, infrastructure, and adaptive capacity. The recovery analysis reinforced this interpretation. Households experiencing repeated hazards required longer periods to restore residential functionality, while accessible savings or credit shortened recovery duration ([Ansah et al., 2019](#)). Kutcha housing independently increased the likelihood of prolonged recovery, connecting structural vulnerability with socioeconomic recovery capacity. Similar patterns have been documented in earlier disaster-recovery studies in which poorer households experienced repeated repair cycles, asset depletion, borrowing, temporary displacement, and incomplete reconstruction following floods or cyclones. The robustness analyses strengthened confidence in the internal statistical pattern. The relationship between healthy housing and resilience remained stable when composite measures were replaced with individual housing domains, when extreme observations were excluded, when complete-case analysis was applied, and when resilience was modeled categorically rather than continuously. Diagnostic statistics also indicated acceptable multicollinearity, residual independence, model discrimination, and influential-case behavior ([Merritt et al., 2016](#)). The urban-rural subgroup results further showed that resilience did not operate identically across residential contexts. Urban resilience was more strongly differentiated by crowding, drainage, ventilation, sanitation sharing, heat, and tenure, whereas rural resilience was more strongly differentiated by structural adequacy, plinth elevation, foundations, roof anchoring, floods, cyclones, salinity, and transportation accessibility. This integrated pattern was consistent with earlier scholarship emphasizing place-specific vulnerability while also demonstrating common underlying dimensions of healthy housing. Across the analyses, residential quality functioned as a measurable link among socioeconomic inequality, environmental exposure, household health, pandemic functionality, structural damage, displacement, and recovery, thereby providing a coherent interpretation of the quantitative relationships reported in this study ([Platt et al., 2016](#)).

CONCLUSION

This quantitative study established that healthy housing in Bangladesh represented a multidimensional condition in which structural quality, spatial adequacy, indoor environmental performance, WASH services, drainage, energy reliability, household safety, socioeconomic resources, and climate-hazard exposure were closely associated with household health and residential resilience. The findings demonstrated substantial inequalities between urban informal settlements and rural climate-exposed communities, while also showing that vulnerability assumed different forms across these settings. Urban informal households experienced greater crowding, inadequate ventilation, shared sanitation, drainage congestion, extreme indoor heat, tenure insecurity, and limited pandemic-related housing functionality, whereas rural households experienced greater structural fragility, low plinth elevation,

weak foundations, inadequate roof anchoring, and higher exposure to floods, cyclones, erosion, and salinity. Poorer Healthy Housing Index scores were significantly associated with increased respiratory symptoms, diarrheal and infectious illness, heat-related symptoms, psychological distress, household injuries, and poorer self-rated health. Structural analyses further demonstrated that kutchra dwellings experienced substantially greater floodwater penetration, roof loss, wall failure, displacement, and recovery duration than more durable housing forms. Socioeconomic inequality was strongly embedded within these residential patterns, as lower income, limited education, insecure employment, insecure tenure, high dependency ratios, and restricted access to savings or credit corresponded with poorer housing conditions and weaker resilience. The mediation analysis showed that housing deprivation accounted for a substantial proportion of the statistical relationship between socioeconomic disadvantage and residential vulnerability, confirming that unequal material housing conditions constituted an important pathway through which broader socioeconomic inequalities were expressed. Climate-hazard exposure independently increased structural damage and prolonged recovery, while higher structural adequacy and access to financial resources were associated with stronger resilience. Retrospective COVID-19 findings additionally demonstrated that overcrowding, insufficient isolation space, shared sanitation, restricted ventilation, and inadequate multifunctional space constrained household capacity to respond effectively to pandemic conditions. The stability of the principal relationships across multivariable, subgroup, mediation, interaction, and sensitivity analyses strengthened the overall quantitative evidence. Taken together, the study demonstrated that climate resilience, pandemic preparedness, public health, housing quality, and socioeconomic equity were interconnected dimensions of residential security in Bangladesh. An equity-centered healthy housing framework therefore required recognition of the distinct conditions of urban informal settlements and rural communities while addressing the structural, environmental, service-related, socioeconomic, and hazard-specific factors that shaped unequal household exposure, health outcomes, damage, displacement, and recovery.

RECOMMENDATIONS

Based on the quantitative findings, an equity-centered healthy housing policy framework for Bangladesh should prioritize differentiated but coordinated interventions for urban informal settlements and rural climate-exposed communities, with resource allocation directed toward households experiencing the greatest combinations of socioeconomic disadvantage, housing deprivation, health risk, and climate exposure. In urban informal settlements, housing programs should emphasize reduction of overcrowding, improvement of natural ventilation and daylight, provision of safer and less thermally conductive roofing, reliable drinking-water systems, private or appropriately managed sanitation, functional drainage, regular waste collection, dependable electricity, and adaptable household spaces capable of supporting isolation, caregiving, education, and livelihood activities during public-health emergencies. In rural communities, housing interventions should prioritize elevated and erosion-resistant plinths, stable foundations, strengthened wall systems, securely anchored roofs, flood-resistant construction materials, cyclone-resistant structural connections, safe drinking-water systems in salinity-affected areas, and improved accessibility to roads, cyclone shelters, healthcare facilities, and emergency services. National and local housing standards should incorporate measurable healthy-housing indicators covering structural adequacy, persons per room, ventilation, indoor temperature, WASH adequacy, drainage, energy reliability, accessibility, and household safety, allowing vulnerable dwellings and communities to be identified through transparent quantitative assessment. Housing assistance should be progressively targeted according to need through grants, concessional loans, microfinance safeguards, repair subsidies, material support, and technical construction assistance, particularly for low-income households, insecure-tenure residents, households with high dependency ratios, and families lacking savings or accessible credit. Retrofitting existing kutchra and semi-pucca dwellings should receive substantial attention because complete replacement may remain financially inaccessible for many households. Community participation should be incorporated into housing assessment, design, upgrading, hazard mapping, maintenance, and monitoring so that interventions correspond with locally experienced flood, cyclone, heat, waterlogging, erosion, and salinity conditions. Coordination among housing, public health, disaster management, water and sanitation, urban development, local government, and social-protection

authorities should reduce fragmented responses to interconnected residential risks. Routine housing assessments should combine household surveys, structural inspections, indoor thermal measurements, WASH indicators, hazard histories, and spatial vulnerability mapping. Particular attention should also be given to pandemic-responsive design through adequate ventilation, reduced crowding, accessible handwashing, reliable water, sanitation privacy, and flexible domestic space. Such measures would enable healthy housing policy to address everyday health requirements alongside climate-hazard resistance, emergency functionality, equitable protection, and household recovery capacity.

LIMITATION

Several limitations should be considered when interpreting the findings of this study. First, the quantitative cross-sectional design measured housing conditions, socioeconomic characteristics, climate-hazard exposure, health outcomes, and household resilience within a defined study period; consequently, the observed statistical associations could not establish definitive temporal or causal relationships between housing deprivation, environmental exposure, and household outcomes. Second, several variables, including previous flood and cyclone exposure, waterlogging duration, housing damage, displacement, repair expenditure, health symptoms, recovery duration, and COVID-19-related housing experiences, depended partly on respondents' retrospective self-reports and may therefore have been affected by recall error or differences in individual perception. This limitation was particularly relevant to pandemic-related indicators because respondents were required to recall household conditions and residential functionality during an earlier period. Third, although the study incorporated urban informal settlements and rural climate-exposed communities, the selected locations could not represent every geographical, socioeconomic, cultural, and environmental setting in Bangladesh. Conditions in Dhaka, Chattogram, Khulna, coastal communities, riverine areas, and other rural locations vary considerably, limiting unrestricted generalization to the entire national population. Fourth, composite measures such as the Healthy Housing Index, Climate-Hazard Exposure Index, Pandemic Housing Functionality Index, and Household Resilience Index simplified multidimensional conditions into standardized numerical scores. Although reliability and validity procedures strengthened their measurement quality, index construction involved decisions concerning indicator selection, coding, standardization, and aggregation that may have influenced estimated relationships. Fifth, direct environmental measurements of indoor temperature and humidity could not capture all seasonal and daily variations in thermal exposure, particularly where measurements were obtained during restricted monitoring periods. Similarly, structural observations identified visible housing conditions but could not substitute for detailed engineering assessments of foundations, roof connections, material strength, or cyclone resistance. Sixth, household health outcomes were primarily based on reported symptoms and conditions rather than clinical examinations, laboratory confirmation, or longitudinal medical records, which limited diagnostic precision. Seventh, unmeasured factors such as neighborhood social cohesion, detailed dietary conditions, occupational exposures, healthcare accessibility, local governance quality, landlord behavior, and variations in disaster assistance may have contributed to residual confounding even after multivariable adjustment. Finally, subgroup and interaction analyses divided the overall sample into smaller analytical categories, reducing statistical precision for some estimates. These limitations required cautious interpretation of effect estimates while retaining the value of the study's systematic quantitative comparison of healthy housing, socioeconomic inequality, climate exposure, health, and residential resilience across contrasting Bangladeshi communities.

REFERENCES

- [1]. Abdullah, H. K., & Alibaba, H. Z. (2020). Window design of naturally ventilated offices in the mediterranean climate in terms of CO₂ and thermal comfort performance. *Sustainability*, 12(2), 473.
- [2]. Abuseif, M., & Gou, Z. (2018). A review of roofing methods: Construction features, heat reduction, payback period and climatic responsiveness. *Energies*, 11(11), 3196.
- [3]. Aflaki, A., Mahyuddin, N., Mahmoud, Z. A.-C., & Baharum, M. R. (2015). A review on natural ventilation applications through building façade components and ventilation openings in tropical climates. *Energy and Buildings*, 101, 153-162.

- [4]. Afroza, P., Ashraful, A. A., & Rumana, A. (2016). A built environment perspective on adaptation in urban informal settlements, Khulna, Bangladesh. In *Urban poverty and climate change* (pp. 73-91). Routledge.
- [5]. Ahmed, I., & Johnson, G. (2014). Urban safety and poverty in Dhaka, Bangladesh: Understanding the structural and institutional linkages. *Australian Planner*, 51(3), 272-280.
- [6]. Alam, A., McGregor, A., & Houston, D. (2020). Women's mobility, neighbourhood socio-ecologies and homemaking in urban informal settlements. *Housing Studies*, 35(9), 1586-1606.
- [7]. Alam, G. M. (2017). Livelihood cycle and vulnerability of rural households to climate change and hazards in Bangladesh. *Environmental management*, 59(5), 777-791.
- [8]. Ali, H., Dumbuya, B., Hynie, M., Idahosa, P., Keil, R., & Perkins, P. (2016). The social and political dimensions of the Ebola response: Global inequality, climate change, and infectious disease. In *Climate change and health: improving resilience and reducing risks* (pp. 151-169). Springer.
- [9]. Alkire, S., & Fang, Y. (2019). Dynamics of multidimensional poverty and uni-dimensional income poverty: An evidence of stability analysis from China. *Social indicators research*, 142(1), 25-64.
- [10]. Amaral, A. R., Rodrigues, E., Gaspar, A. R., & Gomes, Á. (2016). A thermal performance parametric study of window type, orientation, size and shadowing effect. *Sustainable Cities and Society*, 26, 456-465.
- [11]. Ameis, S. H., Lai, M.-C., Mulsant, B. H., & Szatmari, P. (2020). Coping, fostering resilience, and driving care innovation for autistic people and their families during the COVID-19 pandemic and beyond. *Molecular Autism*, 11(1), 61.
- [12]. André, S., Dewilde, C., & Muffels, R. (2019). Housing tenure, housing wealth and subjective wellbeing in Australia: The case of unemployment. In *Wealth (s) and subjective well-being* (pp. 281-304). Springer.
- [13]. Angel, S., & Bittschi, B. (2019). Housing and health. *Review of Income and Wealth*, 65(3), 495-513.
- [14]. Ansah, I. G. K., Gardebroek, C., & Ihle, R. (2019). Resilience and household food security: a review of concepts, methodological approaches and empirical evidence: Ansah IGK et al. *Food Security*, 11(6), 1187-1203.
- [15]. Archer, D. (2016). Building urban climate resilience through community-driven approaches to development: Experiences from Asia. *International Journal of Climate Change Strategies and Management*, 8(5), 654-669.
- [16]. Bahadur, A. V., & Tanner, T. (2014). Policy climates and climate policies: Analysing the politics of building urban climate change resilience. *Urban Climate*, 7, 20-32.
- [17]. Baker, E., Bentley, R., Lester, L., & Beer, A. (2016). Housing affordability and residential mobility as drivers of locational inequality. *Applied geography*, 72, 65-75.
- [18]. Baker, E., Lester, L. H., Bentley, R., & Beer, A. (2016). Poor housing quality: Prevalence and health effects. *Journal of prevention & intervention in the community*, 44(4), 219-232.
- [19]. Banai, R. (2020). Pandemic and the planning of resilient cities and regions. *Cities*, 106, 102929.
- [20]. Bardosh, K. L., Ryan, S. J., Ebi, K., Welburn, S., & Singer, B. (2017). Addressing vulnerability, building resilience: community-based adaptation to vector-borne diseases in the context of global change. *Infectious diseases of poverty*, 6(1), 166.
- [21]. Benjamin, G. C. (2020). Ensuring health equity during the COVID-19 pandemic: the role of public health infrastructure. In (Vol. 44, pp. e70): SciELO Public Health.
- [22]. Bhuiyan, M. A. H., Islam, S. D.-U., & Azam, G. (2017). Exploring impacts and livelihood vulnerability of riverbank erosion hazard among rural household along the river Padma of Bangladesh. *Environmental Systems Research*, 6(1), 25.
- [23]. Boch, S. J., Taylor, D. M., Danielson, M. L., Chisolm, D. J., & Kelleher, K. J. (2020). 'Home is where the health is': Housing quality and adult health outcomes in the survey of income and program participation. *Preventive medicine*, 132, 105990.
- [24]. Brousselle, A., Brunet-Jailly, E., Kennedy, C., Phillips, S. D., Quigley, K., & Roberts, A. (2020). Beyond COVID-19: Five commentaries on reimagining governance for future crises and resilience. *Canadian Public Administration*, 63(3), 369-408.
- [25]. Cajete, G. A. (2020). Indigenous science, climate change, and indigenous community building: A framework of foundational perspectives for indigenous community resilience and revitalization. *Sustainability*, 12(22), 9569.
- [26]. Charalampous, M., Grant, C. A., Tramontano, C., & Michailidis, E. (2019). Systematically reviewing remote e-workers' well-being at work: A multidimensional approach. *European journal of work and organizational psychology*, 28(1), 51-73.
- [27]. Chihuri, S., Mielenz, T. J., DiMaggio, C. J., Betz, M. E., DiGuseppi, C., Jones, V. C., & Li, G. (2016). Driving cessation and health outcomes in older adults. *Journal of the American Geriatrics Society*, 64(2), 332-341.
- [28]. Cinderby, S., Haq, G., Cambridge, H., & Lock, K. (2016). Building community resilience: can everyone enjoy a good life? *Local Environment*, 21(10), 1252-1270.
- [29]. d'Errico, M., Romano, D., & Pietrelli, R. (2018). Household resilience to food insecurity: evidence from Tanzania and Uganda: d'Errico M. et al. *Food Security*, 10(4), 1033-1054.
- [30]. Dabaieh, M., Wanas, O., Hegazy, M. A., & Johansson, E. (2015). Reducing cooling demands in a hot dry climate: A simulation study for non-insulated passive cool roof thermal performance in residential buildings. *Energy and Buildings*, 89, 142-152.
- [31]. De Martino, G., Di Ludovico, M., Prota, A., Moroni, C., Manfredi, G., & Dolce, M. (2017). Estimation of repair costs for RC and masonry residential buildings based on damage data collected by post-earthquake visual inspection. *Bulletin of Earthquake Engineering*, 15(4), 1681-1706.

- [32]. Debasish, A. (2021). Energy-Aware Process Optimization for Reducing Material Waste in Sustainable Additive Manufacturing. *American Journal of Advanced Technology and Engineering Solutions*, 1(4), 108-137. <https://doi.org/10.63125/j0wk7j48>
- [33]. Djalante, R., Shaw, R., & DeWit, A. (2020). Building resilience against biological hazards and pandemics: COVID-19 and its implications for the Sendai Framework. *Progress in disaster science*, 6, 100080.
- [34]. Dong, Y., & Frangopol, D. M. (2016). Performance-based seismic assessment of conventional and base-isolated steel buildings including environmental impact and resilience. *Earthquake engineering & structural dynamics*, 45(5), 739-756.
- [35]. Dwirahmadi, F., Rutherford, S., Phung, D., & Chu, C. (2019). Understanding the operational concept of a flood-resilient urban community in Jakarta, Indonesia, from the perspectives of disaster risk reduction, climate change adaptation, and development agencies. *International journal of environmental research and public health*, 16(20), 3993.
- [36]. Dzigbede, K. D., Gehl, S. B., & Willoughby, K. (2020). Disaster resiliency of US local governments: Insights to strengthen local response and recovery from the COVID-19 pandemic. *Public administration review*, 80(4), 634-643.
- [37]. Fabrizi, E., & Mussida, C. (2020). Assessing poverty persistence in households with children. *The Journal of Economic Inequality*, 18(4), 551-569.
- [38]. Fang, H., Zhao, D., Yuan, J., Aili, A., Yin, X., Yang, R., & Tan, G. (2019). Performance evaluation of a metamaterial-based new cool roof using improved Roof Thermal Transfer Value model. *Applied Energy*, 248, 589-599.
- [39]. Farrell, P., Thow, A. M., Wate, J. T., Nonga, N., Vatucaawaqa, P., Brewer, T., Sharp, M. K., Farmery, A., Trevena, H., & Reeve, E. (2020). COVID-19 and Pacific food system resilience: opportunities to build a robust response: Farrell P. et al. *Food Security*, 12(4), 783-791.
- [40]. Ferdous, J., & Mallick, D. (2019). Norms, practices, and gendered vulnerabilities in the lower Teesta basin, Bangladesh. *Environmental Development*, 31, 88-96.
- [41]. Fereshtehnejad, E., & Shafieezadeh, A. (2016). Multiple hazard incidents lifecycle cost assessment of structural systems considering state-dependent repair times and fragility curves. *Earthquake engineering & structural dynamics*, 45(14), 2327-2347.
- [42]. Fitzpatrick, S., & Watts, B. (2017). Competing visions: security of tenure and the welfarisation of English social housing. *Housing Studies*, 32(8), 1021-1038.
- [43]. Frاسquilho, D., Matos, M. G., Salonna, F., Guerreiro, D., Storti, C. C., Gaspar, T., & Caldas-de-Almeida, J. M. (2015). Mental health outcomes in times of economic recession: a systematic literature review. *BMC public health*, 16(1), 115.
- [44]. Frederick, T. J., Chwalek, M., Hughes, J., Karabanow, J., & Kidd, S. (2014). How stable is stable? Defining and measuring housing stability. *Journal of Community Psychology*, 42(8), 964-979.
- [45]. French, M., Trundle, A., Korte, I., & Koto, C. (2020). Climate resilience in urban informal settlements: Towards a transformative upgrading agenda. In *Climate resilient urban areas: Governance, design and development in coastal delta cities* (pp. 129-153). Springer.
- [46]. Fried, T. R., O'Leary, J., Towle, V., Goldstein, M. K., Trentalange, M., & Martin, D. K. (2014). Health outcomes associated with polypharmacy in community-dwelling older adults: a systematic review. *Journal of the American Geriatrics Society*, 62(12), 2261-2272.
- [47]. Gamero-Salinas, J. C., Monge-Barrio, A., & Sánchez-Ostiz, A. (2020). Overheating risk assessment of different dwellings during the hottest season of a warm tropical climate. *Building and Environment*, 171, 106664.
- [48]. Gössling, S. (2020). Risks, resilience, and pathways to sustainable aviation: A COVID-19 perspective. *Journal of Air Transport Management*, 89, 101933.
- [49]. Grasham, C. F., Korzenevica, M., & Charles, K. J. (2019). On considering climate resilience in urban water security: A review of the vulnerability of the urban poor in sub-Saharan Africa. *Wiley Interdisciplinary Reviews: Water*, 6(3), e1344.
- [50]. Hamidi, A. R., Zeng, Z., & Khan, M. A. (2020). Household vulnerability to floods and cyclones in Khyber Pakhtunkhwa, Pakistan. *International journal of disaster risk reduction*, 46, 101496.
- [51]. Herslund, L. B., Jalayer, F., Jean-Baptiste, N., Jørgensen, G., Kabisch, S., Kombe, W., Lindley, S., Nyed, P. K., Pauleit, S., & Printz, A. (2016). A multi-dimensional assessment of urban vulnerability to climate change in Sub-Saharan Africa. *Natural hazards*, 82(Suppl 2), 149-172.
- [52]. Hoque, M. Z., Cui, S., Xu, L., Islam, I., Tang, J., & Ding, S. (2019). Assessing agricultural livelihood vulnerability to climate change in coastal Bangladesh. *International journal of environmental research and public health*, 16(22), 4552.
- [53]. Hossain, M. N. (2015). Analysis of human vulnerability to cyclones and storm surges based on influencing physical and socioeconomic factors: evidences from coastal Bangladesh. *International journal of disaster risk reduction*, 13, 66-75.
- [54]. Hu, J., & Yu, X. B. (2020). Adaptive building roof by coupling thermochromic material and phase change material: Energy performance under different climate conditions. *Construction and Building Materials*, 262, 120481.
- [55]. Islam, M. M., & Al Mamun, M. A. (2020). Beyond the risks to food availability-linking climatic hazard vulnerability with the food access of delta-dwelling households: Islam MM, Al Mamun MA. *Food Security*, 12(1), 37-58.
- [56]. Islam, M. R., Khan, N. A., Reza, M. M., & Rahman, M. M. (2020). Vulnerabilities of river erosion-affected coastal communities in Bangladesh: A menu of alternative livelihood options. *Global Social Welfare*, 7(4), 353-366.
- [57]. Jabeen, H. (2015). Adapting the assets of urban low-income households with climate extremes: experience from Dhaka. *International Journal of Urban Sustainable Development*, 7(1), 72-88.
- [58]. Jarratt, D., & Davies, N. J. (2020). Planning for climate change impacts: Coastal tourism destination resilience policies. *Tourism Planning & Development*, 17(4), 423-440.
- [59]. Karimi, M., & Brazier, J. (2016). Health, health-related quality of life, and quality of life: what is the difference? *Pharmacoeconomics*, 34(7), 645-649.
- [60]. Keenan, J. M. (2020). COVID, resilience, and the built environment. *Environment Systems and Decisions*, 40(2), 216-221.

- [61]. Khanom, T. (2016). Effect of salinity on food security in the context of interior coast of Bangladesh. *Ocean & Coastal Management*, 130, 205-212.
- [62]. Kikwasi, G., & Mbuya, E. (2019). Vulnerability analysis of building structures to floods: The case of flooding informal settlements in Dar es salaam, Tanzania. *International Journal of Building Pathology and Adaptation*, 37(5), 629-656.
- [63]. Kim, J.-M., Son, K., Yoo, Y., Lee, D., & Kim, D. Y. (2018). Identifying risk indicators of building damage due to typhoons: Focusing on cases of South Korea. *Sustainability*, 10(11), 3947.
- [64]. Klassen, S., & Murphy, S. (2020). Equity as both a means and an end: Lessons for resilient food systems from COVID-19. *World development*, 136, 105104.
- [65]. Kojima, G. (2015). Prevalence of frailty in nursing homes: a systematic review and meta-analysis. *Journal of the American Medical Directors Association*, 16(11), 940-945.
- [66]. Krellenberg, K., & Welz, J. (2017). Assessing urban vulnerability in the context of flood and heat hazard: Pathways and challenges for indicator-based analysis. *Social indicators research*, 132(2), 709-731.
- [67]. Krieger, J., Takaro, T. K., Allen, C., Song, L., Weaver, M., Chai, S., & Dickey, P. (2017). The Seattle-King County Healthy Homes Project: Implementation of a comprehensive approach to improving indoor environmental quality for low-income children with asthma. In *Community Research in Environmental Health* (pp. 49-78). Routledge.
- [68]. Libert Amico, A., Ituarte-Lima, C., & Elmqvist, T. (2020). Learning from social-ecological crisis for legal resilience building: multi-scale dynamics in the coffee rust epidemic. *Sustainability Science*, 15(2), 485-501.
- [69]. Liddell, C., & Guiney, C. (2015). Living in a cold and damp home: frameworks for understanding impacts on mental well-being. *Public health*, 129(3), 191-199.
- [70]. Lin, B., Meyers, J., & Barnett, G. (2015). Understanding the potential loss and inequities of green space distribution with urban densification. *Urban forestry & urban greening*, 14(4), 952-958.
- [71]. Lundgren Kownacki, K., Gao, C., Kuklane, K., & Wierzbicka, A. (2019). Heat stress in indoor environments of scandinavian urban areas: A literature review. *International journal of environmental research and public health*, 16(4), 560.
- [72]. Malik, S., Roosli, R., & Tariq, F. (2020). Investigation of informal housing challenges and issues: experiences from slum and squatter of Lahore: S. Malik et al. *Journal of Housing and the Built Environment*, 35(1), 143-170.
- [73]. Mavrogianni, A., Taylor, J., Davies, M., Thoua, C., & Kolm-Murray, J. (2015). Urban social housing resilience to excess summer heat. *Building Research & Information*, 43(3), 316-333.
- [74]. McNamara, K. E., Olson, L. L., & Rahman, M. A. (2016). Insecure hope: the challenges faced by urban slum dwellers in Bhola Slum, Bangladesh. *Migration and Development*, 5(1), 1-15.
- [75]. Md. Abdur, R., & Iftekhhar, A. (2021). Customer Retention Forecasting in Mobile Wallet Services Using Neural Networks: A Comparative Quantitative Study. *International Journal of Business and Economics Insights*, 1(4), 70-102. <https://doi.org/10.63125/dyrpc387>
- [76]. Meer, T., & Combrinck, H. (2017). Help, harm or hinder? Non-governmental service providers' perspectives on families and gender-based violence against women with intellectual disabilities in South Africa. *Disability & Society*, 32(1), 37-55.
- [77]. Mehdipanah, R., Bess, K., Tomkowiak, S., Richardson, A., Stokes, C., White Perkins, D., Cleage, S., Israel, B. A., & Schulz, A. J. (2020). Residential racial and socioeconomic segregation as predictors of housing discrimination in Detroit Metropolitan Area. *Sustainability*, 12(24), 10429.
- [78]. Merritt, W. S., Patch, B., Reddy, V. R., & Syme, G. J. (2016). Modelling livelihoods and household resilience to droughts using Bayesian networks. *Environment, development and sustainability*, 18(2), 315-346.
- [79]. Mitra, S., Palmer, M., Kim, H., Mont, D., & Groce, N. (2017). Extra costs of living with a disability: A review and agenda for research. *Disability and health journal*, 10(4), 475-484.
- [80]. Montez, J. K., Hayward, M. D., & Wolf, D. A. (2017). Do US states' socioeconomic and policy contexts shape adult disability? *Social Science & Medicine*, 178, 115-126.
- [81]. Morciano, M., Hancock, R., & Pudney, S. (2015). Disability costs and equivalence scales in the older population in Great Britain. *Review of Income and Wealth*, 61(3), 494-514.
- [82]. Morin, V. M., Ahmad, M. M., & Warnitchai, P. (2016). Vulnerability to typhoon hazards in the coastal informal settlements of Metro Manila, the Philippines. *Disasters*, 40(4), 693-719.
- [83]. Morton, K., Dennison, L., May, C., Murray, E., Little, P., McManus, R. J., & Yardley, L. (2017). Using digital interventions for self-management of chronic physical health conditions: a meta-ethnography review of published studies. *Patient education and counseling*, 100(4), 616-635.
- [84]. Mukut Kanti, B. (2020). Integrated Framework for Fire Safety and Electrical Hazard Assessment in Large-Scale Industrial and Commercial Facilities: A Mixed-Method Analysis. *American Journal of Advanced Technology and Engineering Solutions*, 1(01), 40-86. <https://doi.org/10.63125/zxsbd47>
- [85]. Mullen, C., Marsden, G., & Philips, I. (2020). Seeking protection from precarity? Relationships between transport needs and insecurity in housing and employment. *Geoforum*, 109, 4-13.
- [86]. Nazem, N. I., & Sultana, S. (2020). Slums, squatter settlements and affordable housing in the Dhaka metropolitan area. AUC 2019: Proceedings of the 15th International Asian Urbanization Conference, Vietnam,
- [87]. Nijman, J., & Wei, Y. D. (2020). Urban inequalities in the 21st century economy. *Applied geography*, 117, 102188.
- [88]. Nocca, F. (2017). The role of cultural heritage in sustainable development: Multidimensional indicators as decision-making tool. *Sustainability*, 9(10), 1882.
- [89]. Oakman, J., Kinsman, N., Stuckey, R., Graham, M., & Weale, V. (2020). A rapid review of mental and physical health effects of working at home: how do we optimise health? *BMC public health*, 20(1), 1825.

- [90]. Ormandy, D., & Ezratty, V. (2016). Thermal discomfort and health: protecting the susceptible from excess cold and excess heat in housing. *Advances in building energy research*, 10(1), 84-98.
- [91]. Owusu, M., & Nursey-Bray, M. (2019). Socio-economic and institutional drivers of vulnerability to climate change in urban slums: the case of Accra, Ghana. *Climate and Development*, 11(8), 687-698.
- [92]. Owusu, M., Nursey-Bray, M., & Rudd, D. (2019). Gendered perception and vulnerability to climate change in urban slum communities in Accra, Ghana: M. Owusu et al. *Regional environmental change*, 19(1), 13-25.
- [93]. Palinkas, L. A. (2014). Qualitative and mixed methods in mental health services and implementation research. *Journal of Clinical Child & Adolescent Psychology*, 43(6), 851-861.
- [94]. Pan, X., & Yang, T. (2020). Postdisaster image-based damage detection and repair cost estimation of reinforced concrete buildings using dual convolutional neural networks. *Computer-Aided Civil and Infrastructure Engineering*, 35(5), 495-510.
- [95]. Patankar, A., & Patwardhan, A. (2016). Estimating the uninsured losses due to extreme weather events and implications for informal sector vulnerability: a case study of Mumbai, India. *Natural hazards*, 80(1), 285-310.
- [96]. Patel, A., Joseph, G., Shrestha, A., & Foint, Y. (2019). Measuring deprivations in the slums of Bangladesh: implications for achieving sustainable development goals. *Housing and Society*, 46(2), 81-109.
- [97]. Paterson, J., Berry, P., Ebi, K., & Varangu, L. (2014). Health care facilities resilient to climate change impacts. *International journal of environmental research and public health*, 11(12), 13097-13116.
- [98]. Pelz, S., Pachauri, S., & Groh, S. (2018). A critical review of modern approaches for multidimensional energy poverty measurement. *Wiley Interdisciplinary Reviews: Energy and Environment*, 7(6), e304.
- [99]. Peterson, N. A. (2014). Empowerment theory: Clarifying the nature of higher-order multidimensional constructs. *American journal of community psychology*, 53(1), 96-108.
- [100]. Platt, S., Brown, D., & Hughes, M. (2016). Measuring resilience and recovery. *International journal of disaster risk reduction*, 19, 447-460.
- [101]. Qin, H., Romero-Lankao, P., Hardoy, J., & Rosas-Huerta, A. (2015). Household responses to climate-related hazards in four Latin American cities: A conceptual framework and exploratory analysis. *Urban Climate*, 14, 94-110.
- [102]. Rabinowitz, P. M., Slizovskiy, I. B., Lamers, V., Trufan, S. J., Holford, T. R., Dziura, J. D., Peduzzi, P. N., Kane, M. J., Reif, J. S., & Weiss, T. R. (2015). Proximity to natural gas wells and reported health status: results of a household survey in Washington County, Pennsylvania. *Environmental health perspectives*, 123(1), 21-26.
- [103]. Rahaman, M. A., Rahman, M. M., & Rahman, S. H. (2019). Pathways of climate-resilient health systems in Bangladesh. In *Confronting Climate Change in Bangladesh: Policy Strategies for Adaptation and Resilience* (pp. 119-143). Springer.
- [104]. Rahman, S., Islam, M. S., Khan, M. N. H., & Touhiduzzaman, M. (2019). Climate change adaptation and disaster risk reduction (DRR) through coastal afforestation in South-Central Coast of Bangladesh. *Management of Environmental Quality: An International Journal*, 30(3), 498-517.
- [105]. Rasch, R. (2017). Income inequality and urban vulnerability to flood hazard in Brazil. *Social Science Quarterly*, 98(1), 299-325.
- [106]. Rolfe, S., Garnham, L., Godwin, J., Anderson, I., Seaman, P., & Donaldson, C. (2020). Housing as a social determinant of health and wellbeing: developing an empirically-informed realist theoretical framework. *BMC public health*, 20(1), 1138.
- [107]. Santamouris, M., & Kolokotsa, D. (2015). On the impact of urban overheating and extreme climatic conditions on housing, energy, comfort and environmental quality of vulnerable population in Europe. *Energy and Buildings*, 98, 125-133.
- [108]. Sellers, S., & Ebi, K. L. (2018). Climate change and health under the shared socioeconomic pathway framework. *International journal of environmental research and public health*, 15(1), 3.
- [109]. Shameem, M. I. M., Momtaz, S., & Rauscher, R. (2014). Vulnerability of rural livelihoods to multiple stressors: A case study from the southwest coastal region of Bangladesh. *Ocean & Coastal Management*, 102, 79-87.
- [110]. Sheffield, P. E., Uijttewaall, S. A., Stewart, J., & Galvez, M. P. (2017). Climate change and schools: Environmental hazards and resiliency. *International journal of environmental research and public health*, 14(11), 1397.
- [111]. Sokolowski, J., Lewandowski, P., Kielczewska, A., & Bouzarovski, S. (2020). A multidimensional index to measure energy poverty: the Polish case. *Energy Sources, Part B: Economics, Planning, and Policy*, 15(2), 92-112.
- [112]. Sultana, F. (2017). Gender and water in a changing climate: Challenges and opportunities. *Water security across the gender divide*, 17-33.
- [113]. Swinburn, B. A., Kraak, V. I., Allender, S., Atkins, V. J., Baker, P. I., Bogard, J. R., Brinsden, H., Calvillo, A., De Schutter, O., & Devarajan, R. (2019). The global syndemic of obesity, undernutrition, and climate change: the Lancet Commission report. *The lancet*, 393(10173), 791-846.
- [114]. Taylor, S. (2020). Anxiety disorders, climate change, and the challenges ahead: Introduction to the special issue. *Journal of anxiety disorders*, 76, 102313.
- [115]. Te Lintelo, D. J., Gupte, J., McGregor, J. A., Lakshman, R., & Jahan, F. (2018). Wellbeing and urban governance: Who fails, survives or thrives in informal settlements in Bangladeshi cities? *Cities*, 72, 391-402.
- [116]. Thomson, D. R., Kuffer, M., Boo, G., Hati, B., Grippa, T., Elsey, H., Linard, C., Mahabir, R., Kyobutungi, C., & Maviti, J. (2020). Need for an integrated deprived area "slum" mapping system (IDEAMAPS) in low-and middle-income countries (LMICs). *Social Sciences*, 9(5), 80.
- [117]. Thomson, H., Simcock, N., Bouzarovski, S., & Petrova, S. (2019). Energy poverty and indoor cooling: An overlooked issue in Europe. *Energy and Buildings*, 196, 21-29.
- [118]. Thorbecke, E. (2015). Multidimensional poverty: conceptual and measurement issues. In *The many dimensions of poverty* (pp. 3-19). Springer.

- [119]. Uddin, M. N., Islam, A. S., Bala, S. K., Islam, G. T., Adhikary, S., Saha, D., Haque, S., Fahad, M. G. R., & Akter, R. (2019). Mapping of climate vulnerability of the coastal region of Bangladesh using principal component analysis. *Applied geography*, 102, 47-57.
- [120]. Uddin, N. (2018). Assessing urban sustainability of slum settlements in Bangladesh: Evidence from Chittagong city. *Journal of urban management*, 7(1), 32-42.
- [121]. Van den Berg, M., Wendel-Vos, W., Van Poppel, M., Kemper, H., Van Mechelen, W., & Maas, J. (2015). Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. *Urban forestry & urban greening*, 14(4), 806-816.
- [122]. Vanhoutteghem, L., Skarning, G. C. J., Hviid, C. A., & Svendsen, S. (2015). Impact of façade window design on energy, daylighting and thermal comfort in nearly zero-energy houses. *Energy and Buildings*, 102, 149-156.
- [123]. Vellei, M., Ramallo-González, A. P., Coley, D., Lee, J., Gabe-Thomas, E., Lovett, T., & Natarajan, S. (2017). Overheating in vulnerable and non-vulnerable households. *Building Research & Information*, 45(1-2), 102-118.
- [124]. Vermeiren, S., Vella-Azzopardi, R., Beckwee, D., Habbig, A.-K., Scafoglieri, A., Jansen, B., Bautmans, I., Verté, D., Beyer, I., & Petrovic, M. (2016). Frailty and the prediction of negative health outcomes: a meta-analysis. *Journal of the American Medical Directors Association*, 17(12), 1163. e1161-1163. e1117.
- [125]. von Reichert, C., & Berry, E. H. (2020). Rural-urban patterns of disability: The role of migration. *Population, space and place*, 26(1), e2271.
- [126]. Williams, D. R., & Cooper, L. A. (2019). Reducing racial inequities in health: using what we already know to take action. *International journal of environmental research and public health*, 16(4), 606.
- [127]. Won, J., Lee, C., Forjuoh, S. N., & Ory, M. G. (2016). Neighborhood safety factors associated with older adults' health-related outcomes: a systematic literature review. *Social Science & Medicine*, 165, 177-186.
- [128]. Zabaniotou, A. (2020). A systemic approach to resilience and ecological sustainability during the COVID-19 pandemic: Human, societal, and ecological health as a system-wide emergent property in the Anthropocene. *Global transitions*, 2, 116-126.
- [129]. Zavaleta-Cortijo, C., Ford, J. D., Arotoma-Rojas, I., Lwasa, S., Lancha-Rucoba, G., García, P. J., Miranda, J. J., Namanya, D. B., New, M., & Wright, C. J. (2020). Climate change and COVID-19: reinforcing Indigenous food systems. *The Lancet Planetary Health*, 4(9), e381-e382.
- [130]. Zhang, D., Li, J., & Han, P. (2019). A multidimensional measure of energy poverty in China and its impacts on health: An empirical study based on the China family panel studies. *Energy Policy*, 131, 72-81.
- [131]. Zhang, M., Yang, Y., Li, H., & van Dijk, M. P. (2020). Measuring urban resilience to climate change in three chinese cities. *Sustainability*, 12(22), 9735.
- [132]. Zune, M., Rodrigues, L., & Gillott, M. (2020). The vulnerability of homes to overheating in Myanmar today and in the future: A heat index analysis of measured and simulated data. *Energy and Buildings*, 223, 110201.