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Sustainability Assessment of Urban Informal Settlements: A Case Study in Kolkata, India

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Abstract

Rapid urbanization in India has intensified the challenges of informal housing, particularly among the urban poor. This study investigates the sustainability conditions of four slum settlements in the Kolkata Metropolitan Area, Kundu Bagan, Bapuji Nagar, Ganges Bank and Kadapara Samity, through a mixed-methods approach involving 160 household surveys (40 per site), 20 stakeholder interviews and field mapping. Using five analytical dimensions that is environmental, economic, social, infrastructural and spatial. The research reveals significant intra-urban disparities in sustainability outcomes. Kadapara Samity demonstrated the most favorable conditions, with 93% of households accessing electricity, an average income of ₹7,100 and high satisfaction with safety and education services. In contrast, Ganges Bank showed critical vulnerabilities, including high kutcha housing (58%), poor sanitation (rated 2.1/5) and only 59% financial inclusion. Perceived sustainability ratings across all settlements indicate a trade-off between affordability and living standards, with Kadapara scoring highest on sanitation and services, while Ganges Bank scored lowest despite being the most affordable. The study identifies the underlying trade-offs between affordability, accessibility and quality of life. The study's novelty lies in its comparative, data-driven evaluation of slum sustainability, offering insights that can inform more context-sensitive, evidence-based policy interventions for urban low-income housing in India. Future research could expand this framework to peri-urban and rural-urban fringe settlements and examine the longitudinal impacts of post-redevelopment transitions. By repositioning slums as integral to the urban fabric, this study contributes to inclusive planning frameworks that promote equitable and resilient urban futures.

Keywords: Kolkata, Slum Settlements, Sustainable Housing, Urban Development, Urban Informality, Urban Poor.

Introduction

Urbanization has transformed the economic and spatial fabric of Indian cities, bringing both opportunity and acute inequality (1, 2). Among the most visible expressions of this imbalance are slum settlements, densely packed neighborhoods characterized by substandard housing, insecure tenure and lack of essential services (3–5). In India, over 65 million people reside in slums, often located in environmentally vulnerable and economically marginal areas (6, 7). Despite various policy interventions, a substantial portion of its population continues to live in informal settlements marked by deteriorating housing, poor sanitation and limited access to clean water and healthcare (8–10). The sustainable development discourse has increasingly focused on inclusive urbanization, particularly through frameworks such as the Sustainable Development Goals (SDG 11), which call for access to safe, adequate and affordable housing for all by 2030 (11, 12). Achieving these goals requires integrated solutions that consider not just physical infrastructure but also environmental health, social cohesion, economic viability and governance (13–15). Studies show that informal settlements typically suffer from weak physical infrastructure, low-quality housing materials and severe overcrowding (16–18). These physical deficiencies are compounded by inadequate access to clean drinking water, poor drainage and sanitation systems, conditions that exacerbate the risk of communicable diseases and perpetuate cycles of poverty (19).

In Kolkata's slums, over 80% of residents rely on shared toilets and water supply is often intermittent (20, 21). Poor environmental conditions in urban slums significantly compromise public health and well-being, as high air temperatures and inadequate urban design exacerbate thermal discomfort and heat stress (22). Inhabitants of informal settlements are particularly vulnerable due to poorly ventilated

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housing and lack of shading or green cover (23, 24). Studies in Kolkata confirm that elderly slum residents experience more intense heat stress compared to those in rural areas, especially women, who spend more time indoors and often cook in enclosed spaces (25, 26). Beyond the physical infrastructure and environmental challenges, the social and political realities of slum life are equally consequential. Insecure land tenure remains a persistent obstacle to sustainable housing interventions, as residents lacking formal ownership or legal recognition are often reluctant to invest in home improvements (27–29). This insecurity not only perpetuates poor living conditions but also heightens the risk of forced evictions and displacement, undermining long-term community stability (30). Even redevelopment initiatives with genuine intentions often fail when they overlook the importance of secure tenure or disrupt residents established social and economic networks (31). Evidence from Indian cities indicates that many post-rehabilitation housing schemes suffer from inadequate living space, poor community integration and distance from employment centers, which collectively drive numerous families to return to informal settlements (32, 33).

Community participation has proven essential to the long-term success of slum upgrading initiatives. Programs that empower residents to co-design and maintain infrastructure foster stronger social ownership and sustainable improvements (34, 35). Yet, the effectiveness of such models relies on robust institutional support and the political willingness to share planning authority with marginalized urban groups (36–38). Despite decades of intervention, slum redevelopment in Indian cities remains dominated by standardized solutions such as high-rise resettlement and mass relocation, which often neglect the complex social, economic and spatial dynamics of urban informality (39, 40). This one size fits all approaches frequently disrupt livelihoods, weaken social networks and create new affordability pressures for displaced households (41–43). Emerging research highlights that incremental and in situ upgrading, which allows residents to improve their living conditions gradually while maintaining community ties, offers a more equitable and context appropriate alternative (44-47). Yet, there remains a significant empirical gap in understanding how sustainability conditions vary across different types of informal settlements (48, 49), especially in highly congested and politically complex urban environments like Kolkata. While programs such as Ahmedabad's Slum Networking Project and Mumbai's community led sanitation initiatives demonstrate hybrid successes (50–52), few studies have systematically examined the intra urban disparities in sustainability outcomes across multiple slum contexts (53, 54).

This study is grounded in urban sustainability theory and aligned with the United Nations Sustainable Development Goals (SDGs), particularly SDG 11, SDG 6, SDG 3 and SDG 10. Sustainability is assessed across five dimensions: environmental, economic, social, infrastructural and spatial, recognizing that housing sustainability includes livelihood security, social wellbeing, accessibility and environmental resilience.

The study examines four slum settlements in the Kolkata Metropolitan Area, Kundu Bagan, Bapuji Nagar, Ganges Bank and Kadapara Samity, using 160 household surveys, 20 stakeholder interviews and field mapping. By comparing sustainability conditions across these settlements, the study identifies intra urban disparities and provides evidence to support more inclusive and context sensitive urban planning.

Study Area

The study was conducted across four informal settlements in the Kolkata Metropolitan Area (KMA), selected to represent diverse urban conditions across the north, south, east and west of the city. These settlements reflect common challenges associated with urban informality, including insecure tenure, inadequate infrastructure, environmental risks and limited access to basic services (55–59). Figures 1A-1G shows the spatial distribution of the selected sites: Kundu Bagan (north), Bapuji Nagar (south), Kadapara Samity (east) and Ganges Bank in Howrah (west). The approximate GPS coordinates are Ganges Bank (22.595° N, 88.317° E), Kundu Bagan (22.642° N, 88.374° E), Kadapara Samity (22.574° N, 88.421° E) and Bapuji Nagar (22.495° N, 88.369° E).

Kundu Bagan and Ganges Bank are characterized by dense housing, inadequate infrastructure and high environmental vulnerability. Bapuji Nagar faces recurrent waterlogging and service deficiencies, while Kadapara Samity benefits from

relatively better infrastructure and connectivity due to its proximity to major urban corridors. Together, these settlements provide a representative basis for examining how spatial and locational factors influence sustainability outcomes within informal settlements across the KMA.

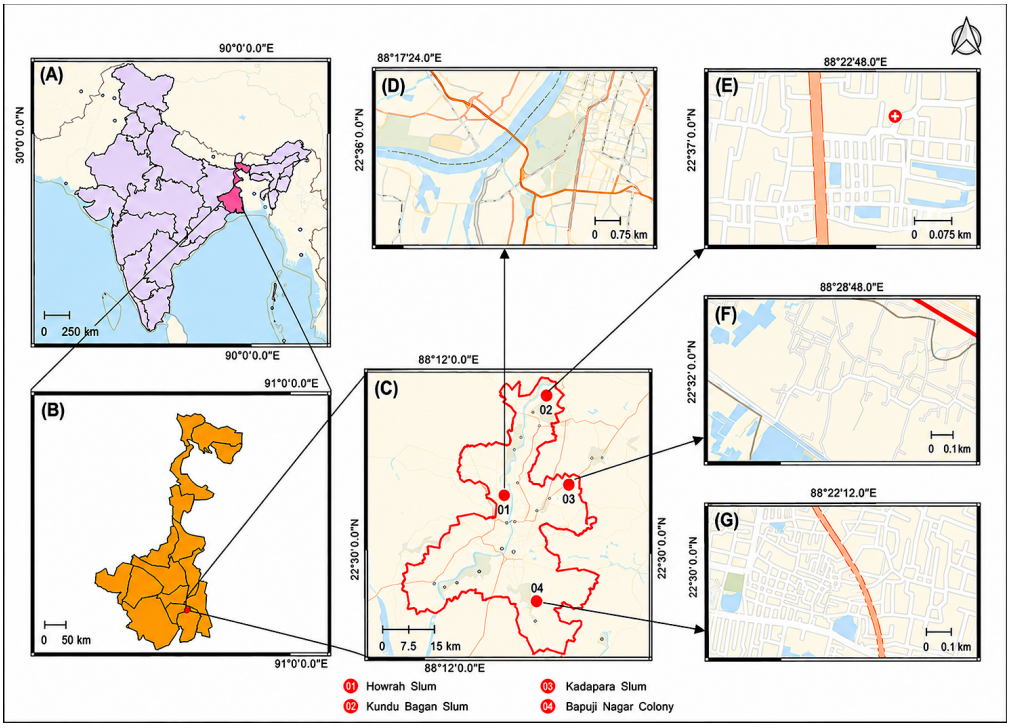


Figure 1: Location of the Study Area and Selected Informal Settlements in the Kolkata Metropolitan Area. (A) India, (B) West Bengal, (C) Kolkata Metropolitan Area (KMA), (D) Howrah Slum, (E) Kundu Bagan Slum, (F) Kadapara Slum, (G) Bapuji Nagar Colony

Methodology

Research Design

This study adopted a convergent mixed-methods case study design to investigate sustainability conditions within informal settlements in the Kolkata Metropolitan Area. The case study approach is well suited for examining complex socio-spatial phenomena within real-life urban contexts (52). Combining quantitative and qualitative methods enabled both measurable comparison across settlements and deeper interpretation of residents lived experiences. The study is grounded in principles of urban informality and participatory urbanism, recognizing that conventional development metrics often overlook the realities of slum communities.

In the convergent mixed-methods design, quantitative and qualitative data were collected simultaneously, analyzed separately and integrated during interpretation. Quantitative household surveys enabled comparative assessment of sustainability indicators across settlements, while qualitative interviews and field observations provided explanatory insights into the social, environmental and institutional dynamics underlying observed patterns. The research followed a comparative cross-sectional design involving four geographically distributed informal settlements in Kolkata: Kundu Bagan (North), Bapuji Nagar (South), Ganges Bank (West) and Kadapara Samity (East). The selection of sites ensured representation of diverse socio-spatial and environmental conditions within the metropolitan region.

Quantitative survey data were analyzed using descriptive and inferential statistical techniques. Descriptive statistics, including means, percentages and frequency distributions, were used to summarize socio-economic and environmental conditions across settlements. To evaluate whether observed differences between settlements were statistically significant, one-way Analysis of Variance (ANOVA) tests were conducted for selected continuous and perception-based indicators, including household income,

perceived sustainability scores, environmental comfort and access to services. Statistical significance was evaluated at a 95% confidence level ($p < 0.05$). The inferential analysis strengthened the assessment of intra-urban disparities and validated cross-settlement comparisons. A structured sustainability assessment framework guided the methodology by integrating environmental, economic, social, infrastructural and spatial dimensions was shown in Table 1. The framework was informed by established urban sustainability literature and aligned conceptually with the United Nations Sustainable Development Goals (SDGs), particularly SDGs 3, 6, 10 and 11.

Table 1: Dimensions and Indicators Used in the Sustainability Assessment Framework for Evaluating Urban Slum Settlements

Dimension	Indicators	Related SDG
Environmental	Ventilation, air quality, exposure to flooding/waterlogging, waste management	SDG 3, SDG 6, SDG 11
Economic	Household income, employment type, rent/ownership status, asset ownership	SDG 1, SDG 8, SDG 10
Social	Education levels, gender participation, community networks, safety perception	SDG 4, SDG 5, SDG 11
Infrastructure	Access to water, sanitation, electricity, roads and public services	SDG 6, SDG 9, SDG 11
Spatial/Locational	Proximity to job hubs, schools, transport and healthcare	SDG 11

Table 1 presents the multidimensional sustainability assessment framework adopted in this study. The framework integrates environmental, economic, social, infrastructural and spatial indicators to capture the complex conditions of informal settlements. Each dimension was linked with relevant Sustainable Development Goals (SDGs) to ensure conceptual alignment with global urban sustainability objectives. The selected indicators enabled comparative assessment across the four surveyed settlements.

To improve methodological transparency, all sustainability indicators were operationally defined prior to field investigation. The framework incorporated both objective and subjective indicators to capture the multidimensional nature of sustainability in informal settlements. Objective indicators included measurable variables such as household income, dwelling type, room size, sanitation access, electricity connectivity and school attendance. Subjective indicators captured residents' perceptions and lived experiences, including perceived safety, environmental comfort, affordability and satisfaction with services.

Perception-based indicators were assessed using a 5-point Likert scale ranging from 1 (very poor/very unsafe/not satisfied) to 5 (very good/very safe/highly satisfied). The inclusion of subjective indicators was considered important because sustainability in informal settlements is shaped not only by material conditions but also by residents lived experiences, coping strategies and perceived quality of life.

The study adopted a non-weighted comparative sustainability assessment framework in which all five dimensions—environmental, economic, social, infrastructural and spatial—were treated with equal analytical importance. No numerical weighting coefficients were assigned because the research aimed to provide an exploratory and context-sensitive comparison across settlements rather than develop a composite sustainability index. This equal-weight approach is widely used in exploratory urban sustainability assessments where dimensions are highly interdependent and context specific.

Sampling and Data Collection

The overall methodological workflow adopted in this study is illustrated in Figure 2, which outlines the integration of the convergent mixed-methods research design, household surveys, stakeholder interviews and field observations used for the sustainability assessment of informal settlements. A purposive sampling strategy combined with systematic household selection was employed to identify survey participants across the four settlements. Due to the absence of reliable household databases, informal settlement mapping, or standardized addressing systems, probability-based random sampling was not feasible. Households were therefore selected to

ensure representation across key socio-economic and spatial characteristics, including tenure status, gender, occupational diversity, housing typology and length of residence. Surveyors followed systematic walking routes and approached households at regular spatial intervals to reduce clustering bias and improve spatial coverage within each settlement.

A total of 160 households were surveyed, comprising 40 households from each settlement. Equal sample allocation enabled balanced comparative analysis across settlements with differing infrastructural, environmental and socio-economic conditions. The sample size was also informed by logistical feasibility, accessibility constraints and precedents from similar neighbourhood-scale mixed-method studies conducted in informal urban environments. Women constituted at least 40% of respondents in each settlement to improve gender representation in perception-based indicators such as safety, sanitation and environmental comfort. Key survey questions assessed dwelling quality, sanitation access, frequency of water supply interruptions, exposure to seasonal flooding, ventilation sufficiency, environmental comfort, perceived well-being and housing affordability. Respondents were additionally asked to evaluate current living conditions using a 5-point Likert scale. To supplement the survey data, 20 semi-structured interviews were conducted with community leaders, ward representatives, NGO workers, sanitation volunteers, informal service providers and long-term residents. These interviews provided contextual insights into settlement histories, infrastructure challenges, informal governance systems and redevelopment aspirations. All interviews were conducted in Bengali and Hindi by researchers familiar with the local socio-cultural context. Interviews were audio-recorded with participant consent and subsequently translated into English during transcription for thematic coding and qualitative analysis. To improve translation reliability and preserve contextual meaning, translated transcripts were cross-checked by bilingual researchers familiar with both the local languages and research objectives. Selected excerpts were additionally verified against original audio recordings to minimize translation-related distortion.

Systematic field observations were conducted between March and June 2025 using transect walk methods to document housing typologies, drainage conditions, waste accumulation, community spaces and road accessibility. Geotagged photographs and sketch maps were also prepared to support spatial interpretation. A transect walk method was used to document environmental and infrastructural conditions such as housing typologies, open drainage, waste accumulation, community spaces and road access. Geotagged photos were captured and sketch maps of each site were prepared to visualize internal layouts.

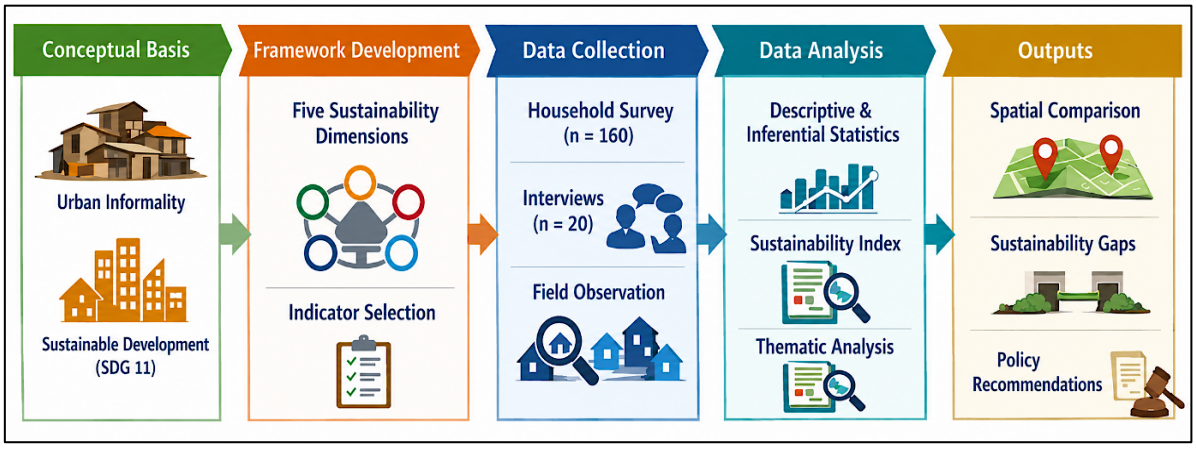


Figure 2: Conceptual Framework Outlining the Research Methodology for the Urban Informality Study

Figure 2 illustrates the overall methodological workflow adopted in the study. The framework integrates quantitative household surveys, qualitative stakeholder interviews, field observations and spatial analysis within a convergent mixed-methods design. The approach enabled triangulation of findings and strengthened the reliability of the comparative sustainability assessment across the four settlements.

Integration of Mixed-Methods Findings

Integration of qualitative and quantitative findings was achieved through triangulation during interpretation and discussion. Quantitative results identified patterns and disparities across settlements, while qualitative evidence was used to explain, validate and contextualize these findings. For example, lower sanitation satisfaction and environmental comfort scores in Ganges Bank were supported by interview narratives describing recurrent flooding, inadequate drainage and weak municipal service provision. Similarly, higher sustainability perceptions in Kadapara Samity were reinforced through qualitative accounts highlighting NGO support, improved accessibility and stronger community organization. This integration enhanced the reliability and interpretive depth of the sustainability assessment.

Although the sampling strategy enabled diverse representation within each settlement, the study acknowledges limitations associated with purposive and non-probability sampling approaches. Certain socially marginalized or highly transient populations may have been underrepresented due to accessibility constraints and willingness to participate. Therefore, the findings should not be interpreted as statistically representative of all slum settlements in Kolkata or India, but rather as analytically transferable insights into contrasting informal settlement typologies within the Kolkata Metropolitan Area.

Results

This section presents the primary findings from the field survey and interview data, categorized under key sustainability dimensions: environmental, economic, social, infrastructural and spatial. Qualitative observations and interview narratives were used throughout the analysis to contextualize quantitative findings and explain variations observed across settlements. Quantitative data from 160 household surveys were statistically analyzed and qualitative insights were synthesized from 20 semi-structured interviews and field observations. The comparative approach enables a nuanced understanding of spatial inequalities and localized

sustainability deficits across the four selected slum settlements: Kundu Bagan (North), Bapuji Nagar (South), Ganges Bank (West) and Kadapara Samity (East). The surveyed households reflected the socio-economic diversity of the selected informal settlements. The average household size among respondents was 5.2 members, while reported monthly household incomes ranged from ₹3,000 to ₹12,000. Occupationally, 58% of respondents were engaged in informal labor, 17% in domestic work, 12% were self-employed and 13% were unemployed. Educational attainment remained limited, with 22% of respondents being illiterate, 37% having completed primary education and 41% reaching secondary education level. In terms of tenure, 71% of respondents were informal occupants without formal property rights, while 29% were renters or temporary license holders.

Clear spatial differences emerge across the four settlements. Kadapara Samity consistently demonstrates the most favorable sustainability conditions, particularly in infrastructure provision, social indicators and environmental quality. In contrast, Ganges Bank exhibits the most severe deficits, especially in sanitation, flooding exposure and financial inclusion. Kundu Bagan and Bapuji Nagar occupy an intermediate position, displaying moderate performance but persistent vulnerabilities related to housing quality, space adequacy and safety.

To examine whether differences observed across settlements were statistically meaningful, one-way ANOVA tests were conducted on selected sustainability indicators. The analysis revealed statistically significant differences in composite perceived sustainability scores across the four settlements ($p < 0.001$), indicating that variations in living conditions are unlikely to be attributable to random fluctuation alone. Significant differences were also observed in average household income, environmental comfort perception, sanitation satisfaction and access to basic services. Kadapara Samity consistently recorded significantly higher mean scores across multiple sustainability dimensions, while Ganges Bank exhibited significantly lower scores in environmental and infrastructural indicators. These findings provide quantitative evidence supporting the existence of substantial intra-urban disparities within Kolkata's informal settlements.

Housing and Physical Infrastructure

Housing typologies across the sites vary considerably in terms of material quality, durability and internal space availability. As shown in Table 2, Kundu Bagan and Ganges Bank

exhibited the highest percentages of kutcha structures (64% and 58% respectively), while Kadapara Samity showed a significant proportion (51%) of semi-pucca housing, attributed to recent NGO interventions and proximity to formal residential zones.

Table 2: Comparative Housing Characteristics Across Four Slum Settlements in Kolkata, Including Percentages of Housing Types (Kutcha, Semi-Pucca, Pucca), Average Room Sizes in Square Feet and the Proportion of Households with Electricity Access

Slum Area	% Kutcha	% Semi-Pucca	% Pucca	Avg. Room Size (sq. ft.)	% Households With Electricity
Kundu Bagan	64	28	8	95	72
Bapuji Nagar	49	42	9	110	80
Ganges Bank	58	36	6	90	65
Kadapara Samity	29	51	20	130	93

Note: % = percentage, sq. ft. = square feet.

In terms of basic services, Kadapara outperformed other sites, with 85% access to piped water and 70% sanitation coverage. In contrast, Ganges Bank reported the lowest indicators, with over 40% of households relying on shared open latrines and manually collected water, reinforcing exposure to waterborne illness risks. As illustrated in Figure 3, substantial variation exists in the housing and infrastructure conditions across the surveyed settlements. Kadapara Samity demonstrates the most robust infrastructure, with larger average room sizes (130 sq. ft.) and 93% of households having electricity access. In contrast, Ganges Bank and Kundu Bagan show elevated levels of kutcha housing and lag behind in basic service provision, underscoring spatial inequality within Kolkata's urban poor communities.

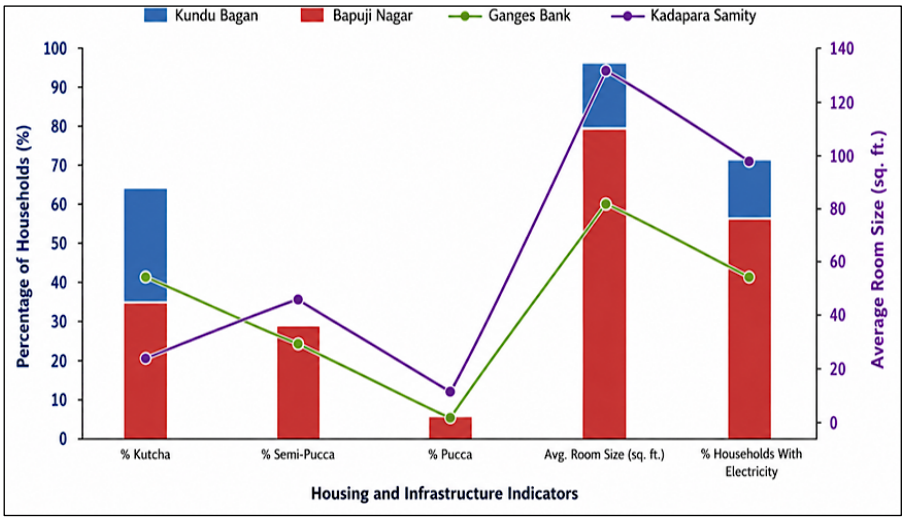


Figure 3: Comparative Chart Displaying Housing Typology and Physical Infrastructure Indicators Across Four Slum Settlements in Kolkata

Economic Conditions and Livelihoods

The Household income levels were generally low across all sites, with Bapuji Nagar and Kundu Bagan exhibiting the highest income instability due to a concentration of casual labor. As seen in Table 3, the mean monthly household income ranged from ₹4,800 at Ganges Bank to ₹7,100 at Kadapara Samity. A significant portion of the residents (43%) across sites reported engaging in more than one informal occupation to sustain household needs.

Table 3: Economic Indicators Across Four Slum Settlements in Kolkata, Including Average Monthly Household Income, Employment in the Informal Sector, Female Participation in Income Generation and Financial Inclusion Through Bank Account Access

Slum Area	Avg. Monthly Income (INR)	% Employed in Informal Sector	% Women in Income Generation	% With Bank Account
Kundu Bagan	₹ 5,200	91	28	64
Bapuji Nagar	₹ 5,500	88	34	71
Ganges Bank	₹ 4,800	96	21	59
Kadapara Samity	₹ 7,100	83	39	79

Despite higher income levels, Kadapara households also reported greater expenditure pressures due to inflated rents and service payments. Conversely, Ganges Bank lags significantly across all dimensions, with the lowest average income (₹4,800), the highest rate of informal employment (96%) and limited financial connectivity, reflecting deeper economic precarity in this cluster.

The scatter plot illustrates in Figure 4 is a clear positive association between average monthly household income and the percentage of households with bank accounts across the four studied slum settlements. Kadapara Samity, with the highest average income (₹7,100), also reports the greatest financial inclusion, with 79% of households having access to formal banking. Conversely, Ganges Bank lags behind both economically and financially, with an average income of ₹4,800 and only 59% of households maintaining a bank account. This trend underscores the pivotal role of income security in fostering financial participation, which in turn may influence long-term housing stability and access to credit for home improvements or entrepreneurship (60).

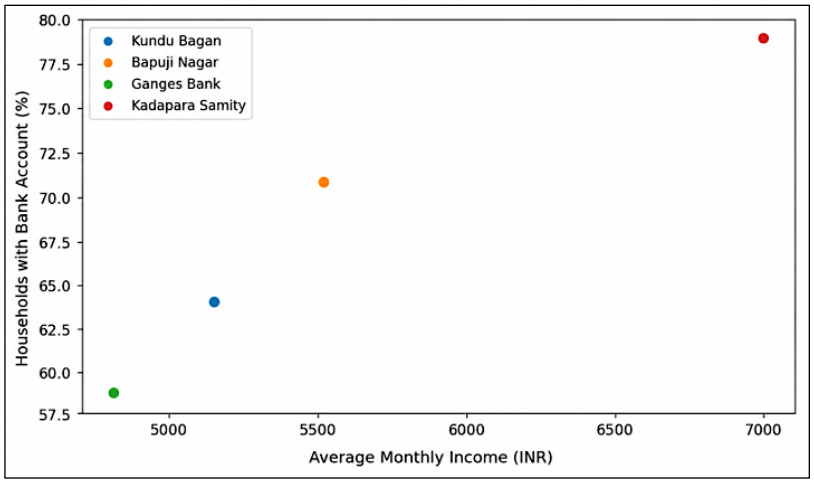
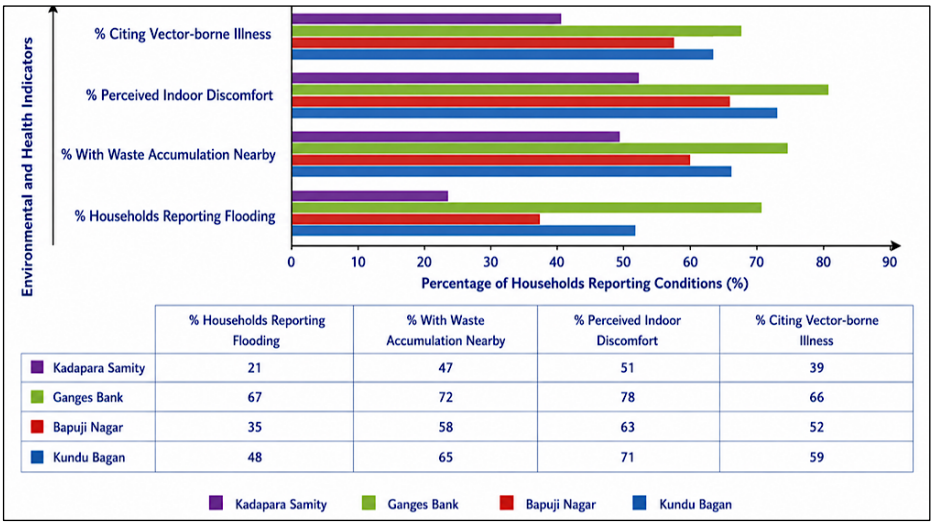


Figure 4: A Plot Illustrating the Relationship Between Average Monthly Income and Financial Inclusion (Measured by Access to Bank Accounts). It Reveals That While Kadapara Shows Both High Income and Inclusion, Ganges Bank Remains Below Average on Both Dimensions

Environmental Conditions and Health Perception

Environmental stress was a recurring theme across all settlements, though the nature of exposure varied. Residents of Ganges Bank reported high vulnerability to flooding and waterlogging during monsoon months. More than 76% of respondents across all sites complained of poor ventilation and rising indoor temperatures, particularly in structures with asbestos roofing.

Figure 5 highlights the significant variation in environmental vulnerabilities and health perceptions among the surveyed settlements. Ganges Bank emerges as the most environmentally stressed cluster, with 67% of households reporting seasonal flooding, 72% identifying nearby waste accumulation and 78% citing indoor discomfort. In contrast, Kadapara Samity exhibits comparatively improved environmental outcomes, particularly with lower reports of flooding (21%) and illness (39%), aligning with its superior housing and infrastructure quality discussed earlier.



	% Households Reporting Flooding	% With Waste Accumulation Nearby	% Perceived Indoor Discomfort	% Citing Vector-borne Illness
Kadapara Samity	21	47	51	39
Ganges Bank	67	72	78	66
Bapuji Nagar	35	58	63	52
Kundu Bagan	48	65	71	59

Figure 5: Environmental and Health Perception Indicators Across Four Slum Settlements in Kolkata. The Chart Presents Data on Households Reporting Seasonal Flooding, Nearby Waste Accumulation, Perceived Indoor Discomfort and Incidence of Vector-borne Illness

Residents in Kadapara Samity reported the lowest levels of perceived environmental stress, attributed to relatively wider roads, occasional garbage removal services and some availability of shaded spaces.

Social indicators such as education levels, community cohesion and access to public spaces varied notably across the settlements. Kadapara Samity displayed better access to community-run educational centers and parks, while Kundu Bagan and Ganges Bank exhibited more fragmented service delivery. As shown in Figure 6, social well-being and access to education vary significantly across the settlements. Kadapara Samity leads in all indicators, with 74% of adults being literate, 88% of children attending school and 77% of households reporting a sense of neighborhood safety. In contrast, Ganges Bank exhibits low scores in both social and educational access, with only 9% of households having access to play-grounds and just 48% feeling safe in their locality. These disparities underscore the need for spatially targeted interventions to promote inclusive urban development.

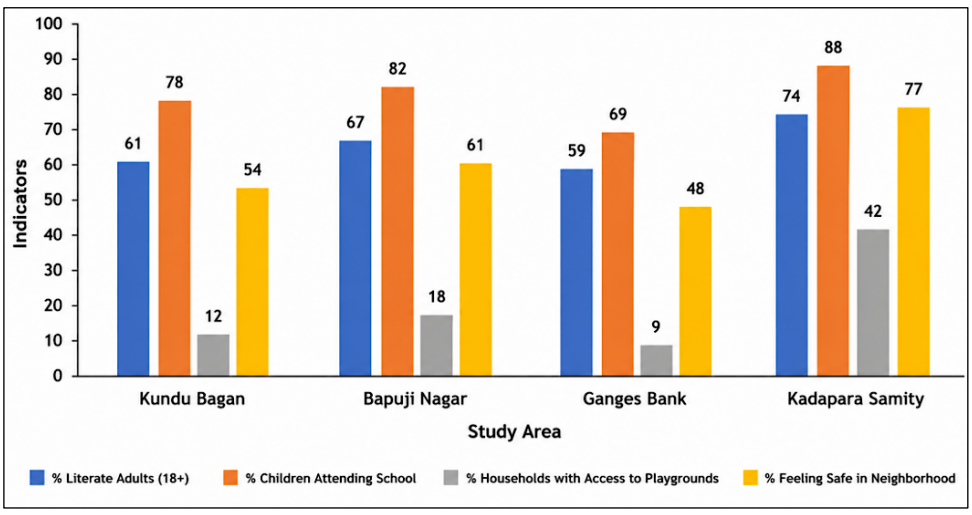


Figure 6: Comparative Chart of Social and Educational Indicators Across Four Slum Settlements in Kolkata. Metrics Include Adult Literacy, School Attendance Among Children, Access to Recreational Spaces and Perceived Neighborhood Safety

Qualitative responses showed that safety concerns and absence of recreational spaces in Ganges Bank restricted women's and children's mobility. Bapuji Nagar, despite better schooling access, still lagged in adolescent retention rates due to early entry into informal labor.

Perception of Sustainability and Redevelopment Aspirations

Respondents were asked how sustainable they felt their current housing conditions were across six criteria: affordability, safety, sanitation, space, access to services and environmental comfort. Responses were coded using a 5-point Likert scale, where 1 represented 'very poor/not sustainable' and 5 represented 'very good/highly sustainable'. Mean scores were calculated to compare perceived sustainability conditions across settlements. The average scores are summarized in the Figure 7.

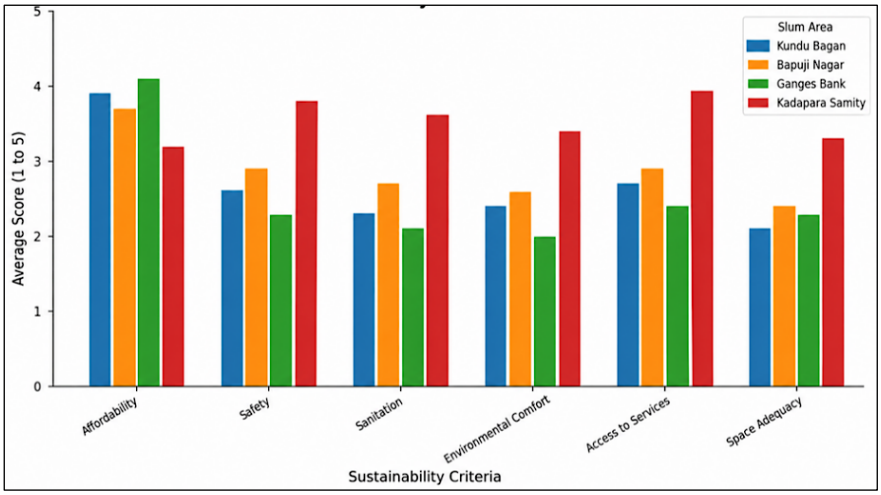


Figure 7: Comparative Bar Chart Illustrating Average Resident Ratings (Scale 1 To 5) on Key Sustainability Criteria—Affordability, Safety, Sanitation, Environmental Comfort, Access to Services and Space Adequacy—Across Four Slum Sites in Kolkata

Kadapara scored highest in perceived sustainability across all domains except affordability, where higher rents due to improved services were viewed as burdensome. Conversely, Ganges Bank scored the lowest, with respondents expressing despair about lack of drainage, waste buildup and exposure to flooding.

Perceived sustainability ratings reveal important trade-offs between affordability and living conditions. Ganges Bank records the highest affordability score (mean = 4.1) but simultaneously exhibits the lowest scores for sanitation (2.1), environmental comfort (2.0) and overall sustainability. Kadapara Samity records the highest sustainability ratings across most dimensions but is perceived as less affordable due to rising rents associated with service improvements.

The sustainability heatmap reveals significant spatial disparities in perceived livability across the four slum settlements based on six key criteria: affordability, safety, sanitation, environmental comfort, access to services and space shown in Figure 8. Ganges Bank, despite scoring highest on affordability (4.1), performs poorly in all other dimensions, particularly sanitation (2.1) and environmental comfort (2.0) that indicating a trade-off between low housing cost and quality of life. In contrast, Kadapara Samity emerges as the most balanced and sustainable settlement, achieving the highest ratings in safety (3.8), sanitation (3.6) and access to services (3.9). Kundu Bagan and Bapuji Nagar fall in the mid-range but remain below optimal thresholds in critical categories such as safety and space. These findings underscore the need for differentiated intervention strategies tailored to the distinct vulnerabilities of each locality.

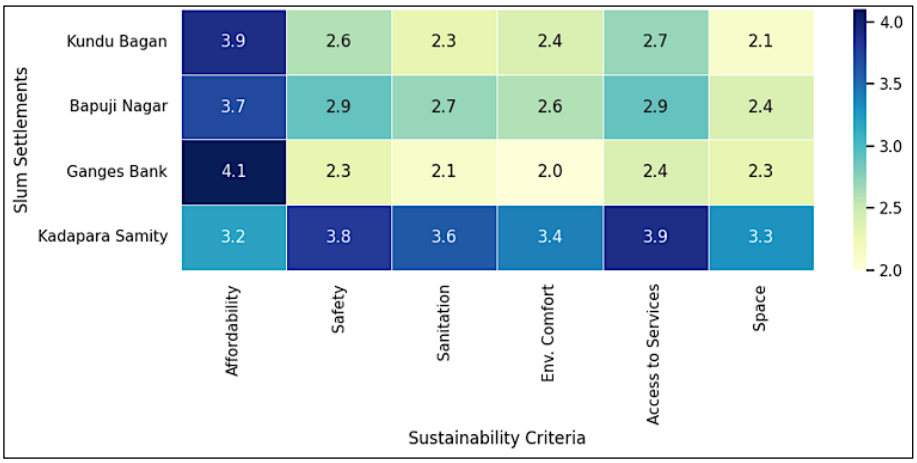


Figure 8: A Heatmap Showing Comparative Scores Across Six Sustainability Criteria for the Four Slum Settlements. This Enables Quick Identification of Performance Gaps (e.g., Kadapara's Strength in Access and Safety; Ganges Bank's Consistent Underperformance)

Across all four settlements, residents express strong preference for in-situ redevelopment over relocation. More than 70% of respondents indicated willingness to accept vertical housing provided that tenure security, affordability and access to basic services are ensured.

The observed sustainability disparities across the four settlements are shaped by the interaction between broader systemic urban inequalities and settlement-specific locational conditions. Figure 9 presents a conceptual framework illustrating how structural determinants such as insecure tenure, weak governance and informal labor dependence interact with locational factors including flood exposure, connectivity and proximity to employment centers to influence sustainability outcomes in informal settlements.

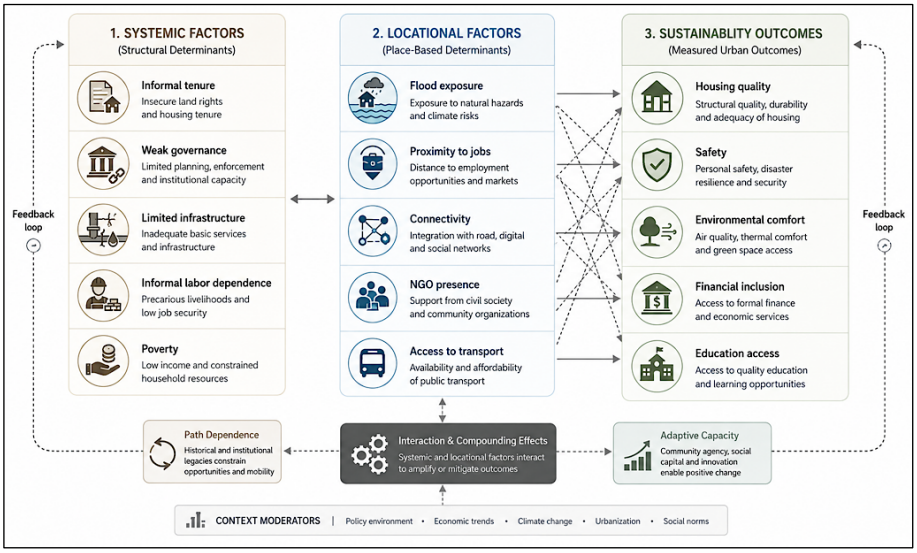


Figure 9: Drivers of Sustainability Disparities in Informal Settlements

Conceptual framework illustrating how systemic factors (e.g., informal tenure, governance limitations, infrastructure deficits and poverty) interact with locational conditions (e.g., flood exposure, transport access and proximity to employment) to shape sustainability outcomes such as housing quality, safety, environmental comfort, financial inclusion and educational access across urban informal settlements.

Discussion

This section interprets the empirical findings through the lens of sustainable development for urban slum settlements, highlighting divergences across the four study sites and engaging with broader literature and policy debates. It builds on five key sustainability domains, physical infrastructure, livelihood security, environmental

exposure, social well-being and perceived livability—to generate insights for urban planning frameworks aimed at the urban poor. The findings reveal that objective and subjective sustainability indicators do not always align directly, highlighting the complex trade-offs embedded within informal settlement life. For example, Ganges Bank demonstrated severe infrastructural and environmental deficits according to objective indicators such as sanitation coverage, flood exposure and housing quality, yet residents reported relatively high affordability perceptions due to low rental costs and proximity to informal employment opportunities. Conversely, Kadapara Samity exhibited stronger objective sustainability performance through improved infrastructure, electricity access and environmental conditions, but affordability perceptions were comparatively lower because of increasing rents and service costs. These contrasts demonstrate that sustainability in informal settlements cannot be understood solely through physical or economic metrics; residents' perceptions provide critical insight into how urban inequalities are experienced and negotiated in everyday life.

Spatial Inequality in Physical Infrastructure

A critical outcome of the field data was the stark contrast in housing quality and infrastructure availability between Kadapara Samity and the other three sites. For instance, while 51% of houses in Kadapara were semi-pucca or pucca structures, only 8% in Kundu Bagan and 6% in Ganges Bank achieved similar status. This disparity is partly due to Kadapara's adjacency to the Eastern Metropolitan Bypass and its exposure to urban development spillovers from Salt Lake and Sector V business districts.

In contrast, residents in Ganges Bank reported that many structures are constructed with salvaged tin sheets and bamboo with no legal electricity connection. In addition to narrow lanes and ad hoc layouts, only 65% of Kundu Bagan residents had household electricity and 48% reported that their dwellings lacked natural ventilation. These findings resonate with (12), who emphasizes that spatial marginality often correlates with state neglect and infrastructural exclusion, reinforcing generational poverty traps in slums (61).

Further, the average room size in Ganges Bank (90 sq. ft.) and Kundu Bagan (95 sq. ft.) fell below WHO-recommended thresholds for healthy occupancy per capita. Residents reported overcrowding, with a household of 6–7 members frequently sharing one multipurpose room. This over-congestion not only compromises privacy and mental health (62) but also exacerbates transmission of respiratory infections, especially among children and the elderly.

Livelihood Insecurity and Economic Vulnerability

Despite physical hardship, the resilience of slum communities lies in their adaptive economic strategies. All settlements showed high dependency on informal employment, ranging from 83% in Kadapara to 96% in Ganges Bank. Ganges Bank in particular houses many coolies, flower vendors, ferry workers and loaders due to its proximity to Howrah Station and Mallick Ghat. However, these income sources are precarious, subject to seasonal and daily volatility.

Bapuji Nagar showed relatively stable employment in household services and handcrafts, partially supported by community self-help groups (SHGs). Meanwhile, Kadapara demonstrated the highest proportion of dual-income households and women's economic participation (39%), aided by flexible work in roadside food stalls and caregiver services to Salt Lake residents. Gendered access to livelihood opportunities has been identified as an important component of sustainability in informal settlements.

Access to financial tools also varied. Only 59% of Ganges Bank households had bank accounts, compared to 79% in Kadapara, indicating disparities in financial inclusion. Interviews revealed that lack of documentation and transient addresses often deter formal enrolment. This financial invisibility further isolates the urban poor from state subsidies and formal credit schemes, a problem documented in other study (63).

Environmental Exposure and Climate Vulnerability

Environmental stress was among the most commonly reported hardships, particularly in flood-prone and poorly ventilated settlements. At Ganges Bank, 67% of respondents reported annual monsoon flooding, with stagnant water persisting for days. More than 72% lived within 50 meters of waste dumps or open drains, creating significant health hazards. Residents reported regular

outbreaks of dengue and diarrheal illness, especially among children.

Kundu Bagan, though less prone to flooding, suffers from extremely poor sanitation. With shared toilets and unpaved lanes, 65% of respondents cited poor drainage and waterlogging as regular issues. Air quality was also a concern, especially during summer months, with asbestos roofing materials exacerbating indoor heat exposure. These findings confirm research by past research (64, 65), which link slum morphology to higher urban heat stress and poor thermal comfort. These findings are further supported by recent studies highlighting that inadequate environmental infrastructure and climate-sensitive planning exacerbate vulnerability in informal settlements (66, 67).

Comparatively, Kadapara's better planning layout and NGO-facilitated solid waste management have improved its environmental scores. Only 21% reported flooding and 39% reported illness from mosquitoes or unclean surroundings. While this represents progress, interviews suggested that the improved environment came at a cost: many residents face rising informal rents and crowding due to inward migration.

Social Infrastructure and Educational Disparity

Educational access was one of the most unevenly distributed indicators across sites. While 88% of children in Kadapara were enrolled in school, only 69% in Ganges Bank attended regularly. This was attributed to poor connectivity, lack of nearby schools and income pressures forcing early entry into labor markets. Moreover, only 12% of Kundu Bagan residents reported access to playgrounds or safe community spaces, while Kadapara benefited from a community-built park and part-time tuition centers.

Community safety and cohesion were similarly differentiated. In Bapuji Nagar, historical settlement by refugee families from East Bengal fostered social bonds and local leadership, which aided collective efforts to access services. In contrast, Howrah's Ganges Bank showed signs of fragmentation and distrust, with only 48% reporting they felt safe in their neighborhood. These findings reinforce (59) work on the role of social capital in determining slum sustainability beyond material conditions.

Integrated Perception of Sustainability and Trade-offs

Across all sites, residents expressed nuanced understandings of sustainability—often balancing affordability, legality and environmental quality. The perceived sustainability matrix revealed that although Ganges Bank had the highest affordability score (4.1), it had the lowest sustainability score (2.3), indicating severe trade-offs. Conversely, Kadapara Samity had high sustainability scores across infrastructure, safety and services but was perceived as less affordable (3.2), likely due to increased demand and speculation.

This trade-off (Figure 7) underscores a critical tension: improvements in living conditions often raise costs, threatening long-term affordability for low-income residents. Unless these upgrades are paired with protections such as rent controls, subsidies, or tenure security, they risk triggering gentrification—a concern well documented in (60).

The disparities observed across the four settlements are shaped by both systemic urban inequalities and site-specific locational conditions. Systemic determinants include insecure land tenure, uneven municipal investment, inadequate sanitation infrastructure, dependence on informal employment and exclusion from formal planning processes, which affect nearly all informal settlements to varying degrees. However, the severity and manifestation of these challenges differ according to each settlement's geographic location, environmental exposure and degree of integration with the formal urban economy. For instance, Kadapara Samity benefits from proximity to the Eastern Metropolitan Bypass and Salt Lake Sector V, one of Kolkata's major employment and service hubs. This locational advantage enhances access to livelihood opportunities, transportation networks, educational institutions and municipal services, while also attracting NGO-led upgrading initiatives. In contrast, Ganges Bank's riverside location exposes residents to recurrent flooding, drainage congestion and environmental degradation. Its concentration of highly informal and seasonal labor further contributes to economic precarity and limited financial inclusion.

Similarly, Kundu Bagan's dense morphology and non-notified settlement status restrict access to formal infrastructure investments, while Bapuji Nagar demonstrates intermediate conditions

shaped by its historical evolution as a refugee colony with relatively stronger social cohesion but limited spatial expansion capacity. These findings suggest that sustainability disparities are not solely the result of household-level poverty but are deeply embedded in broader patterns of urban spatial inequality, environmental vulnerability and institutional exclusion.

Policy Implications and Strategic Pathways

The findings of this study have direct implications for urban housing policy and planning in India, especially in the context of growing political commitments to "Housing for All" and Smart Cities initiatives. The diversity of slum typologies and sustainability outcomes across Kolkata's urban poor settlements calls for a multi-scalar, multi-sectoral and participatory approach to slum redevelopment.

Across all four sites, residents showed a clear preference for in-situ redevelopment with tenure security and incremental improvements rather than forced relocations to distant sites. This echoes national policy shifts seen in the Pradhan Mantri Awas Yojana (PMAY), which now encourages in-situ slum redevelopment (ISSR). However, field evidence suggests that implementation is weak without strong community participation and local governance support. Local municipal bodies must work with urban local bodies (ULBs), NGOs and community-based organizations (CBOs) to co-produce solutions.

Instead of generic redevelopment plans, slum-specific sustainability assessment tools, like the one developed in this study—can guide investments in infrastructure, service delivery and housing design. For instance, settlements like Ganges Bank may require immediate interventions in drainage and sanitation, while Kundu Bagan would benefit from structural housing upgrades and air circulation enhancements. Policy should prioritize context-sensitive indicators and phase-wise improvements tailored to each slum's unique profile.

The affordability–sustainability trade-off indicates that unregulated upgrading may inadvertently raise rents or land values, leading to market-driven exclusion. Governments must consider financial tools like targeted rental subsidies, cooperative housing models and cross-subsidization in redevelopment projects to keep housing affordable post-intervention. Policies must also legalize or formalize informal tenure where possible to unlock credit and investment opportunities without triggering displacement.

Findings show that sustainability is not only about built infrastructure but also access to education, healthcare, safety and collective space. Programs aimed at building human and social capital, community centers, school retention initiatives, health camps that should be integrated into slum renewal budgets. These investments yield long-term returns in economic mobility and gender empowerment.

Given that slum residents are highly exposed to environmental shocks like flooding and heatwaves, future housing programs should integrate climate-resilient design, plinth raising, green roofing and ventilation into construction norms. Urban development authorities must also adopt a watershed-based planning approach to ensure basic ecological services like drainage, solid waste management and safe water are embedded in urban expansion. The inferential statistical results reinforce that sustainability conditions are unevenly distributed across informal settlements and are shaped by locational advantage, infrastructural investment and socio-economic integration. The statistically significant disparities observed across settlements demonstrate that slum communities cannot be treated as homogeneous entities within urban policy frameworks.

This study is subject to certain limitations. The cross-sectional design captures conditions at a single point in time and does not account for seasonal or long-term changes. Additionally, reliance on self-reported data may introduce perception bias. While the sample size allows for meaningful comparative and exploratory analysis, the findings are not statistically generalizable to all informal settlements in Kolkata or other Indian cities. Informal settlements are highly heterogeneous in terms of tenure arrangements, governance structures, population mobility, infrastructure access and socio-economic composition. Therefore, the results should be interpreted as context-sensitive insights derived from selected case study settlements rather than universally representative outcomes.

Future research should adopt longitudinal approaches to examine post-upgrading outcomes and

explore the applicability of the sustainability assessment framework in peri-urban and rapidly expanding fringe settlements. The study acknowledges that translation of qualitative interviews from Bengali and Hindi into English may have resulted in minor loss of linguistic nuance or culturally embedded meanings. Although cross-checking procedures were adopted to maintain interpretive consistency, some contextual expressions may not translate perfectly across languages. However, because the qualitative analysis focused primarily on recurring themes and shared settlement experiences, the overall analytical interpretations are unlikely to have been substantially affected.

Conclusion

This study presents a comparative sustainability assessment of four informal settlements in the Kolkata Metropolitan Area—Kundu Bagan, Bapuji Nagar, Ganges Bank and Kadapara Samity—through the integration of quantitative household surveys (160 households), stakeholder interviews, field observations and spatial analysis. Adopting a convergent mixed-methods approach, the research examined sustainability conditions across five interrelated dimensions: environmental, economic, social, infrastructural and spatial. The findings reveal substantial intra-urban disparities in living conditions, infrastructure provision, environmental exposure and socio-economic well-being across the selected settlements.

Among the four settlements, Kadapara Samity demonstrated comparatively stronger sustainability performance due to its locational advantages, improved infrastructural access and greater integration with formal urban systems. The settlement recorded the highest electricity access (93%), largest average room size (130 sq. ft.), highest adult literacy (74%) and strongest female workforce participation (39%). Qualitative evidence further suggests that NGO involvement, improved transport connectivity and proximity to employment corridors near the Eastern Metropolitan Bypass and Salt Lake contributed to comparatively favorable outcomes. In contrast, Ganges Bank emerged as the most vulnerable settlement, characterized by low average household income (₹4,800), inadequate sanitation, recurrent flooding, weak financial inclusion and poor environmental conditions. Its riverside location, exposure to climate-related risks and dependence on precarious informal labor contribute to compounded sustainability deficits. Kundu Bagan and Bapuji Nagar exhibited intermediate conditions shaped by dense settlement morphology, infrastructure limitations and varying levels of social cohesion.

The study further demonstrates that sustainability disparities are shaped not only by household poverty but also by broader structural and locational determinants such as insecure tenure, uneven infrastructure provision, environmental exposure and access to employment and transport networks. Inferential statistical analysis confirmed that these differences across settlements were statistically significant. Importantly, the findings highlight the need to integrate both objective indicators (e.g., housing quality, income, sanitation access) and subjective perceptions (e.g., safety, affordability and environmental comfort) to better understand the lived realities of informal settlements. Residents across all sites strongly preferred in-situ redevelopment over relocation, emphasizing the importance of community-centered and context-sensitive planning approaches.

This study is subject to several limitations. The cross-sectional design captures conditions at a single point in time and may not fully reflect seasonal or long-term socio-spatial transformations within informal settlements. Additionally, the purposive sampling strategy and moderate sample size limit broader statistical generalizability beyond the selected case study sites. Future research should adopt longitudinal and comparative multi-city approaches to examine post-upgrading outcomes, climate resilience and evolving livelihood dynamics across different forms of urban informality. Expanding the framework to peri-urban and rapidly growing fringe settlements would further strengthen its applicability for inclusive urban planning.

Ultimately, the research argues for reframing informal settlements not as urban deficits, but as integral components of equitable and resilient urban development.

Abbreviations

ANOVA: Analysis of Variance, COVID-19: Coronavirus Disease 2019, GIS: Geographic Information System, GPS: Global Positioning System, ISBN: International Standard Book Number, KMA:

Kolkata Metropolitan Area, NGO: Non-Governmental Organization, UN-Habitat: United Nations Human Settlements Programme, WASH: Water, Sanitation and Hygiene, WHO: World Health Organization.

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Author Contributions

Nupur Banerjee: Conceptualization, Methodology, Writing—Original Draft Preparation, Writing—Review and Editing, Shailendra K Mandal: Investigation, Resources, Formal Analysis, Data Curation, Supervision. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

Authors declare no conflicts of interest.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of Artificial Intelligence (AI) Assistance

AI-assisted language tools were used only for language editing, grammar correction and formatting support during manuscript preparation. All content was reviewed and revised by the authors, who take full responsibility for the accuracy, originality and integrity of the work. No AI tools were used for data collection, analysis, interpretation, or generation of scientific results.

Ethics Approval

This study involved human participants through household surveys and interviews. Informed consent was obtained from all participants prior to data collection. No personal identifiers were recorded and the data were anonymized for analysis.

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