CPD Climate Compendium 2025

CENTRE FOR POLICY DIALOGUE

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Editor's Note on CPD Climate Compendium 2025

Dr Fahmida Khatun
Executive Director and Convenor of Climate Week
Centre for Policy Dialogue (CPD)

CPD Climate Week 2025: Bangladesh's First-Ever Climate Week

In 2025, the Centre for Policy Dialogue (CPD) organised CPD Climate Week 2025, the first-ever Climate Week in Bangladesh, under the theme "Transforming Ambition into Action." The initiative marked an important milestone in Bangladesh's climate discourse by establishing a comprehensive national platform to advance climate policy, research, innovation, and multi-stakeholder engagement. Held from 18–21 October 2025, CPD Climate Week was conceived in recognition of the urgent need to move beyond commitments towards practical, inclusive, and scalable climate action.

Bangladesh remains among the most vulnerable countries to the impacts of climate change, despite its internationally recognised achievements in disaster management, adaptation, and resilience. Rising climate-induced risks, including floods, cyclones, sea-level rise, salinity intrusion, and extreme weather events, continue to threaten livelihoods, food security, public health, and sustainable development.

Against this backdrop, CPD Climate Week 2025 sought to convene policymakers, researchers, development partners, civil society, the private sector, youth, and international experts to identify practical solutions to bridge the gap between climate ambition and implementation.

Climate Week 2025 was designed around several interrelated objectives. These included translating Nationally Determined Contributions (NDCs) and Sustainable Development Goals into concrete actions; promoting climate ambition through innovative finance, technology, and policy reforms; strengthening resilience across climate-sensitive sectors; advancing climate justice and inclusion, particularly for women, youth, and vulnerable communities; fostering partnerships among national and international stakeholders; showcasing innovative climate solutions; and nurturing the next generation of climate leaders.

The Climate Week programme featured a rich mix of high-level policy dialogues, research presentations, youth engagement, competitions, and innovation showcases. The International Conference, titled "A World Beyond Crisis: Climate Solutions That Work," hosted thematic roundtables on operationalising NDCs, climate and gender, carbon pricing and carbon markets, climate-smart agriculture and food security, climate finance and governance, and the relationship between climate change and external debt sustainability. Young scholars presented cutting-edge research on adaptation, mitigation, nature-based solutions, climate justice, green technologies, artificial intelligence for climate resilience, and climate finance.

Recognising that today's youth will shape tomorrow's climate agenda, CPD Climate Week devoted significant attention to youth participation. A dedicated Youth Climate Policy Dialogue enabled young leaders to deliberate on climate budgeting, fiscal policy, climate justice, and locally tailored adaptation strategies. The programme also featured a Climate Olympiad, a Climate Policy Case Competition, and an exhibition of green projects and innovations, encouraging young people to translate ideas into practical policy and technological solutions.

The outcomes extended well beyond the event itself. CPD Climate Week aimed to produce actionable policy recommendations, policy briefs, conference proceedings, innovation catalogues, stakeholder networks, and communication products to support evidence-based policymaking. More importantly, it sought to institutionalise an annual platform for climate dialogue, strengthen cross-sector collaboration, enhance youth leadership, increase public awareness, and reinforce Bangladesh's role as an active contributor to global climate governance.

CPD expresses its sincere appreciation to the Embassy of Denmark in Bangladesh for collaborating on this landmark initiative and for its unwavering commitment to sustainable development and global climate action. Denmark has long been recognised as a global leader in climate policy, renewable energy, and the green transition. Its partnership with CPD to organise Bangladesh's first-ever Climate Week reflects a shared commitment to fostering inclusive dialogue, evidence-based policymaking, innovation, and international cooperation to address one of humanity's greatest challenges. CPD deeply values this collaboration and looks forward to further strengthening the partnership in pursuit of a more resilient, sustainable, and climate-secure future for Bangladesh and the world.

Climate Week Compendium 2025

We are pleased to introduce the CPD Climate Compendium 2025, a collection of research papers that reflects our commitment to inspiring young students and early-career professionals to build evidence-based knowledge on climate change and sustainable development. We recognise that addressing climate challenges requires rigorous research, informed dialogue, and innovative ideas. By providing a platform for researchers and practitioners to share empirical findings and policy insights, CPD aims to support evidence-informed decision-making and promote effective climate action.

The papers in this compendium represent the very best of the research presented at CPD Climate Week 2025. The conference drew an overwhelming response from young researchers, with 315 paper abstracts submitted from across the country and beyond. Following a rigorous blind peer-review process, 54 papers were selected for presentation across six thematic streams. At the conclusion of the conference, one best paper from each thematic stream was recognised for its methodological rigour, analytical strength, originality, and policy relevance. These six award-winning papers were subsequently selected for publication in this compendium and underwent a further independent blind peer-review process to ensure the highest standards of academic quality. Through this publication, CPD seeks to recognise and encourage these promising young scholars while fostering a culture of rigorous, policy-relevant climate research that can contribute meaningfully to Bangladesh's sustainable development journey.

This collection brings together six articles that address a broad range of climate issues, including climate resilience, migration, public health, disaster risk reduction, nature-based solutions, green skills, the circular economy, and sustainable livelihoods. These articles highlight the multidisciplinary nature of climate research and the close links between environmental challenges and economic and social development. As nations advance their climate strategies, ongoing research and knowledge exchange will be vital to developing effective policies and practical solutions. We are committed to improving the quality of this publication and to fostering stronger collaboration among researchers, policymakers, and development practitioners.

We sincerely thank all the authors for their valuable contributions and appreciate the reviewers and the Editorial Staff for their dedication and support throughout the publication process. We look forward to collaborating with young students and early-career professionals to further develop the CPD Climate Compendium as a platform that advances climate knowledge and policy dialogue. We invite further submissions, feedback, and stakeholder engagement for CPD Climate Week to help build a more resilient and sustainable future.

Message

H.E. Mr Christian Brix Møller
Ambassador, Embassy of Denmark in Bangladesh

Climate change is no longer a challenge of the future-it is one of the defining realities of our time. For Bangladesh, one of the world's most climate-vulnerable countries, translating ambition into meaningful action is both an urgent necessity and a remarkable opportunity. Bangladesh has already demonstrated global leadership in resilience and adaptation, showing that innovation, determination and partnership can deliver real progress.

The Embassy of Denmark is pleased to have partnered with the Centre for Policy Dialogue (CPD) in organising Climate Week 2025. By bringing together policymakers, young researchers, development partners, the private sector, civil society, and young people, CPD has created a valuable platform for dialogue, collaboration, and evidence-based solutions to accelerate climate action.

This Climate Compendium is an important outcome of Climate Week 2025. It showcases high-quality research and fresh perspectives from young researchers in Bangladesh and beyond. By creating opportunities for young researchers to present their work, exchange ideas, and engage directly with policymakers and experts, CPD is helping to strengthen the vital connection between research and policy.

As part of Denmark's partnership with Bangladesh for sustainable prosperity, we have been promoting a green, inclusive, and resilient society. We believe that lasting climate solutions are built on strong partnerships, sound evidence, and collective action.

I warmly congratulate CPD, the contributing authors, reviewers, and everyone who made this publication possible. I hope this compendium will inspire further research, informed policy dialogue, and stronger collaboration as we work together to build a more resilient and sustainable future for Bangladesh and beyond.

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Safety Nets Effect on Climate Vulnerable Women's Health

Internally Migrated from Northern Part of Bangladesh

Nusanta Samayel Audri1[1]
Salma Akhter[2]

Abstract

This paper examines whether social safety nets improve the health and livelihood outcomes of climate-displaced women residing in three informal settlements in Dhaka (Korail, Kallyanpur, and City Colony) following migration from northern Bangladesh. Using a mixed-methods design, the study integrates a survey of 120 households (342 individuals) with focus group discussions, in-depth interviews, and key informant interviews. Quantitative findings indicate that receiving safety net support is significantly associated with improved post-migration employment transitions (OR = 2.54, $p \approx 0.0298$), suggesting a role in livelihood stabilisation. However, safety-net participation does not independently predict self-reported health once structural mediators are included. Instead, clinic accessibility emerges as the most robust determinant of health status ($OR \approx 3.34$, $p \approx 0.013$), with effects consistent across model specifications. Health vulnerability also varies significantly across displacement types ($p \approx 0.029$), with higher disease burden observed for drought- and food-insecurity-related displacement pathways. Qualitative evidence explains why nominal entitlements often fail to translate into effective health protection, highlighting barriers to documentation, local gatekeeping, informal fees, and reliance on community intermediaries. Grounded in the Social Determinants of Health framework, this study shows that women's vulnerability is structurally produced through displacement trajectories, institutional exclusion, and unequal healthcare access rather than resolved through transfers.

Keywords: Climate migration; social safety nets; women's health; urban slums; Bangladesh.

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1. Introduction

Climate change has intensified the frequency, duration, and severity of environmental hazards across many low-lying and densely populated countries, and Bangladesh is among the most affected. Recurrent river erosion, drought, floods, and erratic rainfall disproportionately impact rural communities in the northern districts of Kurigram, Gaibandha, Lalmonirhat, and Rangpur. These climate-related hazards are forcing large numbers of women, along with men, into patterns of involuntary internal migration. Like other populations affected by climate change who turn to migration when local conditions become unlivable, women in Bangladesh are increasingly leaving rural areas and moving to urban centers in search of safety, stability, and livelihood opportunities. Upon arriving in Dhaka, most settle in overcrowded informal settlements such as Korail, Kallyanpur, and City Colony, where their daily life is shaped by inadequate sanitation, insecure housing, and limited access to health or social services. For developing countries like Bangladesh, Social Safety Net Programmes (SSNPs) are non-contributory transfer mechanisms designed to reduce poverty and vulnerability among marginalised groups. Over several decades, Bangladesh has expanded a wide range of food-and cash-based SSNPs to improve welfare, support education, mitigate shocks, and address gendered vulnerabilities. Yet despite this comprehensive portfolio, the programmes' effective reach remains uneven. In 2010, roughly 24.6 per cent of households participated in SSNPs (World Bank, 2011), and women (particularly widowed, elderly, rural, or destitute women) continue to face disproportionate barriers. These slums are marked by insecure housing, inadequate sanitation, unsafe water, and limited access to health services, conditions that compound women's vulnerabilities across the life course from young adulthood to old age. Targeted government initiatives such as old-age allowances, widow allowances, and lactating mother support reflect attempts to address these disparities, but gaps in implementation and accessibility persist.

The terms *environmental migrant* and *climate migrant* are often used interchangeably in the literature, yet they reflect distinct analytical emphases. Environmental migration broadly refers to population movements driven by ecological degradation such as land scarcity, pollution, or ecosystem decline, whereas climate migration specifically denotes displacement caused by climate-related stressors, including floods, droughts, riverbank erosion, salinity intrusion, and extreme weather events (Black et al., 2011; IOM, 2014). This study adopts the term *climate-displaced internal migrants* to emphasise mobility directly linked to climate variability and climate-induced livelihood stress rather than generalised environmental change. By focusing on women displaced from northern Bangladesh due to drought, river erosion, and climate-related food insecurity, the research situates itself within the climate migration literature and examines health vulnerability as a climate-specific outcome shaped by displacement and urban resettlement processes. Against this backdrop, the central purpose of this study is to examine how access to social safety nets influences the health and well-being of climate-vulnerable women living in Dhaka's urban slums. This analysis is guided by the objective of assessing how women's physical and mental health outcomes are shaped by their engagement with SSNPs such as food aid, health cards, and age- or marital-status–based allowances. By situating women's experiences within specific slum environments, the study further seeks to clarify how living conditions, community networks, and exposure to urban precarity influence their ability to benefit from existing SSNPs. In reality, climate-affected women living in urban slums are frequently excluded from programmes intended to

support them. Despite a growing body of research on climate-induced migration and urban poverty, little empirical work examines how SSNPs influence the health outcomes of women migrants or how these programmes interact with the physical and social conditions of informal settlements. Much like the inconclusive findings in the environmental perception literature, where some communities accurately perceive climatic changes and others do not, existing research on social protection and migrant women's health remains fragmented, descriptive, and largely detached from the lived experiences of displaced women. Previous studies rarely stratify findings by age, migration history, slum environment, or social support availability. As a result, significant gaps remain in understanding how climate-displaced women navigate health risks, negotiate access to institutional support, and confront the structural constraints of life in informal urban settlements.

Methodologically, the study uses a convergent mixed-methods design to capture both patterned associations and lived experiences shaping women's health in Dhaka's slums. The quantitative component uses cross-sectional survey data to examine relationships among safety-net access, displacement type, clinic access, post-migration income, and self-reported morbidity. The qualitative component (In-Depth Interviews (IDIs), Focus Group Discussions (FGDs), Key Informant Interviews (KIIs) documents administrative exclusion, gendered labour precarity, and the informal networks through which women navigate aid and healthcare in contexts where formal eligibility often fails in practice. The study is primarily grounded in the Social Determinants of Health framework, with supporting insights from Marxist feminist political economy to interpret gendered livelihood insecurity and from social capital to explain network-mediated access to resources (WHO, 2008; Marmot, 2005; Federici, 2004; Fraser, 2016; Bourdieu, 1986; Putnam, 2000). Empirically, the analysis is organised around three questions: whether safety nets improve women's health and livelihood stability; whether displacement type shapes health vulnerability; and whether structural conditions such as clinic access, sanitation, and income mediate these outcomes. By focusing on climate-displaced women from northern regions living in urban informal settlements, this paper provides evidence directly relevant to the design of migrant-inclusive, gender-responsive social protection and urban health policies.

2. Literature Review

2.1. Climate Change, Internal Displacement, and the Study Context

Bangladesh is globally recognised as one of the most climate-vulnerable countries, ranking among the highest on the Long-Term Climate Risk Index due to recurrent floods, riverbank erosion, drought, salinity intrusion, and cyclones (Siddiqui & Billah, 2014). These environmental disruptions intensify livelihood insecurity, especially in northern districts such as Kurigram, Gaibandha, and Lalmonirhat, prompting large-scale internal displacement. Women constitute a disproportionately affected demographic, as climate shocks heighten their caregiving burdens, economic precarity, and exposure to gendered violence during and after migration (Khan et al., 2021). With diminished agricultural and household stability in their local areas, many climate-affected women relocate to urban centres, and particularly in Dhaka, to seek livelihood opportunities amidst environmental uncertainty. However, rural–urban migration often leads to settlement in informal urban areas such as Korail, Kallyanpur, and City Colony, where women encounter new layers of

vulnerability. These slums are characterised by extreme congestion, insecure housing, limited sanitation, unsafe water, and fragmented access to healthcare. While the Government of Bangladesh and NGOs operate numerous Social Safety Net Programmes (SSNPs), existing evidence suggests uneven access and weak outreach to climate-displaced women, especially those lacking identity documents, permanent addresses, or political inclusion (ActionAid Bangladesh, 2024). Despite the growing scale of climate-induced mobility, there remains limited empirical research on how these intersecting vulnerabilities affect health outcomes for migrant women in urban settings. This section synthesises the major strands of literature relevant to climate-induced displacement, urban slum health, gendered vulnerabilities, and the role of SSNPs. Then it identifies methodological and conceptual gaps that inform the purpose of this study.

2.2. Climate Change and Internal Displacement in Bangladesh

The link between climate change and internal displacement in Bangladesh is well established. Riverbank erosion, drought, and salinity intrusion continue to displace hundreds of thousands of households annually, significantly altering demographic patterns (Siddiqui & Billah, 2014). Forecasts indicate that by 2050, nearly 15 million people may be uprooted by climate change, making Bangladesh one of the world's most significant hotspots for climate migration. The literature agrees that climate-induced migration is rarely voluntary. Instead, it emerges from forced adaptation strategies among communities that have exhausted coping mechanisms. Research shows that slow-onset hazards, such as erosion, often produce cyclical displacement in northern Bangladesh, forcing families to relocate multiple times before settling in urban slums (Rabbani et al., 2015). This repeated uprooting erodes social networks, financial capital, and health security.

Studies document gender-specific burdens, including higher health risks, increased household responsibilities, and heightened social exclusion during migration journeys (Khan et al., 2021). Researchers note that climate shocks magnify patriarchal norms, narrowing women's livelihood options and restricting their access to healthcare, information, or institutional support. Despite strong evidence on rural climate displacement, very few studies examine how these disruptions translate into urban health disadvantages and unequal safety-net access among displaced women. Urban informal settlements in Dhaka host large numbers of climate migrants who confront precarious living conditions. Studies consistently show that overcrowding, insecure tenure, poor sanitation, and fragmented healthcare access drive significant health disparities among slum populations (Akhter et al., 2022). For migrant women, these challenges are compounded as gendered vulnerabilities intersect with displacement, socioeconomic disadvantage, and weak urban governance. Women in slums commonly engage in low-wage, irregular, and hazardous occupations such as domestic work, waste collection, or piece-rate garment labour while maintaining substantial unpaid household responsibilities. Research demonstrates that this dual burden severely restricts their time, autonomy, and health-seeking behaviour (Rabbani et al., 2015). Furthermore, studies highlight obstacles including financial constraints, harassment in public spaces, discriminatory treatment in health facilities, and misinformation about available services (Khan et al., 2021). Health problems among migrant women in slums include high prevalence of infectious diseases, malnutrition, chronic pain, reproductive health challenges, and severe mental health stressors linked to displacement trauma (Akhter

et al., 2022). Feminist urban studies argue that slum environments systematically reproduce gendered marginality by denying women safe mobility, health rights, and decision-making authority (Chindarkar, 2012). However, few studies disaggregate health outcomes by migration origin, age group, or access to services. This study addresses these gaps.

2.3. Social Safety Nets in Bangladesh: Potential and Persistent Exclusion

Bangladesh's social safety net system comprises over 100 programmes encompassing food transfers, cash allowances, employment-generation schemes, and health-related subsidies, serving as a central pillar of the country's poverty-reduction and social-protection strategy. These SSNPs play a crucial role in reducing vulnerability, smoothing income shocks, and enabling low-income populations to access essential services, particularly in contexts of economic stress and environmental risk. Core government-led programmes include the Old Age Allowance, Allowances for the Widow, Deserted and Destitute Women, Vulnerable Group Development (VGD), Vulnerable Group Feeding (VGF), and allowances for pregnant and lactating poor mothers, which primarily deliver food or cash support to women and other vulnerable groups (Begum et al., 2014; Rabbani et al., 2015). Empirical evidence suggests that well-designed safety nets can reduce food insecurity, improve health-seeking behaviour, and enhance household resilience against climate-related shocks (Begum et al., 2014). Barriers include a lack of documentation, political gatekeeping, geographic targeting that favours rural populations, bureaucratic complexity, and gender-blind eligibility criteria (ActionAid Bangladesh, 2024; Khan et al., 2021). Migrant households in urban slums often fall outside administrative registries, making it challenging to access old-age allowances, food cards, health cards, or maternal benefits even when eligible.

In the urban health sector, the Asian Development Bank–supported Urban Primary Health Care Project (UPHCP) represents the principal institutional mechanism for delivering basic health services to low-income urban residents, including slum populations. While the project is operational in city corporations, empirical evidence from this study and earlier policy evaluations indicates that UPHCP services are often experienced as fragmented, intermittently available, and difficult to access for informal migrants lacking permanent addresses or identity documentation, underscoring the absence of a migrant-inclusive urban health policy framework (Ministry of Local Government, 2020; ADB, 2022). As a result, climate-displaced women frequently remain excluded from routine preventive care, affordable medicines, and reproductive health services despite the formal existence of urban health infrastructure. Beyond conventional SSNPs, a growing body of climate–health and risk-protection initiatives has emerged that functions as complementary protection mechanisms. These include the Directorate General of Health Services' Climate & Health Innovation Hub, which documents and accelerates locally led adaptation strategies for climate-sensitive diseases, as well as donor- and NGO-led programmes that combine health outreach, climate-resilient livelihoods, freshwater access, and community-based service delivery in climate-affected communities (DGHS, 2021; ActionAid Bangladesh, 2023). At the same time, pilot microinsurance schemes and resilience funds have been introduced as adaptive tools to help buffer households against income and health shocks following climate-related events. However, existing studies caution that such financial tools may exacerbate economic stress when they are not integrated with broader health and social protection safeguards, particularly for women in informal labour markets (Begum et al., 2014).

Recent policy manuals and implementation reviews increasingly recognise these gaps and propose practical reforms. These include explicit urban inclusion of climate-displaced populations within SSNP beneficiary databases using relaxed eligibility criteria (including acceptance of informal addresses), digitalised and transparent beneficiary selection systems to reduce political capture and corruption, expansion of gender-sensitive food and income programmes such as VGD into urban slum contexts with complementary skills training and childcare support, and scaling up and reforming UPHCP to ensure affordable medicines and respectful service delivery (Ministry of Social Welfare, 2021; ADB, 2022). Additional recommendations emphasise targeted investment in slum water, sanitation, and housing upgrades, alignment of climate finance mechanisms such as the Bangladesh Climate Change Trust Fund (BCCTF) and Green Climate Fund (GCF) to address urban displacement explicitly and strengthened support for women's community-based networks as mechanisms for monitoring, accountability, and last-mile access to services. Together, these strands of ongoing work suggest that while Bangladesh possesses an extensive social protection architecture, its effectiveness for climate-displaced women in urban slums depends not only on programme expansion alone, but also on deliberate institutional redesign that reflects the realities of urban informality and climate-induced mobility. The current study contributes by empirically evaluating the health-related effects of SSNPs on an understudied population: northern-origin climate migrant women living in Dhaka's slums.

2.4. Gaps and Analytical Approach

Despite expanding research on climate-induced displacement and urban poverty in Bangladesh, three gaps remain. First, most evidence is rural-focused, offering limited insight into how climate displacement shapes health vulnerability for women after relocation into urban informal settlements. Second, the literature on social safety nets rarely tests whether programme access translates into measurable health differences for migrant women, particularly when access is shaped by documentation constraints, gatekeeping, and uneven service environments. Third, studies often rely on either descriptive quantitative profiles or qualitative narratives without integrating both to explain why programmes succeed for some households and fail for others. Addressing these gaps, the present study examines northern-origin climate-displaced women in three Dhaka slums using a convergent mixed-methods design. Analytically, the study is grounded in the Social Determinants of Health framework, treating health as structurally patterned by service access, living conditions, and economic insecurity, while drawing supporting insights from Marxist feminist political economy to interpret gendered livelihood precarity and from social capital to explain network-mediated access to aid and care (WHO, 2008; Marmot, 2005; Solar & Irwin, 2010; Federici, 2004; Fraser, 2016; Bourdieu, 1986; Putnam, 2000).

3. Theoretical and Conceptual Framework

3.1. Linking Theory to Methodology and Conceptual Framework

The theoretical framework informed both design and measurement (Table 1). Social Determinants of Health (SDH) guided the operationalisation of health vulnerability through structural indicators (clinic access, post-migration income, sanitation constraints,

and safety-net participation) and motivated the use of an adjusted logistic regression model rather than relying on multiple bivariate tests. Marxist feminist political economy shaped the qualitative emphasis on gendered labour precarity and unpaid care burdens that constrain health-seeking after displacement (Federici, 2004; Fraser, 2016). Social capital is treated as an access mechanism, informing attention to NGO intermediaries and community ties and supporting snowball recruitment for hard-to-reach migrant women (Bourdieu, 1986; Putnam, 2000). Together, these lenses align variable selection, sampling, and interpretation around the study's core claim: institutional support affects health only when structural access conditions allow women to convert nominal entitlements into usable care.

Table 1: Key Constructs and Variables of the Study

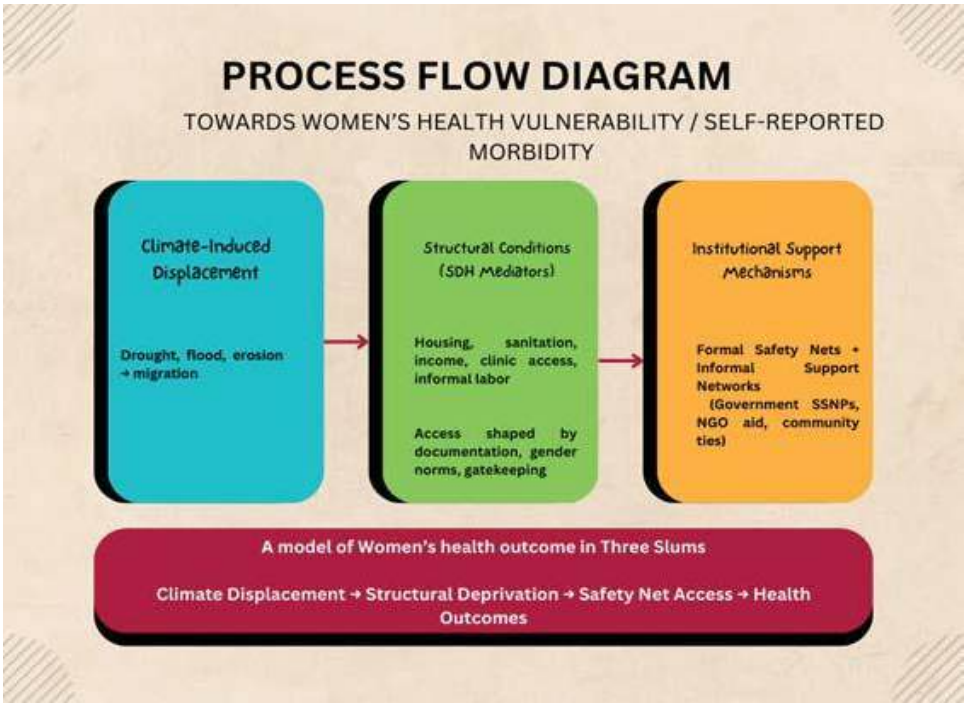
Construct Category	Variables	Operational Description
Independent Variables	Access to Social Safety Nets	Cash transfers, food aid, health assistance, old age or special allowances received from government or NGOs
	Type of Climate Displacement	Displacement due to drought, river erosion, or food insecurity in the place of origin
	Duration of Migration and Slum Location	Length of time since migration to Dhaka and current residence in Korail, Kallyanpur, or City Colony slum
Mediating Variables	Living Conditions	Housing quality, sanitation facilities, access to safe water, and level of overcrowding
	Economic Security	Income stability, employment type, and engagement in informal or formal labour
	Social Capital	Community networks, informal support systems, and reliance on neighbors, kin, or local leaders
Moderating Variables	Gender	Gendered roles and responsibilities shaping access to resources and health services
	Age Group	Early adulthood, middle age, and elderly stages affecting vulnerability and access
	Migration Status and Documentation	Presence or absence of formal documents influencing eligibility for services

Source: Authors' conceptualisation and operationalisation of variables based on survey design (N = 120 households) and theoretical frameworks including Social Determinants of Health, Marmot (2005), and Pierre Bourdieu (1986).

Note: Variables were constructed based on survey responses and aligned with the Social Determinants of Health framework to capture structural, mediating, and moderating influences on health outcomes.

This figure (Figure 1) simplified conceptual framework linking climate-induced displacement to women's self-reported morbidity through structural determinants of health and mediating institutional support mechanisms in three Dhaka slums. The diagram establishes that climate change has intensified internal displacement in Bangladesh and disproportionately affected women's health, yet significant analytical gaps remain.

Figure 1: Process Flow Diagram



Source: Authors' conceptual framework linking climate-induced displacement to women's health outcomes through structural determinants and institutional mechanisms, developed based on field data (N = 120 households) and Social Determinant of Health framework.

3.2. Formulated Hypotheses and Research Questions

Guided by the study's objectives and the conceptual framework derived from the literature, this research examines the health effects of social safety nets on climate-vulnerable women who have internally migrated from the northern part of Bangladesh to urban slums in Dhaka. The research questions and hypotheses are formulated to capture the relationships between climate-induced displacement, access to social safety nets, structural living conditions, and women's health outcomes.

Research Questions

To strengthen theoretical coherence and respond to concerns regarding fragmented hypothesis testing, the empirical analysis is organised around three core analytical questions:

Do social safety nets improve women's health outcomes and livelihood stability after climate displacement?

Does the type of climate displacement shape patterns of vulnerability in urban slum environments?

Do structural conditions such as clinic access, hygiene, and income mediate health inequalities among displaced women?

These questions allow the manuscript to foreground its central contribution: explaining how social protection interacts with structural exclusion rather than assuming uniform health benefits from programme receipt. This structure responds to concerns about fragmented hypothesis testing by foregrounding the paper's central contribution: explaining how social protection operates under conditions of structural exclusion rather than assuming uniform benefits from programme receipt. To retain continuity with the original study design, six hypotheses are reported, but the analysis prioritises the health and displacement mechanisms as the primary inferential focus. Secondary relationships (e.g., education–hygiene and employment transitions) are interpreted as supportive or exploratory evidence rather than parallel confirmatory tests, consistent with parsimonious inference in cross-sectional designs.

H1 (Safety Nets and Health Outcomes): Access to social safety nets is associated with women's reported health status after migration. Health outcomes are operationalised through self-reported disease frequency and a composite indicator of overall health vulnerability.

H2 (Safety Nets and Employment Outcomes): Safety-net participation is associated with improved employment transitions following displacement, reflecting the role of social protection in stabilising livelihoods.

H3 (Duration of Migration and Income): Length of time since migration influences women's post-migration income levels, capturing economic adaptation processes over displacement trajectories.

First three hypotheses are core ones and now the secondary exploratory hypotheses are below to strengthen the claim-

H4 (Education and Hygiene Outcomes): Women's educational attainment is associated with household hygiene practices, reflecting social gradient mechanisms emphasised within Social Determinant of Health theory.

H5 (Displacement Type and Socioeconomic Vulnerability): The form of climate-induced displacement shapes women's health burden and income vulnerability after relocation.

H6 (Aid, Income, and Health Outcomes): Receipt of institutional support is associated with both income security and health outcomes, though these relationships are examined primarily through multivariate models rather than isolated significance testing.

Quantitative analyses employ Fisher's Exact Tests for categorical associations with low expected cell counts, non-parametric rank-based tests for skewed income distributions, and parsimonious logistic regression models to estimate adjusted effects of safety-net access while accounting for clinic accessibility, income resources, and displacement categories. Throughout, results are interpreted as associational rather than causal, given the study's cross-sectional design and the complex institutional constraints shaping programme uptake within informal urban environments. Descriptive statistics on illness profiles, safety-net coverage, hygiene practices, and healthcare access are retained as essential contextual

evidence supporting the inferential results. In slum environments, characterised by overlapping deprivation, these descriptive patterns provide critical insight into the lived burden of disease and the institutional limits of protection mechanisms. To sum up, this analytical strategy enables the study to evaluate whether social protection meaningfully reduces health vulnerability among climate-displaced women, and under what structural conditions such benefits can be realised.

4. Research Methodology and Data

4.1. Research Design and Methodological Approach

This study employs a convergent parallel mixed-methods research design to examine the effects of social nets on the health vulnerability of climate migrant women internally settled to urban slums in Dhaka from the northern part of Bangladesh. This approach was selected due to the complex and multidimensional nature of the research problem, which involves structural, institutional, and lived-experience dimensions of health vulnerability. Quantitative and qualitative data were collected concurrently, analysed independently, and subsequently integrated at the interpretation stage to ensure methodological triangulation and analytical coherence. The quantitative component captures measurable patterns via

Figure 2: Maps and Locations of the Sampling Areas

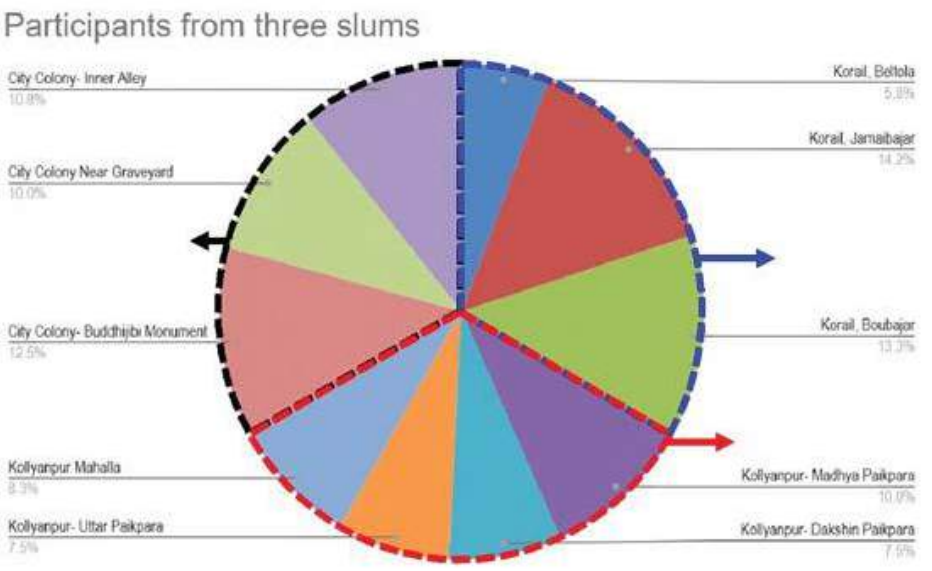
Source: Maps of Korail (Rahman et. al., 2025), City Colony and Kollyanpur slum's residential evidence.

cross-sectional household survey and statistically testable relationships between safety net access, displacement type, income, hygiene, and health outcomes. The qualitative component complements this by exploring women's lived experiences, perceptions of exclusion, coping strategies, and institutional access barriers, administrative exclusion, and everyday health insecurity through in-depth interviews and field narratives. This design strengthens internal validity and is interpreted as identifying associations rather than causal effects, consistent with observational public health research designs by allowing convergence, complementarity, and explanation across data sources.

4.2. Study Area, Population, and Sampling

The research was conducted in three major urban slums of Dhaka city, specifically in Korail Slum, Kollyanpur Pora Slum, and City Colony Slum (Figure 2). These sites were purposely selected due to their high concentration of internally displaced women from climate-affected northern districts of Bangladesh, including Kurigram, Gaibandha, Rangpur, Nilphamari, and Lalmonirhat; they use slums as initial shelters for free. Some people own these free shelters and offer tenants rents who are newcomers to these slums. The study population consists of climate-vulnerable women aged 20–70 years who migrated internally due to climate-induced stressors such as river erosion, drought, floods, and salinity intrusion and who have resided in the selected slums for at least five years. The focus on women reflects their disproportionate exposure to gendered health risks, caregiving burdens, and institutional exclusion in urban slum environments.

Figure 3: Location of Participants



Source: Authors' sampling design based on household population estimates from field mapping in Korail, Kollyanpur, and City Colony slums (2024), From Appendix A1: Table of Study population (4.2).

A multi-stage sampling strategy, combining probability and non-probability techniques, was adopted. First, a stratified random sampling approach was used to select 120 households: 40 from each slum. Stratification was based on sub-areas (Figure 3) within each slum to ensure proportional representation where the population of sub-areas of Korail (Beltola-2,274, Bou Bazar-5,059, Jamai Bazar-5,370), Kollyanpur (Dakshin Paikpara-950, Madhya Paikpara-1,000, Uttar Paikpara- 800, Kollyanpur Mahalla-950) and City Colony (Near Buddhijibi Monument-600, Near Graveyard-500, Inner Alley- 500). Here, household-level surveys covered 342 individuals, allowing cross-validation of health, income, and migration characteristics. Snowball sampling was then employed to recruit participants for qualitative data collection, given the absence of formal registries of climate migrants. Initial participants were identified through NGOs, community leaders, and health workers, who then referred to eligible respondents. This combined strategy ensured both statistical representativeness and depth of experiential insight.

4.3. Data Collection Methods and Instruments

Quantitative data were collected through a structured household survey administered face-to-face to selected respondents. The survey instrument gathered information on demographic characteristics, migration history, household income, occupational status, access to social safety nets, health conditions, disease frequency, and hygiene practices. Before full implementation, the questionnaire was pre-tested to ensure clarity, cultural appropriateness, and relevance to the study context. The structured format of the survey enabled systematic data collection across the three slum sites and facilitated comparative statistical analysis. Descriptive statistics were first used to summarise illness burden profiles, patterns of safety-net coverage gaps, and distribution of clinic accessibility. These descriptive findings provide epidemiological context and are reported separately in the Results section rather than framed as confirmatory hypothesis testing. For categorical associations, Fisher's Exact Test was applied due to small cell sizes and analysed using R software. However, following reviewer guidance, statistical inference was not interpreted solely through p-values. Instead, effect sizes and odds ratios were emphasised to ensure credibility and avoid overstating statistical strength in small samples. Even where associations appear statistically strong, findings are interpreted as correlational rather than causal, given the cross-sectional design. To consolidate the empirical contribution and reduce hypothesis proliferation, the primary quantitative evidence is anchored in a parsimonious multivariate logistic regression model:

$$\text{Good Health} = f(\text{Safety Net Access} + \text{Clinic Access} + \text{Income} + \text{Displacement Type})$$

This specification reflects the reviewer recommendation to prioritise one central explanatory model rather than multiple fragmented bivariate tests. This model includes clinic access, post-migration income, and displacement category because these represent core structural mediators emphasised within the Social Determinants of Health framework capturing how service infrastructure and economic insecurity shape realised health beyond nominal programme receipt. Given the cross-sectional design, coefficients are interpreted as adjusted associations rather than causal effects. Age group and slum location were examined as contextual controls, but the parsimonious specification is retained to avoid overfitting in a modest sample. Adjusted odds ratios (ORs) with 95 per cent confidence intervals are reported.

Qualitative data were collected using in-depth interviews, focus group discussions, and key informant interviews. These methods were employed to capture women lived experiences of displacement, health challenges, access to institutional support, and reliance on informal networks. All interviews and discussions (30 semi-structured interviews- 10 from each slum, 6 FGDs- 2 per each slum, 5 KIIs overall) were conducted in Bangla to ensure linguistic and cultural comfort for participants. With informed consent, the sessions were audio-recorded, transcribed verbatim, and translated into English for analysis. The qualitative tools were designed to complement the survey findings by providing narrative explanations for observed quantitative patterns. Qualitative data were analysed thematically following Braun and Clarke's six-phase framework, involving transcript familiarisation, systematic coding, theme development, refinement, and synthesis. Key themes included barriers to healthcare access, gender-specific vulnerability, administrative exclusion from formal safety nets, sanitation-related illness risks, and reliance on informal social support networks. Quantitative and qualitative findings were integrated through interpretive triangulation. Statistical patterns were contextualised with lived experience narratives, strengthening the explanatory power of the mixed-methods design and supporting the study's institutional argument that structural constraints mediate the health effectiveness of social protection.

To operationalise key variables, Safety-net participation was measured as a binary indicator capturing whether respondents reported receiving any form of government or NGO assistance, including food support, health-related aid, stipends, or allowances. Given the multidimensional nature of health vulnerability in slum contexts, outcomes were operationalised through complementary morbidity-based indicators rather than clinical diagnoses. Two key structural mediators were included in the analysis: post-migration household income (measured continuously in Bangladeshi Taka per month) and displacement type. Displacement was categorised into three groups such as- drought or crop-loss–induced migration, flood or riverbank erosion–related displacement, and other socially driven migration pathways. Respondents reported the number of illness occurrences experienced during the recall period. Respondents reported illness episodes during the past 3 months, and disease frequency was summed across reported episodes. A categorical morbidity indicator was constructed distinguishing higher illness burden (≥3 episodes) from lower burden (<3). To improve interpretability, a derived self-reported health status variable was created, classifying women as having good health (≤1 episode) versus moderate/poor health (≥2 episodes). This approach captures symptom-based vulnerability in contexts where clinical diagnoses are often unavailable. Positioning the illness measure within a short recall window therefore improves interpretability in informal settlements where health burdens are frequent and care seeking is irregular, while also permitting clear categorisation of higher vs lower morbidity burden for contingency and regression modelling. The revised operationalisation makes explicit (i) the recall horizon, (ii) that health is symptom-based/self-reported, and (iii) how multiple illness reports are handled (descriptive profiling by type vs frequency-based burden for modelling).

4.4. Limitations and Ethical Considerations

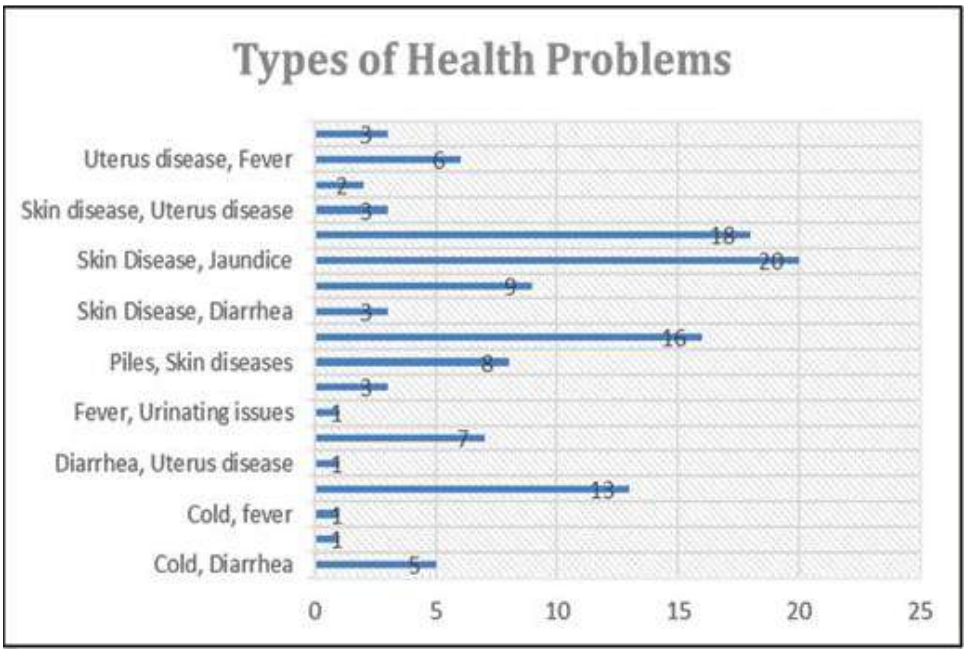
Several methodological limitations were recognised. Recalling and self-report bias remain possible given symptom-based health measures; however, triangulation across survey and qualitative narratives strengthened validity. Selection bias was minimised through stratified

random sampling in the quantitative component, while qualitative recruitment ensured inclusion of harder-to-reach migrant experiences.

Ethical principles of informed consent, confidentiality, and voluntary participation were strictly maintained. Participants were informed of their rights and anonymity protections throughout the research process. The methodology has been transparently described to ensure replicability and scholarly rigor in future climate-migration health research.

Figure 4: Displacement Drivers and Health Burden among

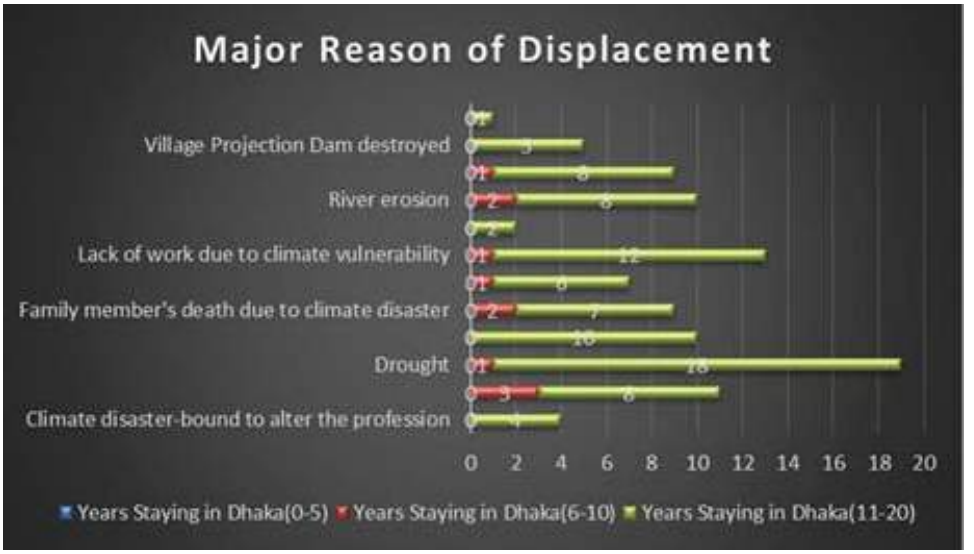
A) Types of Health Problem



(Figure 4 contd)

(Figure 4 contd)

B) Major Reasons for Displacement



Source: Authors' calculations and graphical representation based on primary survey data (N = 120 households); underlying data reported in Appendix Table A3 and A4.

Note: Panel A presents the distribution of self-reported health problems, while Panel B presents the primary climate-related drivers of displacement. The combined figure highlights the simultaneous burden of health risks and displacement pressures among climate-displaced women in the study areas.

5. Analysis and Findings

This chapter presents an integrated mixed-methods analysis to investigate how social safety nets, structural conditions, and displacement trajectories shape health outcomes among climate-displaced women in Dhaka's informal settlements. Guided by the Social Determinants of Health (SDH) framework and informed by Marxist feminist political economy, this chapter synthesises quantitative patterns from a household survey of 120 women with qualitative insights from in-depth interviews (IDIs), focus group discussions (FGDs), and key informant interviews (KIIs). Findings are organised around three core analytical questions: whether social safety nets improve women's health outcomes; the types of climate displacement that shape health vulnerability; and the structural conditions (sanitation, income, care burdens) that mediate these effects.

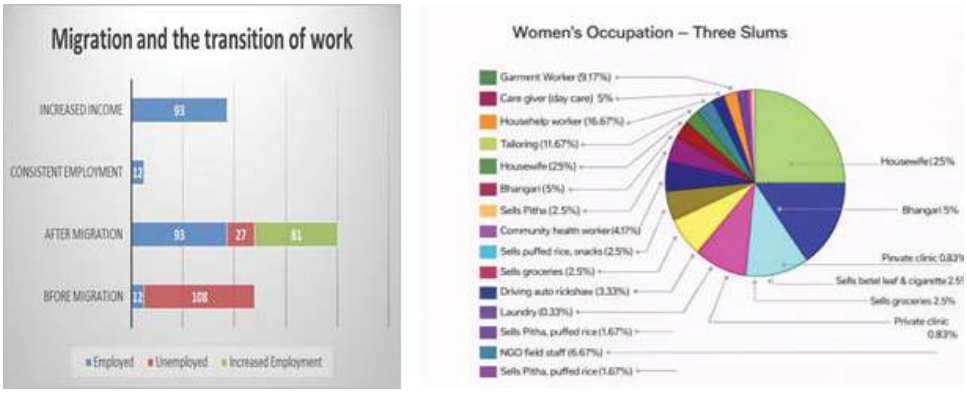
5.1 Descriptive Patterns of Health and Migration

Descriptive statistics reveal a high burden of illness across the sample (Figure 4). The most common self-reported conditions include skin diseases (63.3 per cent), fever (35.8 per cent), and reproductive health problems (26.7 per cent). Overcrowding, poor sanitation, and limited water access underlie many of these outcomes. Reproductive health issues are especially pronounced, reflecting gender-specific vulnerabilities exacerbated by urban poverty. At the same time, displacement patterns are primarily driven by climate-related

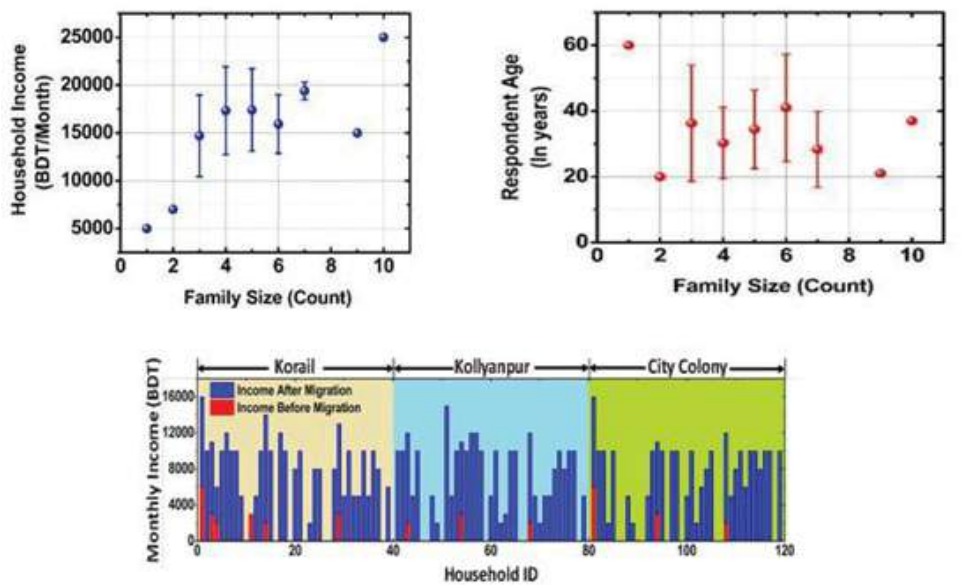
shocks, particularly drought, river erosion, and livelihood loss, indicating that environmental stressors remain central to migration into urban slums.

Figure 5: Migration, Occupational Transition, and Income Patterns among Climate-Displaced Women

A) Occupational Distribution after Migration



B) Household Monthly Income and Age-Based Variation

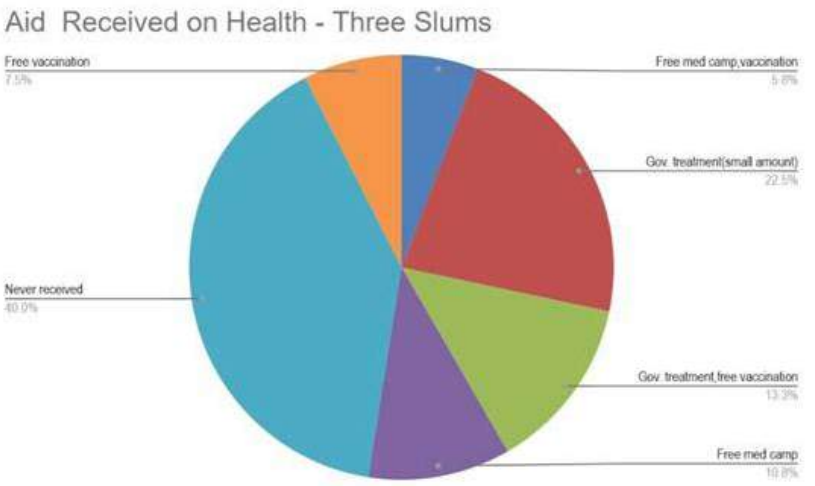


Source: Authors' calculations and graphical representation based on primary survey data (N = 120 households); underlying data reported in Appendix Tables B1, B2 and C1.

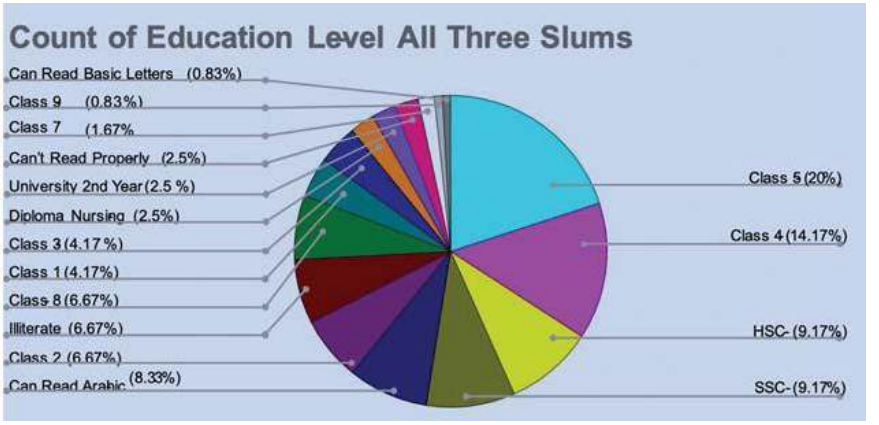
Note: Panel A presents the occupational distribution of respondents after migration, showing a concentration in informal and low-paid sectors such as domestic work, tailoring, and small-scale trading. Panel B presents variation in household monthly income across age groups and household structures, indicating modest but uneven income gains following migration. Together, the figure highlights the transition into precarious urban livelihoods and limited economic mobility among climate-displaced women.

Figure 6: Health Aid Access and Educational Attainment Among Climate-Displaced Women

A) Health-Related Aid Received from Government, NGOs, and Other Organisations



B) Educational Attainment Distribution across Respondents



Source: Authors' calculations and graphical representation based on primary survey data (N = 120 households); underlying data reported in Appendix Tables D, D4, E1.

Note: Panel A shows the distribution of health-related assistance received, including government treatment, NGO-provided services, free medical campaigns, and cases where no aid was received. Panel B presents the distribution of educational attainment among respondents, indicating low levels of formal education and high prevalence of limited literacy. The combined figure highlights structural gaps in both institutional support and human capital, which jointly constrain access to healthcare and social protection among climate-displaced women.

Migration into the slums brought a significant shift in labour force participation (Figure 5). Approximately 75 per cent of previously unemployed women entered the informal workforce post-migration, often in low-paid, insecure jobs. While this transition increased household income contributions, over 60 per cent of women remained in insecure, low-paid informal work. Income level showed a statistically significant association with hygiene conditions, indicating that economic capacity plays a role in maintaining household cleanliness and health-related practices. However, income gains were modest and unstable. Households with 4–5 and 6–7 members constitute most of the sample and report higher average monthly incomes (approximately BDT 17,000–17,400) compared to smaller households (≤3 members), which have substantially lower incomes. This pattern suggests that larger family sizes may be linked to increased income-earning capacity, likely due to multiple earners, although income gains appear to plateau rather than increase consistently with very large family sizes (8 or more members).

Despite policy rhetoric on safety nets, nearly 40 per cent of respondents reported never receiving any form of aid (Figure 6). Informal networks among neighbours, kin, and community intermediaries often filled institutional voids, though these mechanisms remained precarious and uneven. Furthermore, educational attainment was low; 20 per cent of respondents completed Class 5, with only 18 per cent reaching secondary education (SSC or HSC). Roughly one-third of respondents were either minimally literate or illiterate. These low education levels shaped knowledge about entitlements and limited navigational capacity in complex urban bureaucracies.

Table 2: Summary of Quantitative Associations (exploratory results)

Hypothesis	Relationship Tested	Statistical Result	Supported
H1	Safety Net → Good Health	OR = 0.73, p = 0.52	No
H1 (Alt)	Clinic Access → Good Health	OR = 3.34, p = 0.013	Yes
H2	Safety Net → Employment Improvement	OR = 2.54, p = 0.0298	Yes
H3	Migration Duration → Post-Migration Income	ρ = −0.035, p = 0.703; ANOVA p = 0.099	No
H4	Education → Hygiene Practices	Fisher p < 0.00001	Yes
H5	Displacement Type → Disease Frequency	ANOVA p = 0.0293	Yes
H6	Safety Net → Income Recovery	Wilcoxon p = 0.187	No

Source: Authors' statistical analysis based on primary survey data (N = 120 households), including logistic regression and bivariate tests; detailed results reported in Appendix tables E2 and E3.

The quantitative analysis provides a mixed picture of how safety nets, structural conditions, and displacement trajectories shape health and well-being among climate-displaced women (Table 2). Hypothesis 1 is not supported, as safety-net access was not significantly associated with self-reported good health (OR = 0.73, p = 0.52). However, an alternative pathway, such as clinic access emerged as statistically significant (OR =3.34, p = 0.013), highlighting the critical role of service infrastructure. Hypothesis 2 is supported: access to safety nets is significantly associated with improved employment outcomes, with recipients more than twice as likely to transition into employment post-migration (OR = 2.54, p = 0.0298). For Hypothesis 3, there was no significant correlation between migration duration and income (ρ = −0.035, p = 0.703), suggesting that time alone does not improve economic outcomes

in the context of urban precarity. Hypothesis 4 is supported, with strong associations between education and hygiene practices (Fisher $p < 0.00001$), although qualitative data indicate that structural barriers often limit the practical effects of education. Hypothesis 5 is supported, as type of climate displacement significantly affects disease frequency (ANOVA $p = 0.0293$), particularly among drought-affected migrants. While displacement type shows a significant association with disease frequency in bivariate analysis ($p \approx 0.029$), this effect is not statistically significant in the adjusted logistic regression model, suggesting that structural factors such as clinic access and income mediate observed differences in health outcomes. Finally, Hypothesis 6 is not supported: no significant difference was found between safety-net access and income recovery post-migration (Wilcoxon $p = 0.187$), implying that economic support is insufficient in the absence of broader structural change.

5.2. Do Social Safety Nets Improve Health?

5.2.1. Do Social Safety Nets Improve Health? (Hypothesis 1)

To evaluate the relationship between safety-net access and self-reported health, a binary outcome variable was constructed: 'good health' (≤1 illness episode) vs 'moderate/poor health' (≥2 episodes).

A logistic regression model tested whether safety-net participation predicted good health while controlling for post-migration income and clinic access:

Safety-net receipt: OR = 0.73, 95% CI: 0.27–1.89, p = 0.522 (not significant)

Clinic access: OR = 3.34, 95% CI: 1.30–8.88, p = 0.013 (significant)

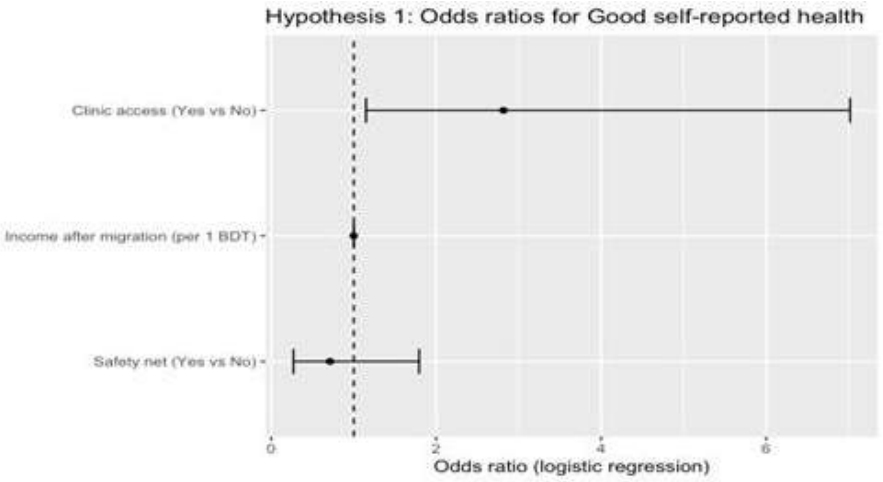
Post-migration income: marginal (p = 0.086)

A multivariate logistic regression model was estimated to examine the relationship between safety-net participation and good self-reported health, controlling for clinic access, income, and displacement type. Safety-net receipt was not significantly associated with good health outcomes (OR = 0.73, p = 0.522). In contrast, access to a nearby clinic was a strong and statistically significant predictor of good health (OR = 3.34, p = 0.013), indicating that individuals with clinic access were more than three times as likely to report good health. Post-migration income showed a marginal positive association (p = 0.086), while displacement type was not statistically significant. These findings suggest that structural healthcare access plays a more decisive role in shaping health outcomes than safety-net participation alone. These results suggest that access to nearby healthcare facilities is a stronger predictor of health outcomes than receipt of safety-net aid. Women with local clinic access were nearly 3 times more likely to report good health. Clinic accessibility consistently outperforms safety-net participation and displacement type as a predictor of health outcomes, indicating that access to healthcare infrastructure plays a more decisive role than programme receipt alone.

Qualitative interviews reinforced this finding (Figure 7). Many women described difficulty converting nominal safety-net access into tangible care. Bureaucratic requirements, hidden costs, and stigma often deterred timely treatment. One woman remarked, 'They say help is there, but without papers or connections, you're nobody'. Thus, while safety nets exist, they do not operate in isolation. Institutional design, delivery mechanisms, and infrastructural accessibility determine whether they reduce health risks in practice.

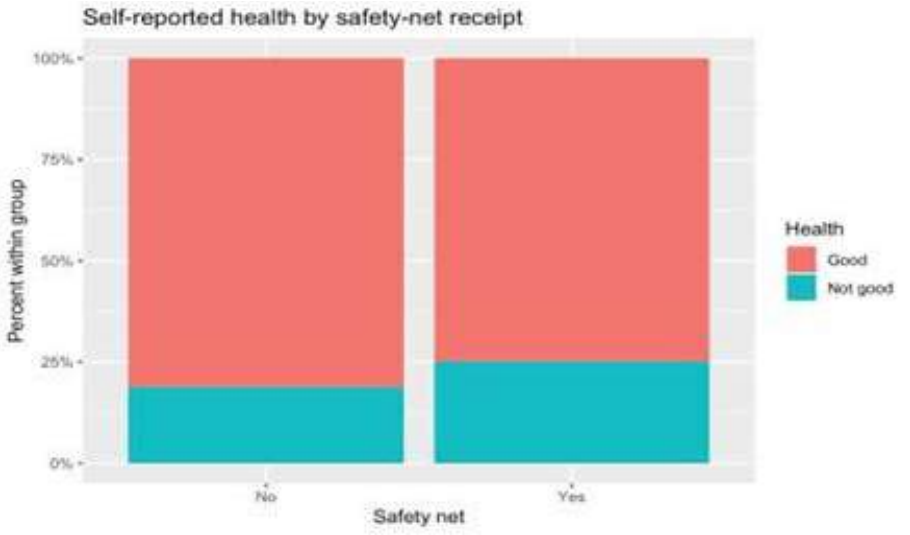
Figure 7: Safety Net Access and Health Outcomes (H1)

A) Distribution of Health Outcomes by Safety Net Access



(Figure 7 contd)

B) Logistic Regression Results for Health Outcomes



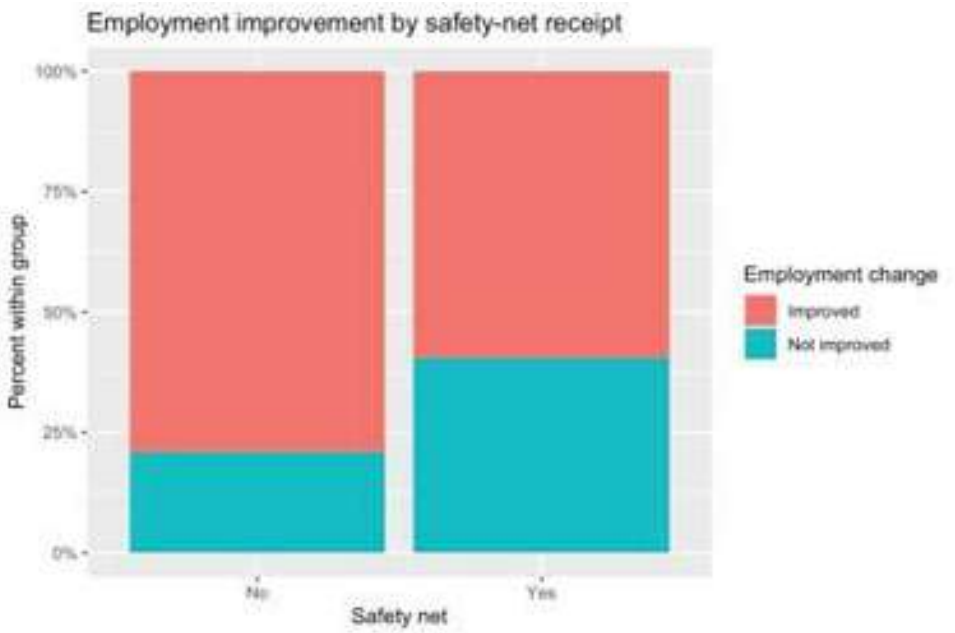
Source: Authors' statistical analysis based on primary survey data (N = 120 households); regression outputs reported in Appendix table E2.

Note: Panel A presents the distribution of self-reported health outcomes by safety-net participation. Panel B presents adjusted odds ratios from logistic regression estimating the association between safety-net access and health outcomes.

5.2.2. Do Safety Nets Promote Post-Migration Employment? (Hypothesis 2)

Hypothesis 2 evaluated whether receipt of social safety nets was associated with improved employment outcomes after migration (Figure 8). Employment improvement was defined as a transition from being unemployed before migration to being employed after arriving in Dhaka.

Figure 8: Association Between Safety Net Access and Employment Transition (H2)

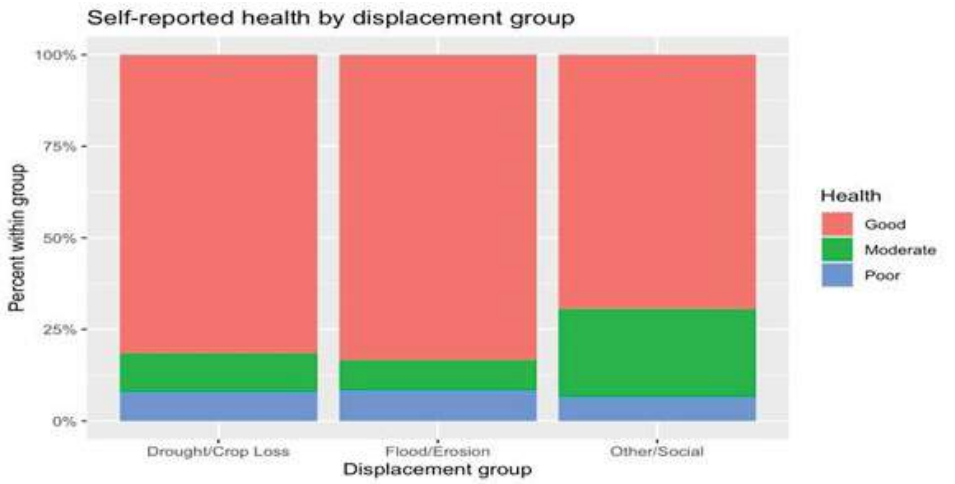


Source: Authors' statistical analysis (Fisher's Exact Test) based on primary survey data (N = 120 households), check table B1, B2, C1.

A Fisher's Exact Test indicated a statistically significant association between safety-net participation and employment improvement ($p = 0.0298$). Women who received safety-net support were more than twice as likely to transition into employment compared to non-recipients (OR = 2.54, 95% CI: 1.04–6.65). This finding contrasts with the results of Hypothesis 1, which found no significant association between safety-net access and health outcomes. Here, safety nets appear to have a more direct impact on economic recovery. This supports the interpretation that safety nets may serve as critical enablers of labour market re-entry by helping displaced women stabilise household finances through informal work, small business activities, or NGO-supported income programmes.

Qualitative accounts reinforce this mechanism. Respondents frequently described safety nets as more economically oriented than health oriented. As one woman noted: 'We got training and some help to start selling snacks, not money for doctors'. Another emphasised, 'It's easier to find work with help from the NGO auntie than to go to a hospital'. However, while these results are promising, they should be interpreted within the broader context

Figure 9: Displacement Type and Health Outcomes (H5)



Source: Authors' statistical analysis based on primary survey data of A3, A4 and D2(N = 120 households).

of structural constraints. Most women remained in low-wage, informal employment even after improvement often without labour protections, sick leave, or access to childcare. Thus, safety-net-supported employment should not be equated with long-term economic security. In sum, Hypothesis 2 is supported. Safety-net access is associated with improved post-migration employment, underscoring the potential of targeted economic support programmes. Yet, without deeper reforms to urban labour structures and care systems, these employment gains may remain fragile.

5.2.3. Does Displacement Type Affect Health Vulnerability? (Hypothesis 5)

An ANOVA test indicates that displacement pathway is associated with differential morbidity burden among climate-displaced women in Dhaka's slums (Figure 9). Disease frequency is higher among women displaced through drought and food insecurity compared with those displaced by flood or riverbank erosion ($p = 0.0293$). In contrast, post-migration income does not differ significantly by displacement type ($p = 0.48$), suggesting that health vulnerability varies by displacement pathway even when economic outcomes converge in informal urban labour markets. Qualitative narratives help interpret this pattern: women displaced by slow-onset livelihood decline described prolonged periods of food scarcity and cumulative stress prior to migration, with illness beginning before relocation and worsening under slum conditions characterised by overcrowding, heat exposure, and poor sanitation. Together, these findings challenge the assumption of uniform 'climate migrant' vulnerability and suggest that slow-onset displacement pathways may generate deeper, more persistent health risk after urban settlement.

5.2.4. Do Structural Conditions Mediate Health and Hygiene? (Hypotheses 3 and 4)

Hypothesis 3 examined whether length of urban residence was associated with higher post-migration income (Figure 10). Results showed no statistically significant relationship:

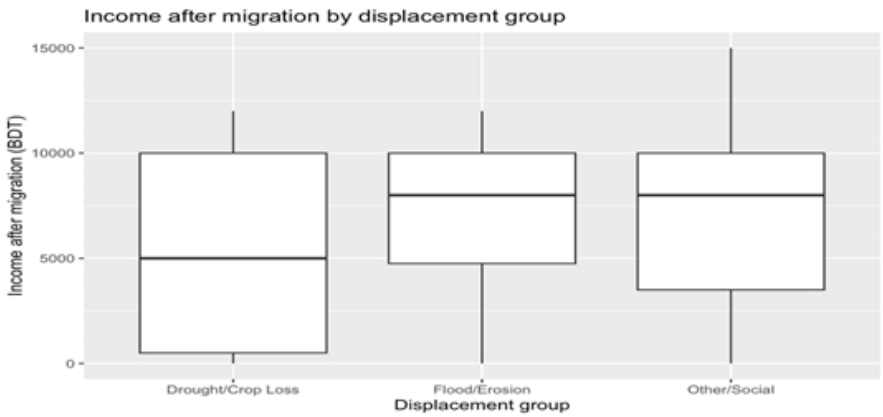
Spearman correlation: ρ = −0.035, p = 0.703

ANOVA: p = 0.099 (marginal at best)

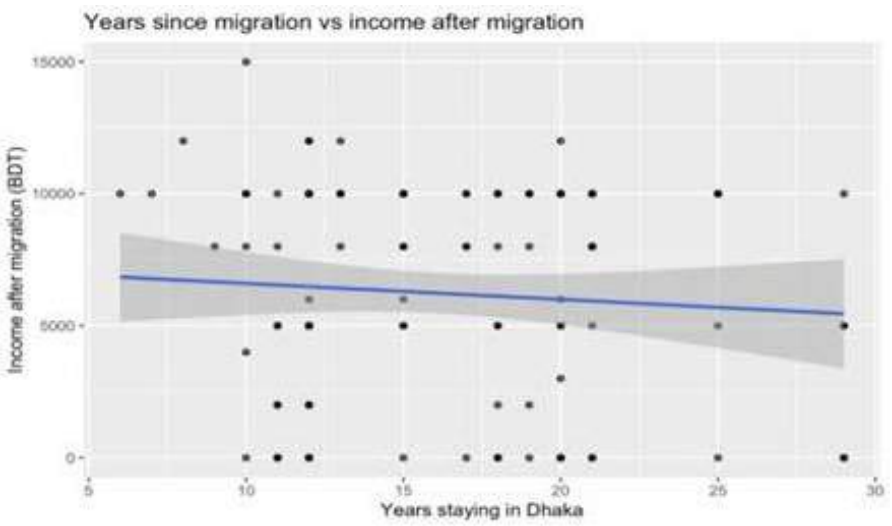
This suggests that structural constraints in informal labour markets, rather than time alone, limit economic advancement among climate-displaced women. As one respondent observed, 'No matter how long we stay, it's always the same work, the same struggle'.

Figure 10: Structural Determinants of Health and Hygiene Outcomes among Climate-Displaced Women (H3 & H4)

A) Association between Income and Health Outcomes

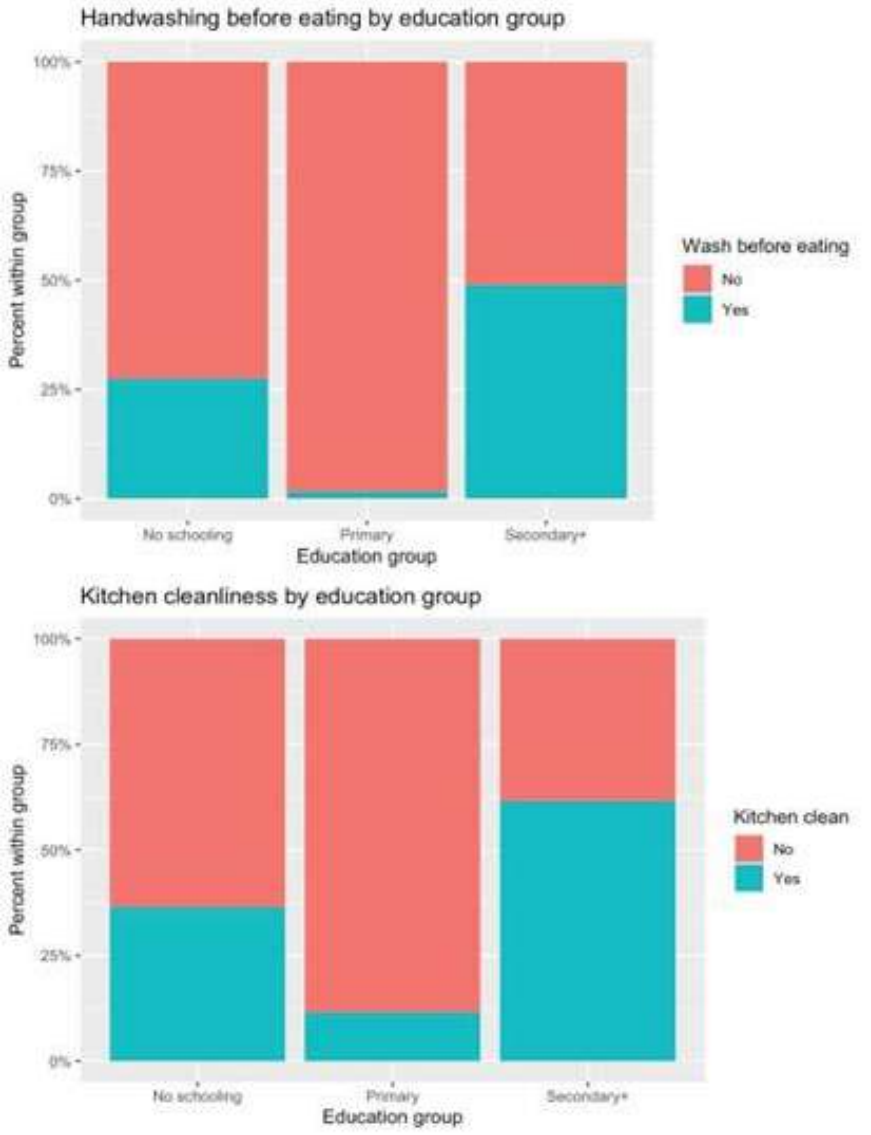


B) Effect of Migration Duration on Health Status



Hypothesis 3

C) Relationship between Educational Attainment and Hygiene Practices



Hypothesis 4

Source: Authors' statistical analysis (including regression estimates) based on primary survey data (N = 120 households); underlying data reported in Appendix Table D1, D2, D3.

Note: Panel A shows the relationship between household income and self-reported health outcomes, indicating that higher income levels are associated with improved health conditions. Panel B illustrates how duration since migration influences health status, with longer urban residence linked to modest improvements but persistent vulnerability. Panel C presents the association between education and hygiene practices; however, the relationship is not statistically significant, suggesting that structural constraints may limit the translation of educational attainment into improved health behaviour.

Hypothesis 4 evaluated whether education influenced hygiene behaviour. Two indicators were tested: kitchen cleanliness and washing hands before eating.

Education vs kitchen cleanliness: Fisher's exact p = 1.396e-07

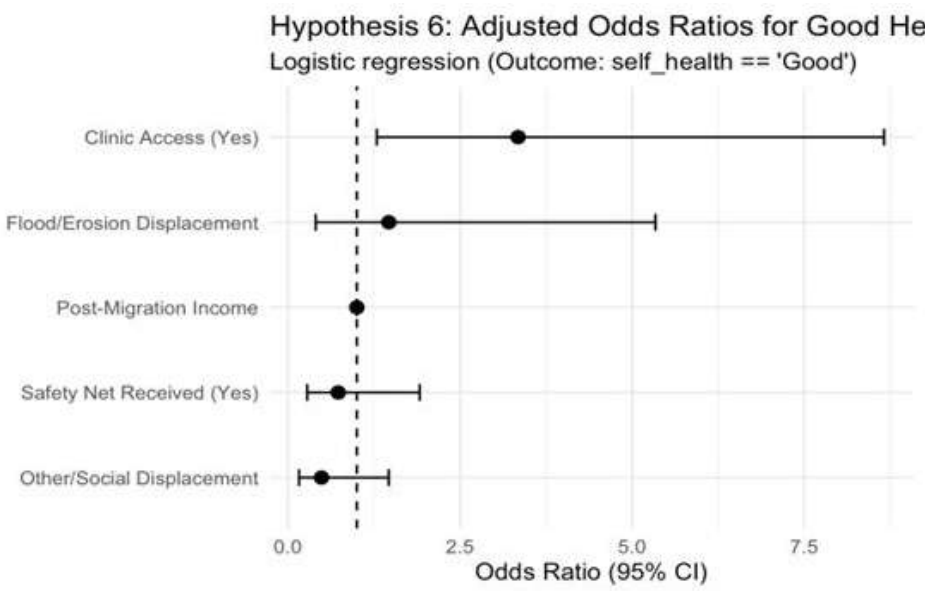
Education vs handwashing: Fisher's exact p = 2.514e-09

These strong associations suggest that education plays a critical role in shaping hygiene practices. Descriptively, only 11.4 per cent of primary-level women maintained clean kitchens, compared to 61.5 per cent of those with secondary education and it is strongly statistically significant.

5.2.5. Exploratory Institutional Robustness Test (H6)

To add the very last data along with this trajectory, H6 is retained as an exploratory institutional robustness test within the adjusted regression framework rather than as a standalone confirmatory hypothesis. Hypothesis 6 examined whether receipt of social safety-net aid independently predicts improved health outcomes among climate-displaced women living in Dhaka's informal settlements (Figure 11). In contrast to the expected protective effect of social assistance, the multivariate logistic regression results indicate that safety-net receipt was not significantly associated with women's self-reported health status

Figure 11: Adjusted Odds Ratios for Predictors of Good Self-reported Health.



Source: Authors' regression analysis based on survey data (N = 120 households); see Appendix Table E2.

Note: Points represent odds ratios; horizontal lines indicate 95% confidence intervals. The dashed vertical line indicates OR = 1 (no effect).

once key structural mediators were included in the model. Women who reported receiving safety-net support did not exhibit higher odds of reporting good health compared to non-recipients (OR ≈ 0.73, p = 0.52), and the confidence interval includes the null value of 1, suggesting no statistically distinguishable direct effect in this sample.

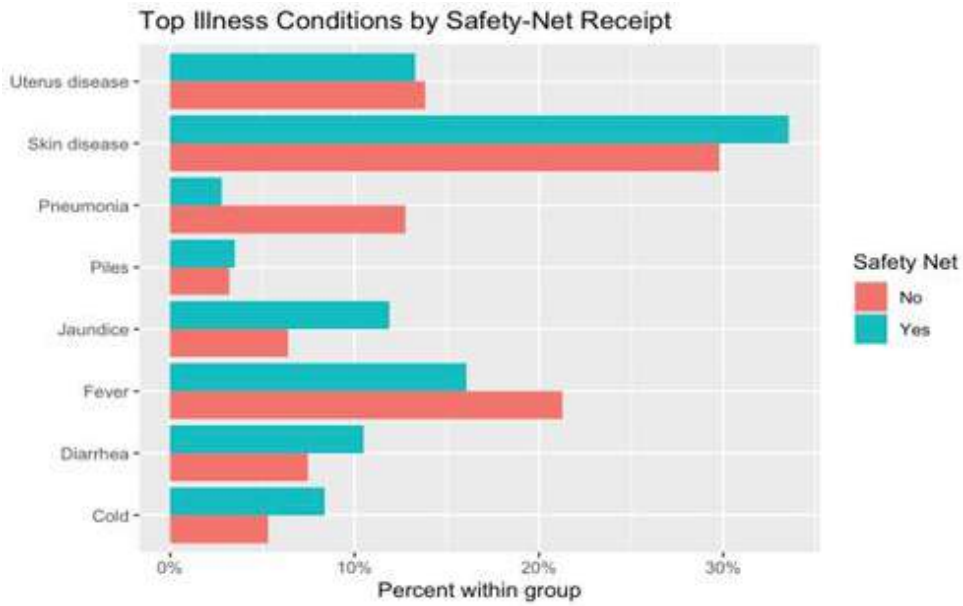
This finding should not be interpreted as evidence that social safety-net programmes worsen health outcomes. Rather, it likely reflects the institutional and targeting realities of social protection delivery in slum contexts. Safety-net benefits are often allocated to the most socioeconomically vulnerable households, meaning that recipients may begin from a position of higher baseline health risk. Moreover, limited benefit adequacy, administrative exclusion, and delays in accessing services may constrain recipients' ability to convert nominal aid into measurable improvements in wellbeing. As such, the result highlights the possibility that safety-net participation alone is insufficient to generate observable health gains without complementary service infrastructure.

The odds ratio plot reinforces this interpretation. In the figure, the estimated odds ratio for safety-net receipt falls slightly below the reference line at OR = 1, visually indicating a negative or null association. However, the wide confidence interval crossing OR = 1 confirms the statistical non-significance of this predictor. In contrast, clinic accessibility remained the most consistent structural determinant of good health across specifications. In the primary adjusted model reported under Hypothesis 1, clinic access was associated with significantly higher odds of good self-reported health (OR = 0.73, p = 0.522). In the robustness model estimated for Hypothesis 6, this association remained statistically significant with a slightly larger effect size (OR ≈ 3.34, p = 0.013), indicating that healthcare infrastructure continues to predict women's health vulnerability even when safety-net receipt shows no independent adjusted effect. So, the findings for Hypothesis 6 are consistent with the multivariate regression results presented in Appendix Table E2 and hypothesis test summary in E3. While safety-net participation shows no independent effect on health outcomes, structural factors, particularly clinic access, remain significant predictors. This indicates that the apparent benefits of safety nets do not persist once access to healthcare and other mediating conditions are taken into account, highlighting the importance of service accessibility over nominal programme participation.

Overall, H1 reports the primary adjusted model; H6 presents a robustness specification. Hypothesis 6 serves as an exploratory but policy-relevant result, suggesting that safety nets are unlikely to deliver sustained health benefits unless integrated with accessible clinical services and reduced institutional barriers within urban slum environments.

Additionally, the graph illustrates the distribution of common illness types among respondents and their corresponding rates of safety net receipt (Figure 12). Among the most frequently reported illnesses like fever, diarrhea, skin disease, and respiratory problems those suffering from skin disease and respiratory issues showed a marginally higher tendency to have received safety net support compared to others. However, the overall trend reveals no consistent alignment between specific illness types and increased access to formal support mechanisms.

Figure 12: Distribution of Common Illness Conditions by Safety-Net Receipt Status



Source: Authors' calculations and graphical representation based on primary survey data (N = 120 households); underlying data reported in Appendix Table D4 (Health Conditions and Aid Receipt).

Note: The figure presents the percentage distribution of common illness conditions among respondents, disaggregated by whether they received safety net support. Percentages are calculated within each subgroup (received vs. not received). While certain conditions such as skin disease and respiratory illness show slightly higher representation among safety-net recipients, there is no consistent pattern indicating that support is systematically aligned with disease burden. The distribution suggests that access to safety nets is not strongly health-need driven, but may instead reflect structural factors such as eligibility constraints, documentation status, and programme targeting limitations.

This pattern reinforces the broader observation that safety net allocation may not be systematically health-need driven. Instead, access is shaped by other factors, including documentation status, political connection, or slum location, as highlighted in qualitative interviews. The lack of strong alignment between the burden of illness and programmatic support suggests that institutional targeting remains insufficiently responsive to actual health vulnerabilities.

However, qualitative data nuance this interpretation. Several educated women reported being unable to maintain hygiene due to poor infrastructure or time burdens. This suggests that education helps but cannot override structural constraints. In this study, covariates in the anchor model were selected to reflect key structural mediators emphasised within the Social Determinants of Health framework, including healthcare accessibility, economic capacity, and displacement-related vulnerability. Because the survey is cross-sectional,

the estimated odds ratios should be interpreted as adjusted associations rather than causal effects. This parsimonious specification therefore prioritises effect sizes and confidence intervals over isolated p-values, aligning the quantitative component with institutional vulnerability research standards.

5.3. Qualitative Analysis: Lived Experiences and Structural Constraints

Qualitative findings provide crucial context for understanding why strong bivariate associations were observed, though adjusted effects were smaller with persistent vulnerability. Women's narratives consistently highlighted bureaucratic gatekeeping, documentation barriers, corruption, and political influence as significant obstacles to accessing social safety nets. Many women reported being excluded from programmes due to lack of permanent addresses, identity documents, or political connections, reinforcing patterns of institutional marginalisation.

Qualitative evidence from IDIs, FGDs, case studies, and KIIs provides a deeper understanding of how structural constraints shape women's health experiences beyond what quantitative indicators can capture. Across interviews, women repeatedly described exclusion from formal safety nets as an everyday reality shaped by bureaucracy, documentation gaps, and political gatekeeping. A woman from Korail Slum remarked, '*They say there is help, but that help is not for people like us. Without papers or connections, you are nobody*'. This sentiment reflects a widespread perception that access to state support is mediated by power rather than need. Living conditions emerged as a central theme linking environmental exposure to recurring illness. Most women reported residing in single-room dwellings with shared toilets and unreliable water sources. One case study participant explained, '*Five families use one toilet. If one child gets sick, everyone gets sick*'. Such statements illustrate how overcrowding and inadequate sanitation transform individual health issues into collective risks. Health-seeking behaviour was often delayed or avoided altogether due to fear of costs and mistrust of public health facilities. Women expressed concern over hidden expenses, informal payments, and dismissive treatment by health staff. Informal social networks, including neighbours, kin, and community leaders, functioned as essential coping mechanisms for accessing jobs, medicine, and information, but women consistently acknowledged that such networks could not substitute for formal protection systems. As one respondent noted, '*Going to the hospital is not free. First, they ask money, then they ask why you came*'. These experiences contribute to prolonged illness and reinforce cycles of vulnerability. Gendered burdens were evident to women's account throughout the qualitative data. Migration increased women's participation in income-generating activities, but domestic and caregiving responsibilities remained unchanged, producing a 'double burden' which has direct implications for physical and mental health. A participant in a focus group discussion stated, '*If I don't work, there is no food. If I work, there is no rest. Either way, I get sick*'. Manifested through anxiety, exhaustion, and uncertainty, psychosocial distress was frequently normalised and underreported, reflecting the intersection of gender, displacement, and poverty. Insights from KIIs corroborate these accounts and highlight institutional perspectives on systemic constraints. One NGO worker acknowledged, *Our programmes are limited. We try to help, but we cannot reach everyone, and sometimes politics decides who gets support*'. Similarly, a local health official noted, '*Urban migrants fall between systems. They are not registered here, and the rural programmes don't follow them*'. These statements reveal structural gaps in policy design that leave climate-displaced

women inadequately protected. Psychosocial distress, while rarely labeled as mental health problems, surfaced implicitly in narratives of exhaustion, fear, and uncertainty. Women often normalised stress as part of survival, indicating a form of silent suffering. Informal social networks such as neighbors, relatives, and community leaders played a crucial role in coping by providing loans, information, and emotional support. However, women consistently recognised the limits of such support. As one participant summarised, '*People can help for one day, maybe two. After that, everyone has their own struggle*'.

5.4. Integrated Interpretation and Theoretical Implications

Across methods, findings support an SDH (Social Determinants of Health)-based explanation and that is women's self-reported morbidity is patterned by structural access conditions (especially clinic accessibility and sanitation constraints) more consistently than by safety-net receipt alone. The adjusted model aligns with this interpretation by showing clinic access as a robust predictor of good health, while safety-net receipt does not independently predict health once key structural mediators are included. Qualitative evidence explains why: administrative exclusion, documentation barriers, and informal fees interrupt the conversion of nominal entitlements into usable health protection. Supporting insights from Marxist feminist political economy help interpret the employment result: safety nets are associated with labour-market entry or re-entry, yet women remain concentrated in insecure informal work without protections, making health gains fragile. Social capital functions as an access mechanism, enabling some women to navigate aid and referrals, while deepening exclusion for others lacking networks. The loss of statistical significance for displacement type in the adjusted model suggests that structural factors, particularly clinic accessibility, mediate observed differences in health outcomes. Overall, the results challenge a purely 'transfer-centric' view of protection and point to institutional redesign: health gains are most likely when social protection is paired with accessible urban primary care and basic WASH infrastructure.

6. Conclusion: Recommendations and Policy Implications

This study examined how social safety nets interact with displacement pathways and structural living conditions to shape health vulnerability among climate-displaced women living in Korail, Kallyanpur, and City Colony slums in Dhaka. Using convergent mixed methods (survey of 120 households/342 individuals alongside IDIs, FGDs, and KIIs), the findings show that health improvements are not produced by aid receipt alone. Instead, women's health outcomes are most consistently shaped by structural conditions, particularly clinic accessibility and sanitation constraints, while safety nets show clearer associations with livelihood stabilisation. In the adjusted model, safety-net receipt does not independently predict good self-reported health once structural covariates are included, whereas clinic access remains a strong predictor. Qualitative accounts explain this gap by emphasising administrative exclusion, documentation barriers, local gatekeeping, and informal fees that prevent nominal entitlements from becoming usable health protection. This pattern indicates that the health disadvantages associated with displacement operate through structural constraints rather than displacement status itself. The analysis also shows that displacement experiences are not uniform because disease frequency differs by displacement type, with elevated disease burden among drought/food-insecurity displaced

women, suggesting that slow-onset livelihood collapse can produce deeper vulnerability that persists after relocation into slum environments. Overall, the evidence supports an institutional interpretation, including that social protection can support resilience, but measurable health gains depend on whether programmes are integrated with accessible urban primary care and basic slum infrastructure.

Policy recommendations

Make urban climate-displaced women administratively 'legible' to safety nets (urban inclusion by design).

Eligibility rules tied to permanent addresses, rural registries, or rigid documentation should be revised so climate-displaced women in informal settlements can enroll using flexible identification and locally verifiable residence proofs. This directly responds to the documented exclusion mechanisms reported in qualitative narratives.

Because clinic access is the strongest predictor of good health (while safety-net receipt alone is not), safety-net programming should be coupled with predictable, low-cost primary care access, for example-referral pathways, community outreach clinics, and reduced informal fees so that assistance can translate into measurable health gains.

Target WASH and housing micro-infrastructure as health policy.

Given women's emphasis on sanitation–disease linkages and the high prevalence of environmentally mediated illnesses, slum-focused investments in water access, shared toilet quality, drainage, and waste management should be treated as core public health interventions rather than 'urban services'.

Move from 'employment entry' to 'employment protection'.

Since safety nets show clearer association with employment improvement, programmes should extend beyond short-term livelihood entry to protections that reduce health risks: childcare supports, safer work conditions, and linkages to low-cost treatment (so illness does not collapse household income).

Because vulnerability differs by displacement pathway, programme design should stratify outreach (especially health screening, reproductive health services, and nutrition support) for high-burden groups such as drought/food-insecurity displaced women, rather than treating climate migrants as a single category.

Overall, the study implies that Bangladesh's safety-net architecture can support resilience, but health benefits require institutional redesign: social protection must be paired with accessible urban health services and slum infrastructure improvements; otherwise, programme receipt will remain weakly connected to measurable health outcomes.

6.1 Limitations and Directions for Future Research

Several limitations should be noted. First, the study focuses on three Dhaka slums, which constrains generalisability to other urban settlements. Second, health outcomes are based on self-reported morbidity episodes rather than clinical measures, which may introduce

recall and reporting biases. These findings indicate that while social safety nets contribute to livelihood stabilisation, their health effects depend on the presence of accessible healthcare infrastructure. Third, the survey is cross-sectional; therefore, the quantitative results should be interpreted as associational, not causal, especially given targeting dynamics (the most vulnerable may be more likely to receive aid). Future research should (i) adopt longitudinal follow-up of migrant women to capture health trajectories over time, (ii) incorporate clinical or biomarker-based measures where feasible, (iii) test heterogeneity more formally by displacement type and service environment, and (iv) evaluate implementation mechanisms (documentation, gatekeeping, informal fees) that shape whether safety nets become usable protections in informal urban settings.

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Reference

ActionAid Bangladesh. (2023). *Climate-induced displacement and urban vulnerability in Bangladesh*. https://actionaid.org

ActionAid Bangladesh. (2024). *Climate change and migration: A human rights perspective*. https://actionaid.org

Akhter, S., Mahmood, N., & Rutherford, S. (2022). A systematic review of the health of internal migrants in Bangladesh. *The International Journal of Health Planning and Management, 37*(2), 673–690. https://doi.org/10.1002/hpm.3380

Asian Development Bank. (2022). *Urban primary health care services delivery project: Completion report*. https://www.adb.org

Begum, R., Ahmed, M., & Islam, M. S. (2014). *Social safety nets in Bangladesh: Issues and challenges*. Bangladesh Institute of Development Studies.

Black, R., Bennett, S. R. G., Thomas, S. M., & Beddington, J. R. (2011). Climate change: Migration as adaptation. *Nature, 478*(7370), 447–449. https://doi.org/10.1038/478447a

Bourdieu, P. (1986). The forms of capital. In J. G. Richardson (Ed.), *Handbook of theory and research for the sociology of education* (pp. 241–258). Greenwood Press.

Bullard, R. D. (1993). Anatomy of environmental racism and the environmental justice movement. In R. D. Bullard (Ed.), *Confronting environmental racism: Voices from the grassroots* (pp. 15–39). South End Press.

Chindarkar, N. (2012). Gender and climate change-induced migration: Proposing a framework for analysis. *Environmental Research Letters, 7*(2), 1-8. https://doi.org/10.1088/17489326/7/2/025601

Crenshaw, K. (1989). *Demarginalizing the intersection of race and sex: A Black feminist critique of antidiscrimination doctrine, feminist theory, and antiracist politics*. University of Chicago Legal Forum, 1989(1), 139–167.

Directorate General of Health Services. (2021). *Climate and health innovation hub.* Ministry of Health and Family Welfare.

Federici, S. (2004). *Revolution at point zero: Housework, reproduction, and feminist struggle*. PM Press.

Fraser, N. (2016). Contradictions of Capital and Care.

Hartmann, H. I. (1979). The unhappy marriage of Marxism and feminism: Towards a more progressive union. *Capital & Class, 3*(2), 1–33. https://doi.org/10.1177/030981687900800102

International Organization for Migration. (2014). *Migration, environment and climate change: Evidence for policy*. https://www.iom.int

Khan, M. Z. H., Rabbi, S. E., Islam, M., & Farha, W. Y. (2021). *Assessment of climate-induced migrant women in Dhaka slums*. Bangladesh Nari Sramik Kendra & Change Initiative.

Marmot M. *Social determinants of health inequalities*. Lancet. 2005 Mar 19-25;365(9464):1099-104. doi: 10.1016/S0140-6736(05)71146-6. PMID: 15781105

Ministry of Local Government, Rural Development and Cooperatives. (2020). *Urban primary health care policy framework*. Government of Bangladesh.

Ministry of Social Welfare. (2021). *Implementation guidelines for social safety net programmes*. Government of Bangladesh.

Putnam, R. D. (2000). Bowling Alone: *The Collapse and Revival of American Community*.

Rabbani, G., Khan, A., & Tuhin, M. H. (2015). *Climate change and migration in Bangladesh: A gender perspective*. UN Women Bangladesh.

Romero-Lankao, P., Gnatz, D. M., Wilhelmi, O., & Hayden, M. (2016). Urban sustainability and resilience: From theory to practice. *Sustainability, 8*(12), 1224. https://doi.org/10.3390/su8121224

Sen, A. (1999). *Development as freedom*. Oxford University Press.

Siddiqui, T., & Billah, M. (2014). Environmental change and forced migration: Evidence from coastal Bangladesh. *Journal of Refugee Studies, 27*(4), 454–476. https://doi.org/10.1093/jrs/feu020

Solar, O. and Irwin, A. (2010). *A Conceptual Framework for Action on the Social Determinants of Health*. Social Determinants of Health Discussion Paper 2 (Policy and Practice). WHO, Geneva.

Taylor, D. E. (2000). The rise of the environmental justice paradigm: Injustice framing and the social construction of environmental discourses. *American Behavioral Scientist, 43*(4), 508–580. https://doi.org/10.1177/0002764200043004003

World Bank. (2011). *Bangladesh - Household income and expenditure survey: key findings and results 2010* (English). http://documents.worldbank.org/curated/en/554771468207262934

World Bank. (2024). *Climate change, migration, and adaptation in South Asia*. https://www.worldbank.org

World Health Organization. (2008). *World health statistics 2008*. https://www.who.int/statistics

A Comparative Study of River Braiding Indices and Their Relationships with Peak Discharge of the River Jamuna

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Abstract

The morphological dynamics of braided rivers are significantly influenced by river discharge. This study investigates the relationship between river discharge and braiding intensity in the Jamuna River. Using multi-temporal satellite imagery and GIS techniques, Bar Index and Braiding Index values were calculated. Planform Index values were derived from cross-sectional data at station RMJ11, and the number of islands was determined via satellite imagery analysis. The results indicated high braiding intensity across the years. Index values were moderate to high. Further analysis revealed a positive correlation between peak discharge and braiding intensity, with a coefficient of determination of 0.74 for Peak Discharge vs Braiding Index. The R^2 value for Peak Discharge vs Planform Index was 0.67. Bar Index and Number of Islands had R^2 values of 0.52 and 0.64 with peak discharge, respectively. Higher discharge corresponded to greater braiding, characterised by islands. This study addresses a research gap by analysing these indices for the Jamuna and investigating the morphological relationship with hydrological parameters in Bangladesh. The findings highlight the role of hydrological variability in shaping river morphology and offer a valuable baseline for future studies, supporting improved river management and sediment monitoring in the Jamuna River Basin.

Keywords: GIS, braiding index, planform index, discharge.

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1. Introduction

The Jamuna River, one of the major rivers in Bangladesh, is known for its dynamic and complex braided channel patterns (Chalov and Alexeevsky, 2015). River braiding refers to a river system that consists of multiple interweaving channels separated by bars or islands. These braided channels are characterised by high sediment transport, variable flow patterns, and significant morphological changes over time. A catalyst for such changes may be peak discharge values that have varied over the years (Ozturk and Sesli, 2015). For convenience, the time range is from 2001 to 2020, primarily the months of May, June and July, with regard to peak discharge values, with intervals in between the years. The study of river braiding is crucial for understanding sediment dynamics, flood risks, and riverine ecology. The dataset offers a diverse range of morphological changes and patterns that can be captured through the application of various river braiding indices (Dhali et al., 2020; Swarnkar et al., 2020). Rivers are dynamic natural systems that play a crucial role in shaping the landscape and supporting various ecological processes (Islam and Chowdhury, 2003). Understanding river dynamics is essential to ensure sustainable management and conservation of valuable natural resources, especially in a country like Bangladesh, which is rich in such resources. River braiding indices have been widely used to assess the morphological characteristics of rivers, particularly their tendency to form multiple channels or braids. However, existing research papers on such indices cater to specific rivers with diverse geographies. As such, the Jamuna River, a major transboundary river originating from the Himalayas and flowing through Bangladesh, was selected for this study due to its unique geomorphological characteristics and the significant impact it has in the form of floods on the surrounding regions (Haque & Nicholls, 2018). The aim of this paper is to find the 'best fit' for the river Jamuna with respect to the low-lying country, Bangladesh, over a significant period of time, to better understand its relationship with the river morphology of some specific river stations (Sarker et al., 2013). This is generally possible by establishing a correlation between various braiding indices and year-wise peak discharge values at the Jamuna River. As such, this thesis paper provides a thorough comparative analysis of commonly used river braiding indices, evaluating their strengths and limitations in characterising the morphology of the Jamuna River, a major transboundary river in Bangladesh.

Much of the data for these indices has been derived using GIS (Balouchi et al., 2024). Each of these indices has been designed to capture different aspects of the braiding pattern, such as the number of islands, main and side channel length, their width, and their distribution. However, most of these indices were developed and tested in specific geographical contexts, and their applicability to the Jamuna River, with its unique hydrological and morphological characteristics.

Research on river braiding has been extensive, with numerous studies focusing on developing and refining braiding indices on rivers around the world with diverse geographies. Recent research has emphasised the need for indices that can adapt to varying river systems and provide reliable measures of braiding intensity under different hydrological conditions. Studies such as 'Reviewing Braiding Indices of the River Channel in an Attempt to Establish Alternatives' (Das and Islam, 2023) have highlighted the strengths and limitations of existing indices and proposed new methodologies for more accurate assessments. As such, this thesis paper aims to contribute to this growing body of knowledge by conducting a comprehensive

analysis of the applicability of various braiding indices to the Jamuna River and exploring their relationship with the river's discharge.

In the context of the Jamuna River, there is a significant gap in the literature regarding the applicability and effectiveness of these indices. While studies on the hydraulic characteristics of the Jamuna River, such as 'Hydraulic Characteristics of the Jamuna River Gauging Section, Bangladesh' and 'A Study on Variation in Channel Width and Braiding Intensity of the Brahmaputra River in Assam, India' (Sarma and Acharjee, 2018) provide valuable insights into its flow dynamics, there is a lack of comprehensive analysis linking these characteristics to river braiding indices. This gap presents an opportunity to develop a deeper understanding of the relationship between braiding patterns and peak discharge values in the Jamuna River (Khan et. al, 2020). This case study aims to resolve this gap and provide a more informed basis for river management and water resources planning in Bangladesh, especially with regard to floods.

1.1 Objectives of the Study

The primary objective of this study is to evaluate the relationship between river discharge and the degree of braiding in the Jamuna River by calculating and comparing multiple braiding indices across different years. Specifically, the study aims to:

1. Assess the status of braiding of the Jamuna River using different braiding indices across multiple time periods.
2. Analyse the temporal variation in these indices in relation to annual peak river discharge.
3. Identify which braiding index exhibits the strongest statistical correlation with discharge, thereby assessing its suitability as a discharge-responsive indicator of channel morphology.

1.2 Outcomes of the Study

- The quantification of braiding indices offers an objective basis for assessing the river's morphodynamics, which is valuable for flow management and infrastructure planning.
- By linking discharge levels to braiding intensity, the study helps predict how the river might evolve during high-flow events, which can be used as an early warning system and risk assessment.
- The study can help to decide where intervention such as bank reinforcements is necessary and where natural river processes can be left undisturbed.
- The study sets the foundation for automated monitoring systems using satellite imagery and GIS for continuous assessments of the Jamuna's braiding.
- The study creates a morphological baseline of the Jamuna River against which future changes due to climate variability or human intervention can be compared.
- Future work could integrate the indices with sediment transport and flow models to simulate channel evolution under different flow scenarios.

1.3 Research Questions

By collecting satellite imagery from available sources and deriving the necessary data, we aim to carry out simple regression analysis between the diverse braiding index models that

we have undertaken and the annual peak discharge values. From there, we intend to answer the following research questions:

- How do peak discharge values from public sources impact the braiding intensity of the transboundary Jamuna River across diverse time periods?
- Which braiding index best showcases morphological response to changing discharge values?
- How do the Planform Index, Bar Index, Braiding Index, and Number of Islands vary with hydrological extremes?

2. Literature Review

River braiding is a complex phenomenon influenced by a diverse set of factors, including sediment supply, channel slope, bank erodibility, and flow regime. High sediment loads and steep slopes generally promote braiding, since the river's capacity to transport sediment is exceeded, which leads to deposition as well as the formation of bars and islands. Meanwhile, the seasonal changes in rainfall and streamflow in the Ganges-Brahmaputra basins further contribute to the dynamic nature of river braiding (Chowdhury & Ward, 2003). Furthermore, bank erodibility plays a critical role, since easily erodible banks allow the river to widen and form new channels (Oye et al., 2021). However, in this research, the correlation between peak discharge values and existing braiding or planform indices is determined to better assess the susceptibility to potential flood damage in the region around the Jamuna River, especially with regard to the Bahadurabad station.

Braiding or planform indices and flood probability are essentially related to each other since an increase in braiding intensity allows for greater conveyance, thereby allowing more discharge to be carried during flood events (Nicholas, 2000). Furthermore, the presence of islands across the river Jamuna affects the peak discharge values and thus the flood probability by influencing flow patterns and conveyance capacity. These bars and islands can function as obstructions, causing the river flow to diverge and converge, which may either increase or decrease the local flood risk. Also, channel length over the years has been impacted by several factors, including natural processes such as erosion and sedimentation. These factors can change the river's morphology, which in turn affects its braiding patterns and thus the application of various braiding indices.

With regard to the Jamuna River, its selection as a transboundary river for this study is underscored by several critical factors that require thorough examination. Our research focuses on the Jamuna River due to its highly dynamic braided channel morphology, immense annual sediment load, and status as a major transboundary river. Its complex hydrological regime and the extensive morphological changes it undergoes provide an ideal setting for evaluating and comparing various river braiding indices. Furthermore, understanding the river's braiding patterns is important for flood risk assessment and water resource management in Bangladesh. Thus, the following research is particularly important to Bangladesh and its people, especially those in the near vicinity of the river Jamuna, as the findings of the research have the potential to inform strategies that can mitigate flood risks, optimise water resource management, and enhance the resilience of communities living alongside this dynamic river system.

The choice of the Jamuna River for this study is further influenced by its complex hydrological regime and the significant impact it has on the surrounding environment and communities (Pradhan et al., 2021). The river's dynamic nature, characterised by high discharge rates and substantial sediment loads, leads to frequent channel shifting and bank erosion (Beveridge et al., 2020). Thus, by implementing existing braiding and planform indices for such a river and subsequently correlating these indices with peak discharge data obtained from the Bahadurabad station, a more refined understanding of the relationship between river morphology, braiding intensity, and flood risk can be achieved.

3. Conceptual Framework

River braiding represents a natural response to variations in flow regime and channel boundary conditions. The Jamuna River provides a unique system for examining hydrological extremes, especially annual peak discharge values, which indicate channel instability and platform shifts. This section outlines the conceptual logic that connects discharge variability with observed morphological indicators used in this study. The conceptual framework for this study links hydrological forcing with measurable morphological outcomes. Changes in peak discharge drive measurable variations in braiding indices, which collectively represent the river's morphological state.

The framework rests on four core components:

3.1. Hydrological Forcing

Peak discharge values from the Bangladesh Water Development Board (BWDB) determine the magnitude of flow-energy and sediment transport capability.

3.2. Morphological Indicators

The study uses four planform-based indices derived from satellite imagery and GIS measurements:

Planform Index (PI): Represents channel width variability and planform complexity.

Braiding Index (BI): Indicates the number of channels and degree of division.

Bar Index (BarI): Measures bar area/number as indicators of instability.

Number of Islands (NI): Reflects long-term channel division and sediment retention.

3.3. Hydro-Morphological Interaction

Peak discharge influences sediment transport and channel instability, which in turn affects the four indices. Each index captures a different morphological response to hydrological extremes.

3.4. Outcome (River Stability Assessment)

By correlating peak discharge with the four indices, the framework evaluates the Jamuna River's sensitivity to discharge variability and identifies patterns of stability or instability across the study years.

4. Methodology

4.1 Data Collection

This study utilises both hydrological and remote sensing data to analyse the morphodynamical characteristics of the Jamuna River through Planform Index, Bar Index, and Braiding Index calculations. Another analysis was conducted to assess changes in the number of islands on the Jamuna River.

4.2 Hydrological Data

Hydrological data including discharge, water level, and cross-sectional profiles of the Jamuna River were collected from the BWDB. The data corresponds to station RMJ11, which is strategically located on the Jamuna River and provides consistent measurements critical for evaluating the river's behaviour.

- Discharge data (m^3/s) were used to understand flow variability and its relationship to braiding intensity.
- Water level data (m) provided insight into seasonal fluctuation and inundation patterns.
- Cross-sectional data were utilised to assess channel width and depth at RMJ11, informing the calculation of active channel length for Planform Index estimation.

These datasets were selected to represent monsoon-affected periods, which significantly influence the river's planform and hydrodynamics.

4.3 Satellite Imagery

To calculate the Braiding Index and Bar Index, satellite images of the Jamuna River were collected for the monsoon season (May to July) for selected years. The monsoon period was chosen as it corresponds to the peak river activity and morphological adjustments.

- Sources: Satellite imagery was obtained from USGS Earth Explorer for Landsat data.
- Resolution: Medium-resolution (10–30 m) imagery was used to clearly delineate river channels, mid-channel bars, and valley boundaries.
- Temporal coverage: Multiple years were selected to assess temporal changes in river morphology.
- Pre-processing: Images were corrected for atmospheric distortion, and cloud coverage was minimised by selecting cloud-free acquisitions.

5. Analysis and Interpretation

5.1 Planform Index

To calculate the planform index, cross-sectional data were collected to know the reduced level and Distance. The cross-sectional data was collected for the station RMJ11. The station is located near the Sariakandi upazila along the river Jamuna between Bahadurabad and Sirajganj. The RL vs Distance graph was plotted to obtain the cross-section. Then the water level was added to the same graph to identify the number of channels and their distance.

The index was calculated using the following equation.

PFI = [ΣT / B] x 100 /N (Sharma, et al., 2010)

Here, T is the top width of the channels, B is the total flow width, and N is the number of channels.

Planform Index considers the long-term, permanent, stable Islands in a section. Below, the calculation of Planform Index for the year 2005, from the cross-section of the station RMJ11 is shown. The Y-axis represents the reduced level, and the X-axis represents the Distance. Here, the water level divides the cross-section into several channels. In the case of the year 2005, we can see the water level creates 6 distinct channels. From which, the top widths are measured, as well as the total flow width.

5.2 Braiding Index

To calculate the braiding index, a satellite image of the Jamuna River during the monsoon period—between Bahadurabad transit and Sirajganj was collected for multiple years. Then, shapefiles were created for calculating the main channel and side channel distances. First, polylines were created along the Bahadurabad and Sirajganj stations to identify the reach. Then, polylines were created following the main channel and side channels. For spatial referencing, the WGS1984 UTM zone 45N geographic coordinate system was selected, which was imported from the satellite image. Spatial referencing ensures accurate estimation of distances. In the attribute table, a lengths field was created for the main channel and side channel geometries, and the main channel and side channel lengths were calculated. From the statistics of the main channel and side channel lengths, the values of the total main channel distance and the total side channel distance were taken from the sum of lengths.

The formula used for calculating braiding index is,

BI = [ΣLS + ΣLM] / ΣLM (Kuo, et al., 2017)

Where LS is the side channel distance, and LM is the main channel distance.

5.3 Bar Index

To calculate the bar index, also known as the Brice index, satellite images of the Jamuna River between Bahadurabad transit and Sirajganj were collected for multiple years. First, shapefiles were created pointing to Bahadurabad and Sirajganj stations. Then, shapefiles were created to calculate the length of individual bars and the main channel distance. Spatial referencing was done using the WGS1984 geographic coordinate system, UTM zone 45N, which was imported from the satellite image. Spatial referencing ensures accurate estimation of distances. Fields were created in the attribute table for Bar Length and straight-line distance between the reaches. From the attribute table, the values of the total straight-line distance and the total length of bars were calculated from the geometry.

The formula used for calculating bar index is,

$BI=2\Sigma Lb/ Lr$ (Brice, 1964)

Where Lb. is the bar length and Lr is the straight-line distance between stations.

5.4 Number of Islands

Satellite images for multiple years of the river Jamuna between Bahadurabad and Sirajganj were used to analyse the number of islands. The satellite images were spatially referenced specifying the geographic coordinate system WGS1984 UTM zone 45N. Then polygon shapefiles were created around the individual islands. The total number of islands were gathered from the attribute table.

5.5 Results

The calculated values of indices and the type of braiding in accordance with their corresponding tables have been provided in the appendix.

6. Conclusion and Recommendations

6.1 Conclusion

The following study has successfully applied multiple existing braiding indices to characterise the Jamuna River and correlate it with peak discharge values.

The Braiding Index, Bar Index and Number of Islands values were calculated by analysing multi-temporal satellite imagery in GIS, while the Planform Index values were derived from analysing the cross-sectional data of Reduced level and Distance in Excel.

The value of Braiding Index ranged from 5.24 in 2001 to 6.93 in 2007. Bar Index values ranged from 5.84 in 2001 to 7.53 in 2007. Planform Index values ranged from 4.32 in 2010 to 18.2 in 2011. The highest number of islands was seen to be 112 in 2004.

For all indices, an increase in discharge results in an increase in braiding intensity. The positive correlation suggests that higher river discharge leads to greater sediment transport and channel instability, thereby encouraging the development and complexity of braided patterns.

Among the various comparisons conducted, the strongest relationship was observed between peak discharge and Braiding Index. The correlation analysis revealed that the co-efficient of determination (R^2) for discharge vs Braiding Index reached a value of 0.74. This suggests that 74 per cent of the variability of Braiding Index can be explained by variations in Peak discharge.

The calculated Braiding Index and Bar Index values were consistent with the classification table and the nature of Jamuna River as they consistently show a high degree of braiding throughout the years.

While the planform index values fall within the moderate range, the stronger correlation with braiding Index indicates the overall number of channels and their complexity is more responsive to discharge than formation of stable islands. As the Jamuna River is a highly dynamic river with a high sediment load and frequent channel migration, the bars often erode, preventing them from becoming stable islands; thus, the index values reflect moderate braiding.

The analysis indicates a positive correlation between river discharge and the number of mid-channel bars or islands in the Jamuna River. This trend suggests that higher flow rates enhance sediment transport and deposition processes, promoting the formation and emergence of bars. Increased bar formation with higher discharge reinforces the braided nature of the reach during high-flow periods.

The present findings have important implications for integrated water resources management in the Jamuna River Basin and the Global South more broadly. The observed relationship between annual peak discharge values and increased braiding intensity may suggest heightened channel instability, likely caused by climate change. This leads to sediment redistribution and floodplain interaction during high-flow periods. Such observed changes throughout the years are believed to directly influence riverbank erosion, flood risk, and navigation issues for all vessels, thus highlighting the need for river training and flood control infrastructure. As such, effective flood management in the Jamuna basin must rely both on structural interventions and an understanding of dynamic river morphological behaviour. Emphasising these indicators in basin-scale planning can support adaptive flood management strategies, sediment management, and river stabilisation efforts well into the future.

The findings affirm that discharge plays a crucial role in influencing the river's morphodynamic behaviour. Understanding this relationship is essential for river management, sediment control, and predicting morphological responses to hydrological changes in large, braided rivers like the Jamuna.

6.2 Recommendations

- **Expand Spatial Coverage:** Future studies should consider expanding the spatial coverage of data collection efforts by incorporating data from multiple gauging stations along the Jamuna River. This would ensure a comprehensive understanding of the spatial variability in flow conditions and allow for a more robust assessment of flood risk across the region.

- **Incorporate 3D Modeling:** Further research should explore the use of more sophisticated three-dimensional models to represent the complex morphology of the Jamuna River. These models showcase a wider range of morphological features and processes, e.g., sediment transport and bank erosion, that are not completely accounted for by existing braiding and planform indices.
- **Investigate Climate Change Impacts:** Supporting the strategic objectives of Bangladesh Delta Plan 2100, future studies should explicitly investigate the potential impacts of climate change on river morphology and flooding patterns in the Jamuna River. Considering the increasing discharge variability caused by Himalayan glacier melt and intensified monsoon rainfall, integrated water management approaches that simultaneously address sedimentation and flood management are essential for the river system. This involves using climate models for projecting future changes in parameters such as rainfall pattern, temperature, etc., and then incorporating these projections into relevant models to assess any and all changes regarding river flow and flood risk.
- **Tidal River Management:** Tidal River Management is a greatly relevant area for further study, especially for the region (Hossain and Khandaker, 2015). This is because it can help to improve drainage in the Bengal Delta by using the natural tidal forces to convey water and sediment through a network of channels.
- **Use of Drones:** Drones, regardless of size, equipped with high-resolution cameras and LiDAR technology, could be used to collect detailed topographic data of the river channels and floodplain (Hemmati et al., 2020). Consequently, integrating these remote sensing methods provides a clearer assessment of braiding and planform indices across the study area, allowing researchers to accurately calculate monsoon season water depth.
- **Combination of Scientific Knowledge and Indigenous Solutions:** Though satellite-based analyses and quantitative indices provide valuable data into large-scale river dynamics, effective river management also requires the integration of indigenous knowledge systems. Riverine communities of char and floodplain areas are said to possess long-standing knowledge of seasonal channel shifts, erosion patterns, and flood behaviour. Combining such locally grounded observations with modern geospatial and hydrological analysis can enhance early warning systems. This will consequently improve risk communication across all levels, and support context-sensitive adaptation strategies. Strengthening transboundary data sharing and integrating community-level knowledge with scientific assessments in an inclusive manner can strengthen participatory water governance. This improves the social relevance of both river-based research and the effectiveness of river management interventions.

6.3 Limitations

Though this study provides important insights into the relationship between braiding indices and peak discharge values in the Jamuna River, it is important to address certain limitations.

The analysis is based on data from a single gauging station. Braiding Index and Bar index were calculated based on the whole reach between Bahadurabad and Sirajganj, Planform index was derived from a single cross-sectional segment located in the middle of the reach. While this station provides a consistent record of discharge, it may not fully capture the spatial variability of flow conditions along the entire reach of the study region in Jamuna River.

The inconsistency in spatial coverage between different indices and discharge data may affect the direct comparability of the metrics and their correlation with flow, especially in downstream segments where tributary inflows or localised hydrological events could influence flow dynamics.

The study uses existing braiding and planform indices, which, even though widely accepted, may not fully represent the complex three-dimensional morphology of a dynamic braided river like the Jamuna. These indices are but simplifications of reality and may not account for all relevant morphological features or processes.

The correlation analysis between braiding indices and peak discharge is based on historical data. Even then, the data have been taken from non-consecutive time periods, i.e. 2007 after 2004, 2015 after 2002, etc. Future changes in land use, climate patterns, or river management practices could alter the relationships observed in this study.

This research does not explicitly model the impacts of sediment transport or bank erosion, which play a notable role in the Jamuna River's dynamics. The findings highlight the importance of considering braiding intensity regarding river flow assessments.

Acknowledgement

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References

Balouchi, B., Rüther, N., Schwarzwälder, K. (2024). Temporal variation of braided intensity and morphodynamic changes in a regulated braided river using 2D modeling and satellite images. *River Research and Applications*. Volume 40, Issue 5: 708-724

Beveridge, C., Hossain, F., Bonnema, M. (2020). Estimating Impacts of Dam Development and Landscape Changes on Suspended Sediment Concentrations in the Mekong River Basin's 3S Tributaries. *Journal of Hydrologic Engineering, Volume 25*, Issue 7. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001949.

Brice, J. C. (1964). *Channel Patterns and Terraces of the Loup Rivers in Nebraska*. Professional Paper 422d. US Geological Survey. https://doi.org/10.3133/pp422d.

Chalov, S. R. and Alexeevsky, N. I. (2015). Braided rivers: structure, types and hydrological effects. *Hydrology Research* (2015) 46 (2): pages 258–275.

Chowdhury, R. and Ward, M. N. (2003). *Seasonal Rainfall and Stream-flow in the Ganges-Brahmaputra Basins of Bangladesh: Variability and Predictability*. World Water and Environmental Resources Congress 2003. https://doi.org/10.1061/40685(2003)29.

Das, B. C. and Islam, A. (2023). Reviewing Braiding Indices of the River Channel in an Attempt to Establish Alternatives. *MethodsX 10* (2023), 102042. https://doi.org/10.1016/j.mex.2023.102042.

Dhali, M. K., Ayaz, S., Sahana M., Guha S. (2020). Response of sediment flux, bridge scouring on river bed morphology and geomorphic resilience in middle-lower part of river Chel, Eastern Himalayan foothills zone, India. *Ecological Engineering, Volume 142*, January 2020, 105632. https://doi.org/10.1016/j.ecoleng.2019.105632.

Haque, A. and Nicholls, R. J. (2018). *Floods and Ganges-Brahmaputra-Meghna Delta*. Ecosystem Services for Well-Being in Deltas, 30 May 2018, pages 147-159.

Hemmati, M., Ellinwood B. R., Mahmoud H. N. (2020). The Role of Urban Growth in Resilience of Communities Under Flood Risk. *Earth's Future, Volume 8*, Issue 3, March 2020. https://doi.org/10.1029/2019EF001382.

Hossain, F. and Khandakerl, Z. H. (2015). Tidal river management in Bangladesh. *Nature Climate Change* 5(6): 492. https://doi.org/10.1038/nclimate2618.

Islam, G.M.T. and Chowdhury, J.U. (2003). Hydraulic Characteristics of the Jamuna River Gauging Section, Bangladesh. *Water & Maritime Engineering 156*, September 2003, Issue WM3, Pages 219-224.

Kuo, C. W., Chen, C. F., Chen S. C., Chen C. W., Yang T. C. (2017). Channel Planform Dynamics Monitoring and Channel Stability Assessment in Two Sediment-Rich Rivers in Taiwan. *Water 2017, Volume 9*, Issue 2. https://doi.org/10.3390/w9020084

Khan T.I., Mehrun, Opu R. K., Islam Md. N. (2020). Modeling on Probability Analysis of Flood Frequencies at Bahadurabad Station of Jamuna River in Bangladesh. *International Journal of Contemporary Applied Researches Vol. 7, No. 4*, April 2020. Pages 59-83.

Nicholas, A.P. (2000). Modelling bedload yield in braided gravel bed rivers. *Geomorphology, Volume 36*, Issues 1-2, December 2000, Pages 89-106.

Oye, O. M., Hart, L., Orupabo, S. (2021). Bathymetric components towards ensuring navigable channels along a section of lower river Niger, lokoja, kogi state, Nigeria. I*nt J Hydro*. 2021;5(5):231-238

Ozturk, D. and Sesli, F. A. (2015). Determination of Temporal Changes in the Sinuosity and Braiding Characteristics of the Kizilirmak River, Turkey. Pol. J. *Environ. Stud. Vol. 24*, No. 5 (2015), 2095-2112

Pradhan, N. S., Das, P.J., Gupta N., Shrestha A. B. (2021). Sustainable Management Options for Healthy Rivers in South Asia: The Case of Brahmaputra. *Sustainability 2021, 13*(3), 1087. https://doi.org/10.3390/su13031087.

Sharma N. (2004). Mathematical modelling and braid indicators. *The Brahmaputra basin water resources (Vol. 47*, pages. 229-260). Springer. 45

Sharma N., Johnson F. A., Hutton C. W., Clark M. J. (2010). Hazard, Vulnerability and Risk on the Brahmaputra Basin: A Case Study of River Bank Erosion. *The Open Hydrology Journal, 2010, 4*, Pages 211-226.

Sarker M. H., Thorne, C.R., Aktar M. N., Ferdous Md. R. (2013). Morpho-dynamics of the Brahmaputra–Jamuna River, Bangladesh. *Geomorphology, Volume 215*, 15 June 2014, Pages 45-59

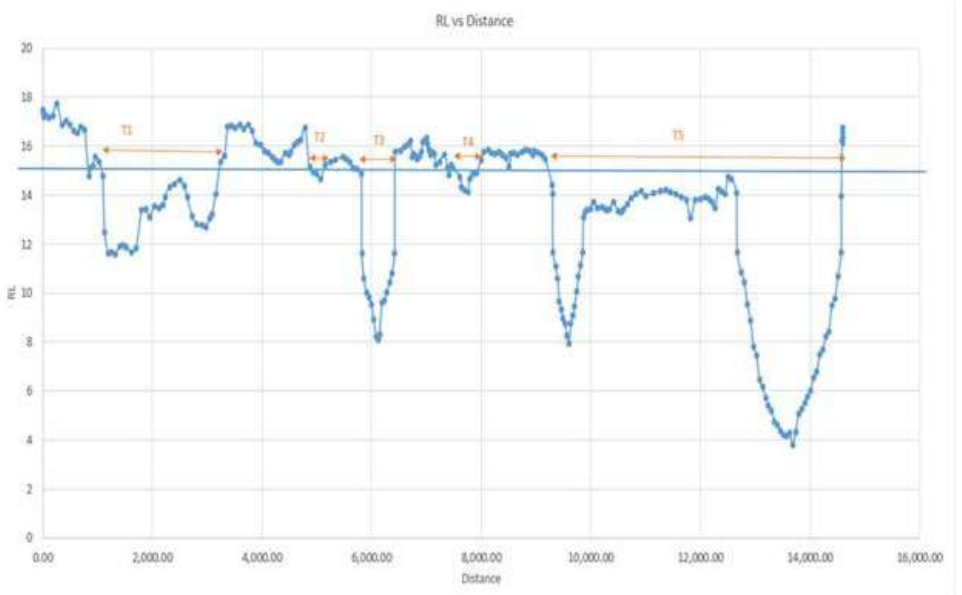
Sarma, J. N. and Acharjee, S. (2018). A Study on Variation in Channel Width and Braiding Intensity of the Brahmaputra River in Assam, India. *Geosciences 2018, 8*(9): 1-19

Swarnkar S., Sinha, R., Tripathi, S. (2020). Morphometric diversity of supply-limited and transport-limited river systems in the Himalayan foreland. *Geomorphology, Volume 348*, 1 Jan 2020, 106882. https://doi.org/10.1016/j.geomorph.2019.106882.

Wahiduzzaman, M., Yeasmin, A. (2022). An Observation of the Changing Trends of a River Channel Pattern in Bangladesh Using Satellite Images. *Applied Sciences (2022), Volume 12*, Issue 22. https://doi.org/10.3390/app122211604.

Appendix

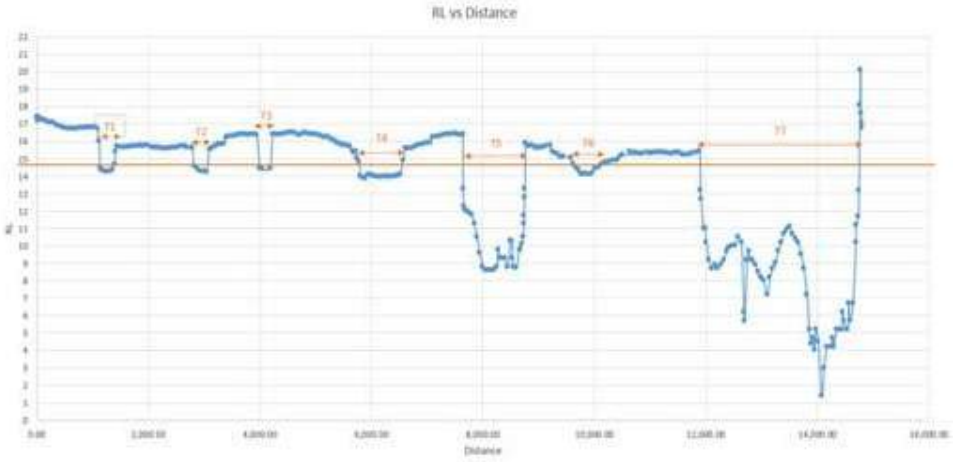
Figure A1: Cross Section at Station RMJ11 in 2006



Source: Authors' own work. Cross-sectional data obtained from Bangladesh Water Development Board (BWDB).

Note: T1=2150 m, T2 =289 m, T3= 707 m, T4= 435 m, T5= 5293 m,
B= 14,600 m; N=5
PFI = (2150+289+707+435+5293)/14600 * (100/5)= 12.16.

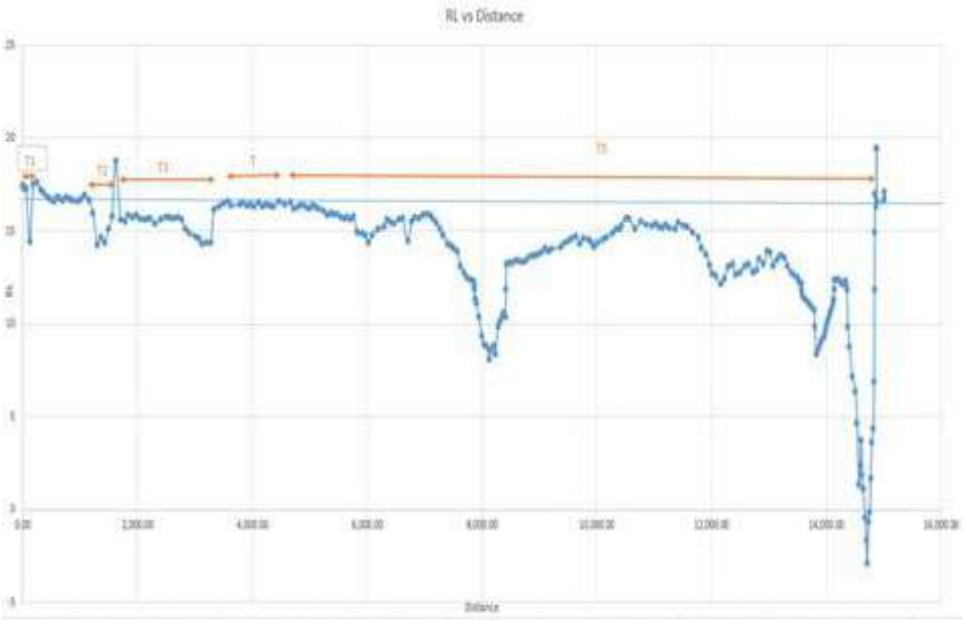
Figure A2: Cross Section at Station RMJ11 in 2008



Source: Authors' own work. Cross-sectional data obtained from Bangladesh Water Development Board (BWDB).

Note: T1=225 m, T2 =230 m, T3= 190 m, T4= 760 m, T5= 1114 m, T6= 350m, T7= 2859
B= 14,800 m; N=7.
PFI = (225+230+190+760+1114+350+2859)/14800 * (100/7)= 5.52.

Figure A3: Cross Section at Station RMJ11 in 2010



Source: Authors' own work. Cross-sectional data obtained from Bangladesh Water Development Board (BWDB).

Note: T1= 60 m, T2 = 463 m, T3= 2050 m, T4= 710 m, T5= 10400 m.

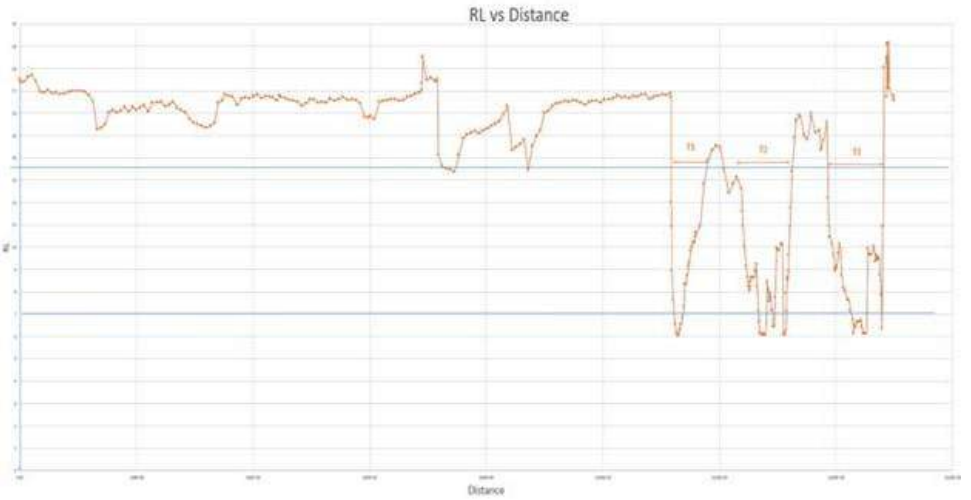
B= 15000 m; N=5; PFI = (60+463+2050+710+10400)/15000 * (100/5) = 18.244.

Figure A4: Cross Section at Station RMJ11 in 2011

Source: Authors' own work. Cross-sectional data obtained from Bangladesh Water Development Board (BWDB).

Note: T1=300m, T2 =420 m, T3= 140m, T4= 170 m, T5= 200 m, T6= 470m, T7= 850m, T8 = 2635m.
B= 15000 m; N=8.
PFI = (300+420+140+170+200+470+850+2635)/15000 * (100/8)= 4.32.

Figure A5: Cross Section at Station RMJ11 in 2012

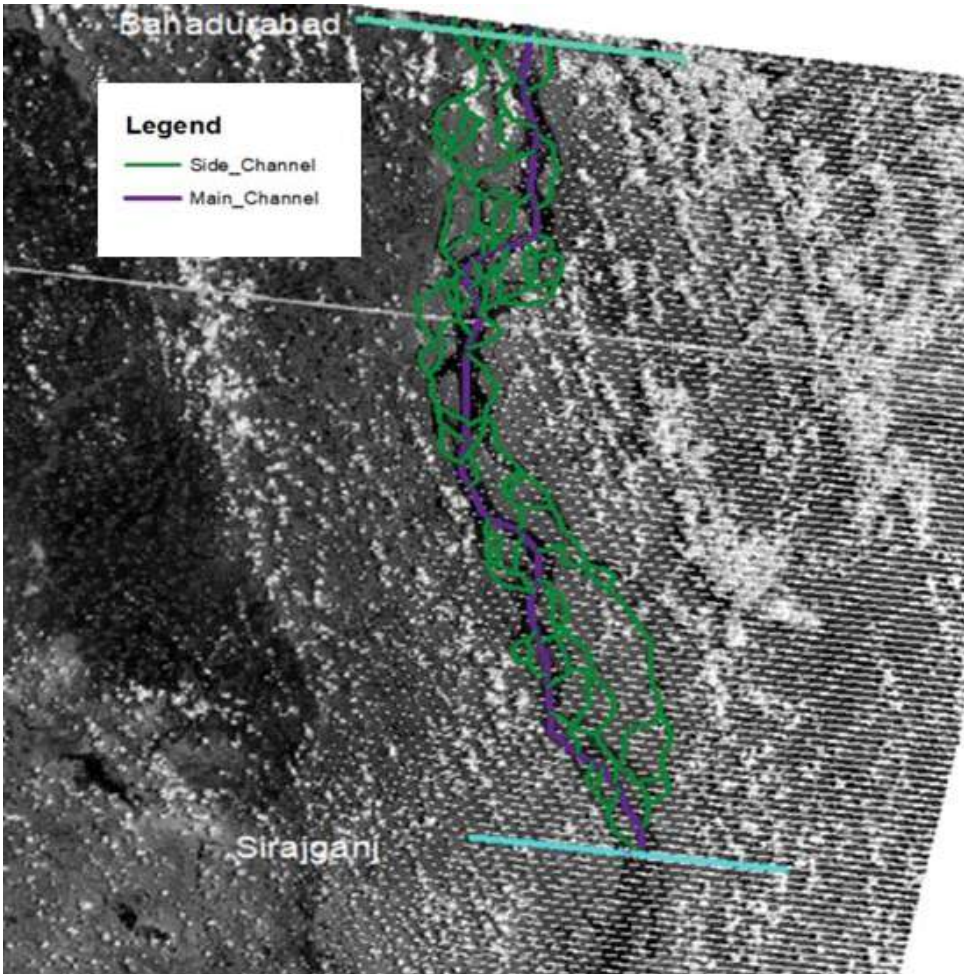


Source: Authors' own work. Cross-sectional data obtained from Bangladesh Water Development Board (BWDB).

Note: T1=630 m, T2 =870 m, T3= 960 m.

B= 15000 m; N=3; PFI = (630+870+960)/15000 * (100/3)= 5.47.

Figure A6: Main Channel and Side Channels in 2004

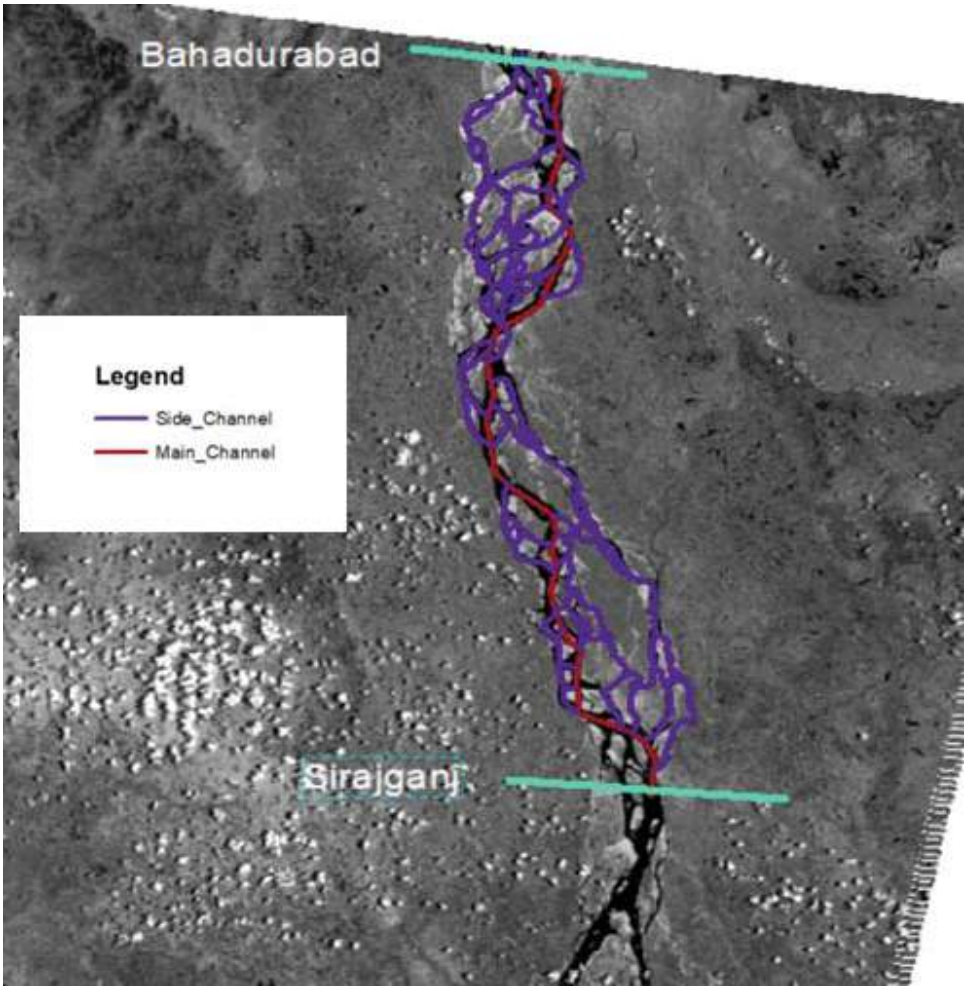


Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

Note: the main channel distance was found to be 119871 m. The total side channel distance was found to be 556469 m.

So BI = (556469+ 119871)/ 119871= 5.64.

Figure A7: Main Channel and Side Channels in 2006

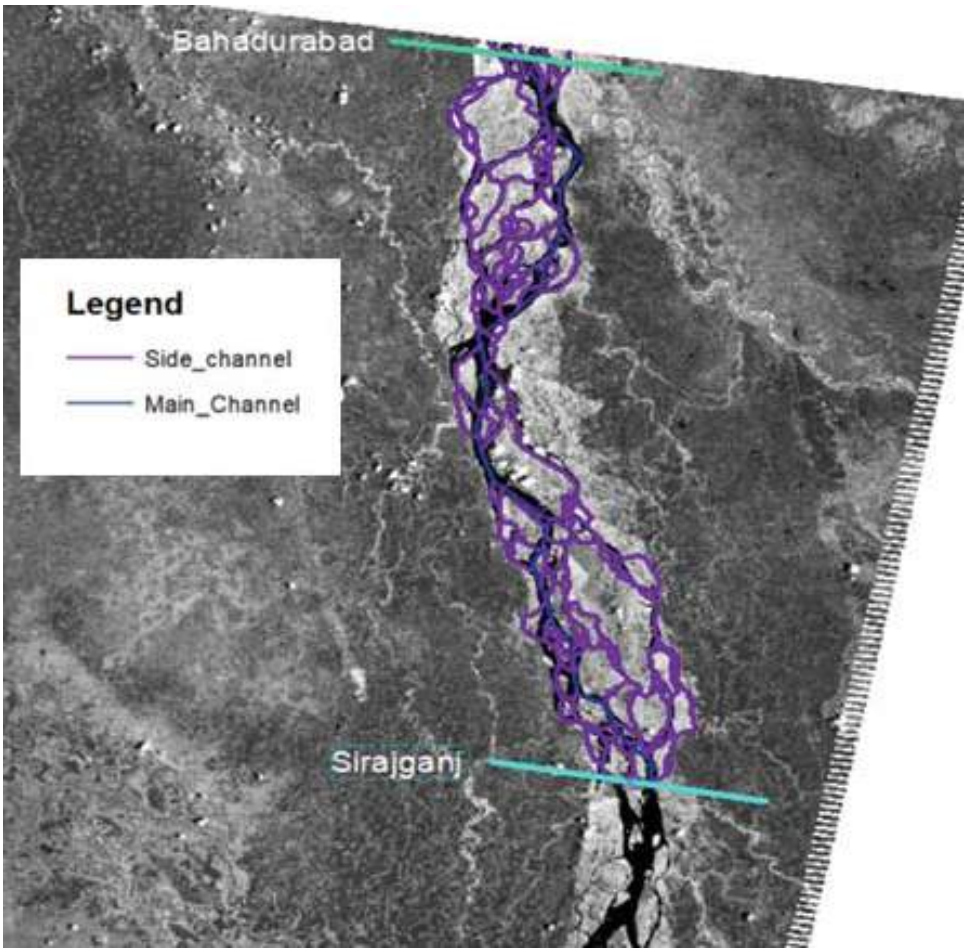


Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

Note: the main channel distance was found to be 118824 m. The total side channel distance was found to be 503272 m.

So BI = (503272+118824)/ 118824= 5.24.

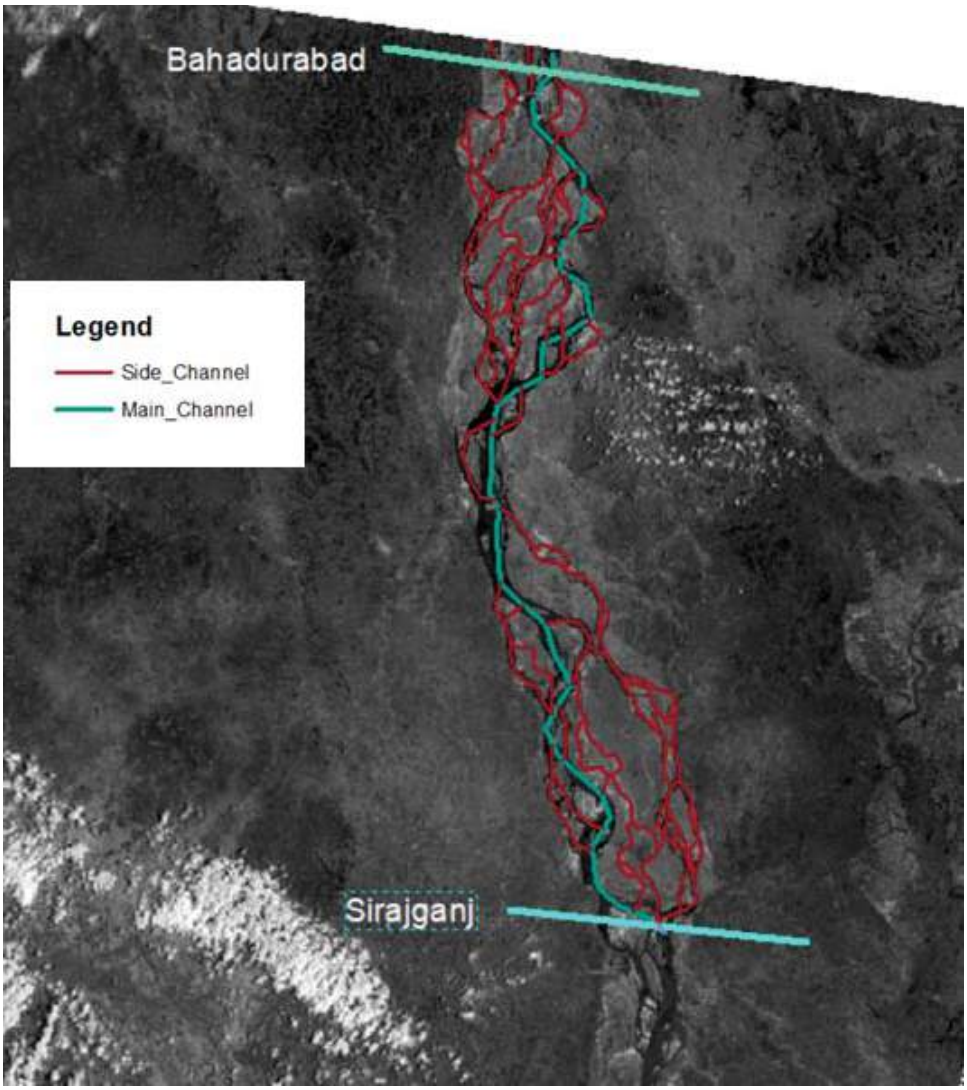
Figure A8: Main Channel and Side Channels in 2007



Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

Note: the main channel distance was found to be 113551 m. The total side channel distance was found to be 672998 m.
So BI = (672998+113551)/ 113551
= 6.93.

Figure A9: Main Channel and Side Channels in 2011

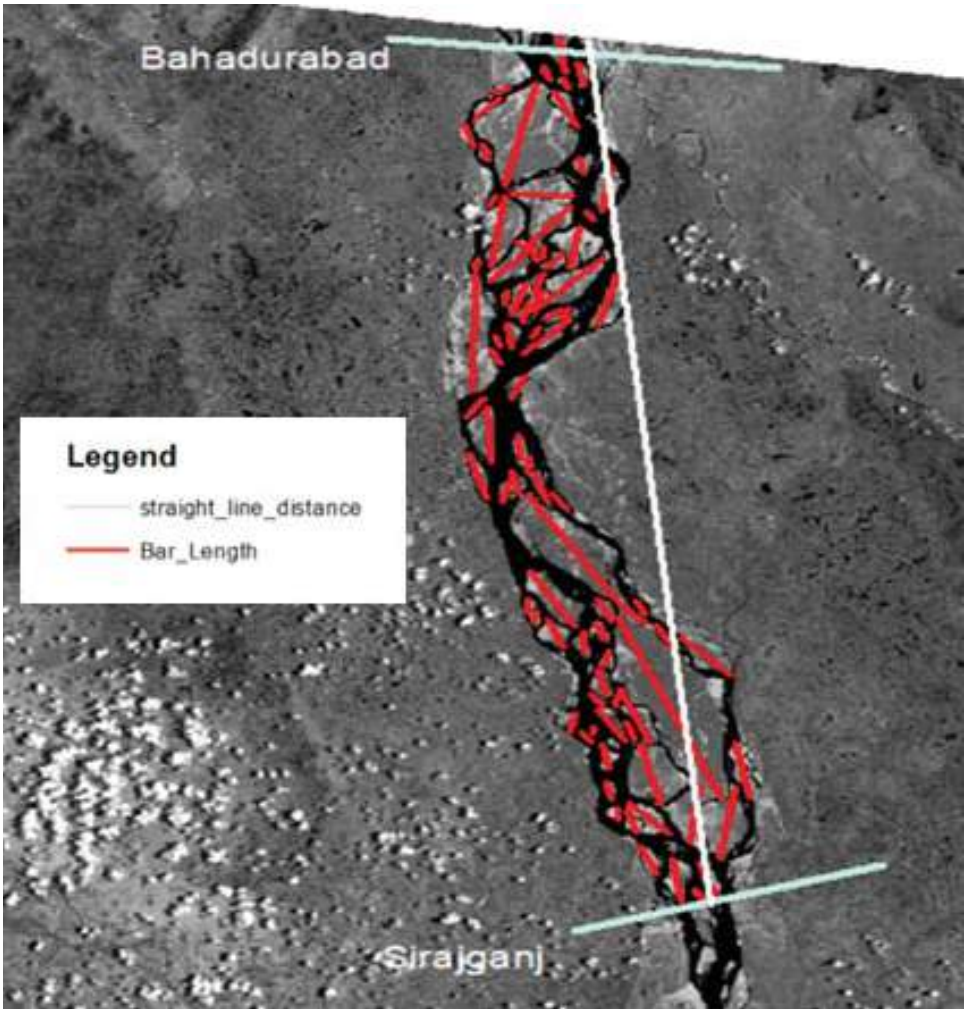


Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

Note: the main channel distance was found to be 118979 m. The total side channel distance was found to be 536650 m.

So BI = (536650 + 118979)/ 118979= 5.51.

Figure A10: Bar Index Calculation, 2004

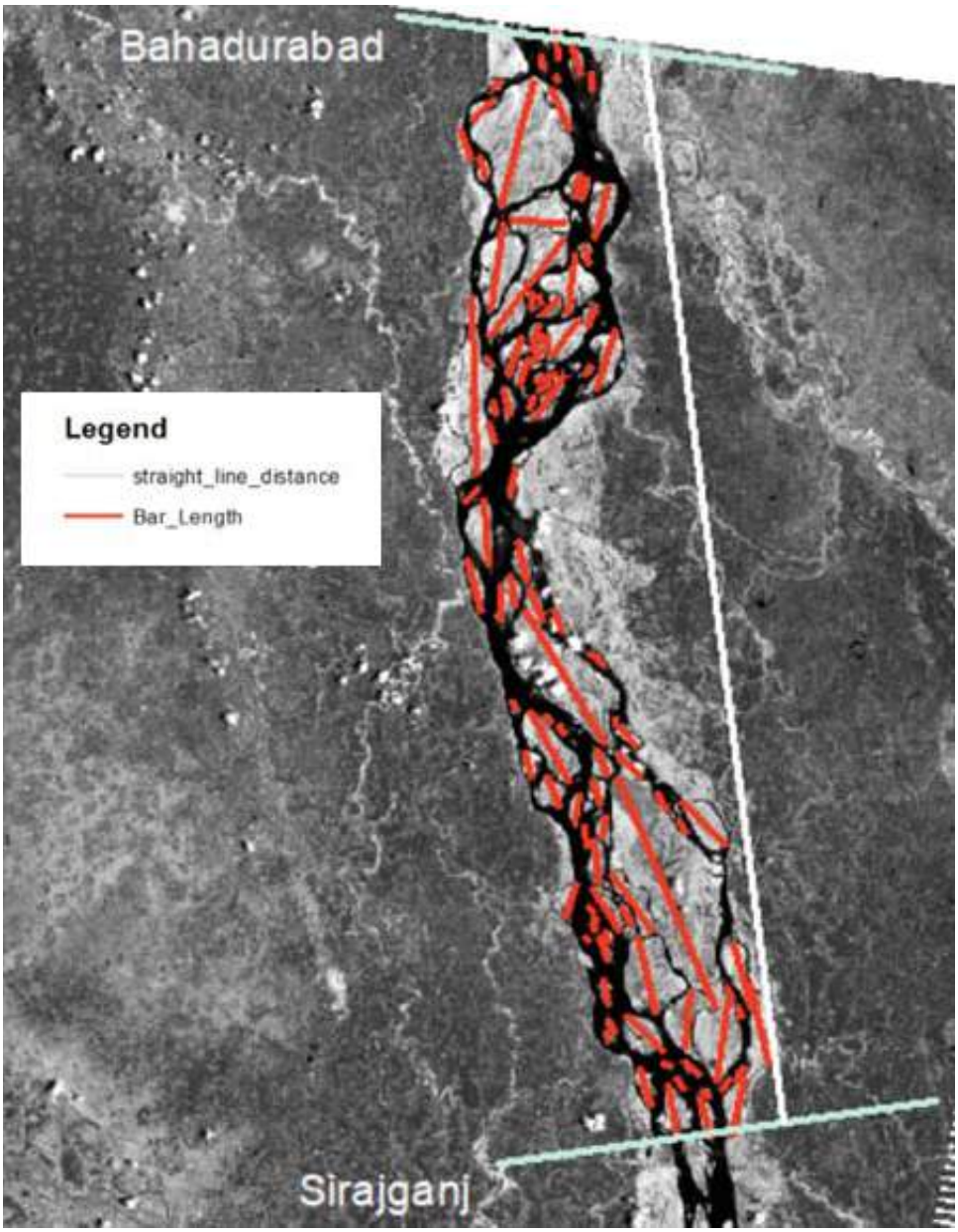


Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

Note: total length of bars is found to be 327133 m and the straight-line distance between Bahadurabad and Sirajganj was 99789 m.

Bar Index = 2*327133/99789=6.55.

Figure A11: Bar Index Calculation, 2006

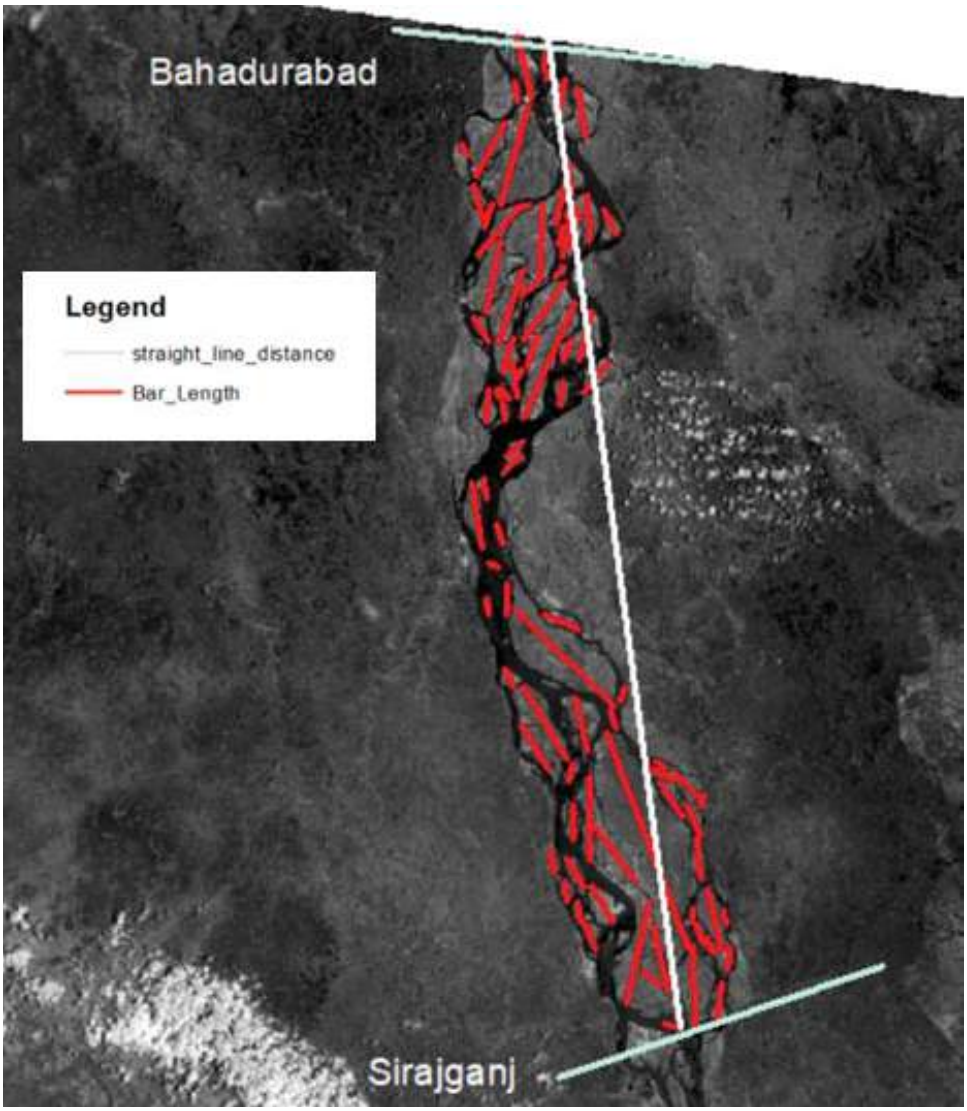


Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

Note: Total length of bars is found to be 358895 m and the straight-line distance between Bahadurabad and Sirajganj was 95358 m.

Bar Index = 2*358895/95358=7.53.

Figure A12: Bar Index Calculation, 2007



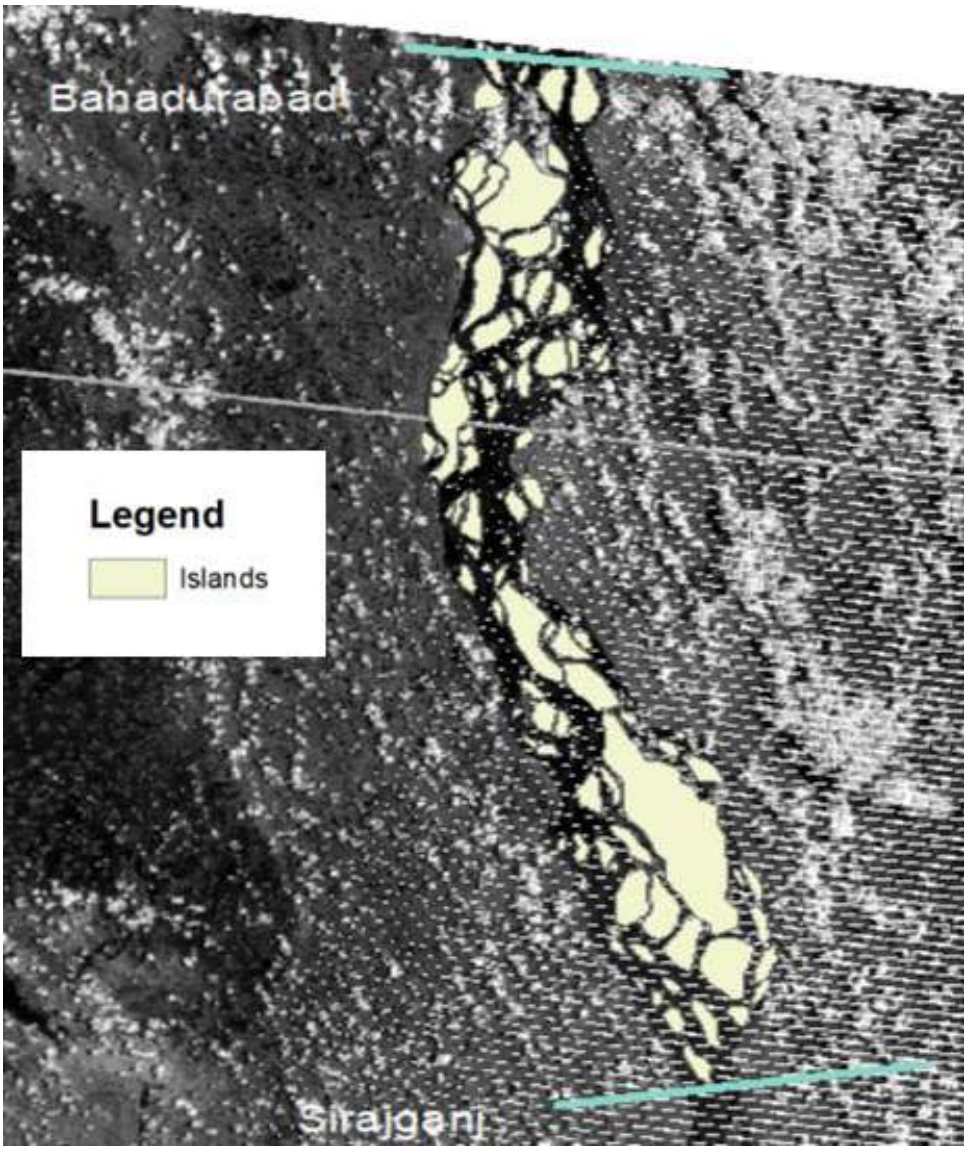
Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

Note: Total length of bars is found to be 337520 m and the straight-line distance between Bahadurabad and Sirajganj was 95709 m.

Bar Index = 2* 337520 /95709

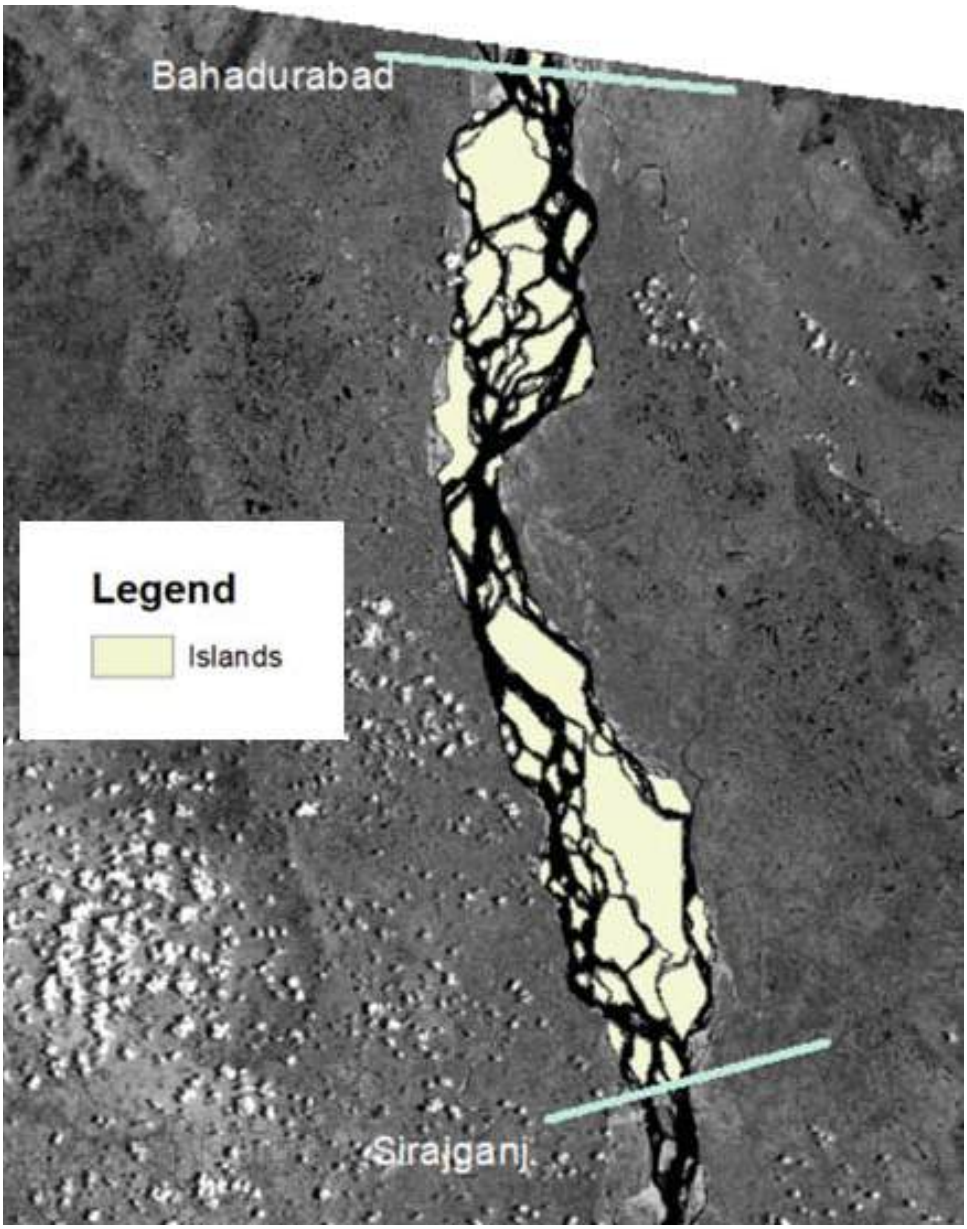
=7.05.

Figure A13: Bar Index Calculation, 2011



Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

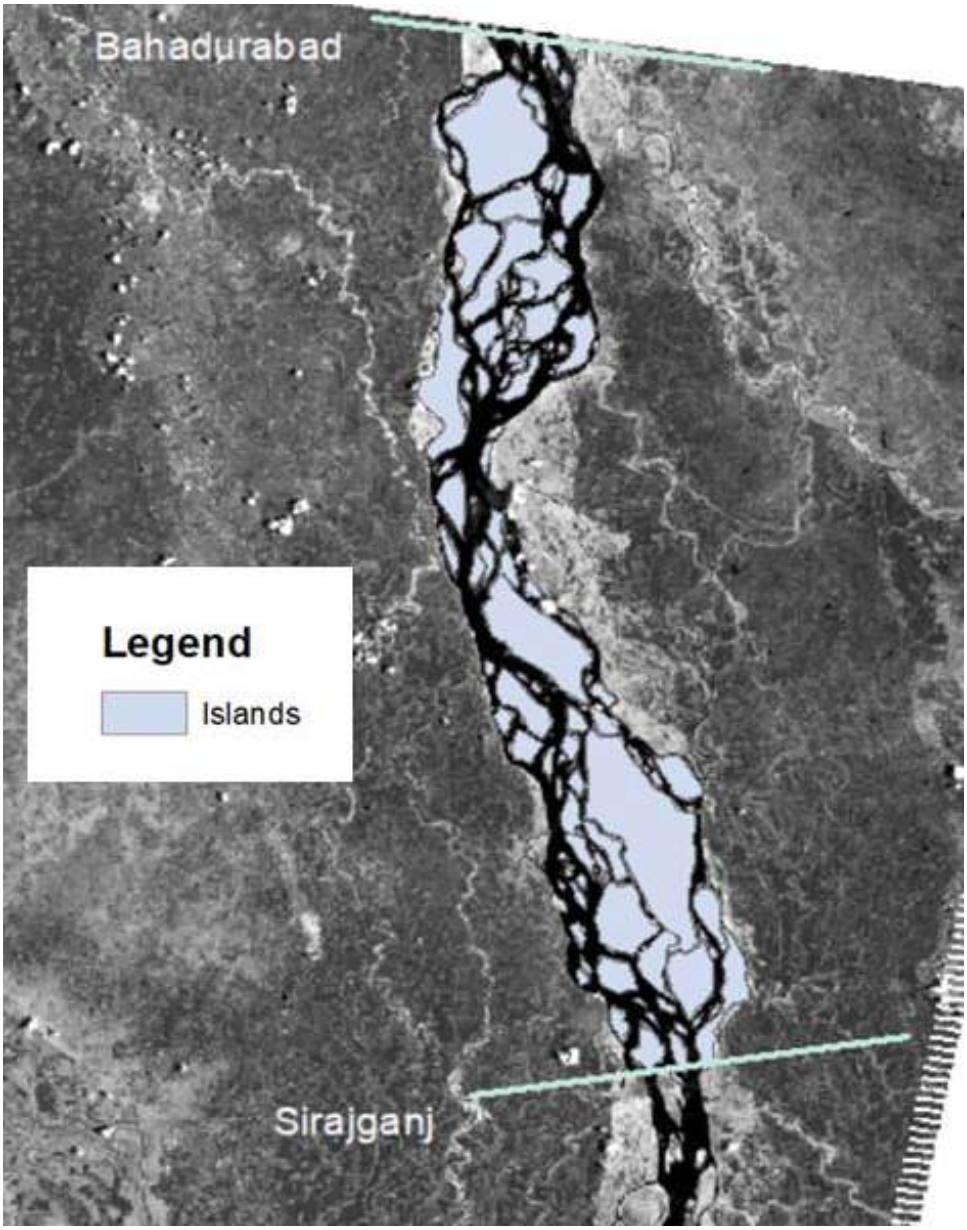
Figure A14: Number of Islands in 2004



Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

From the attribute table the total number of Islands was found to be 85.

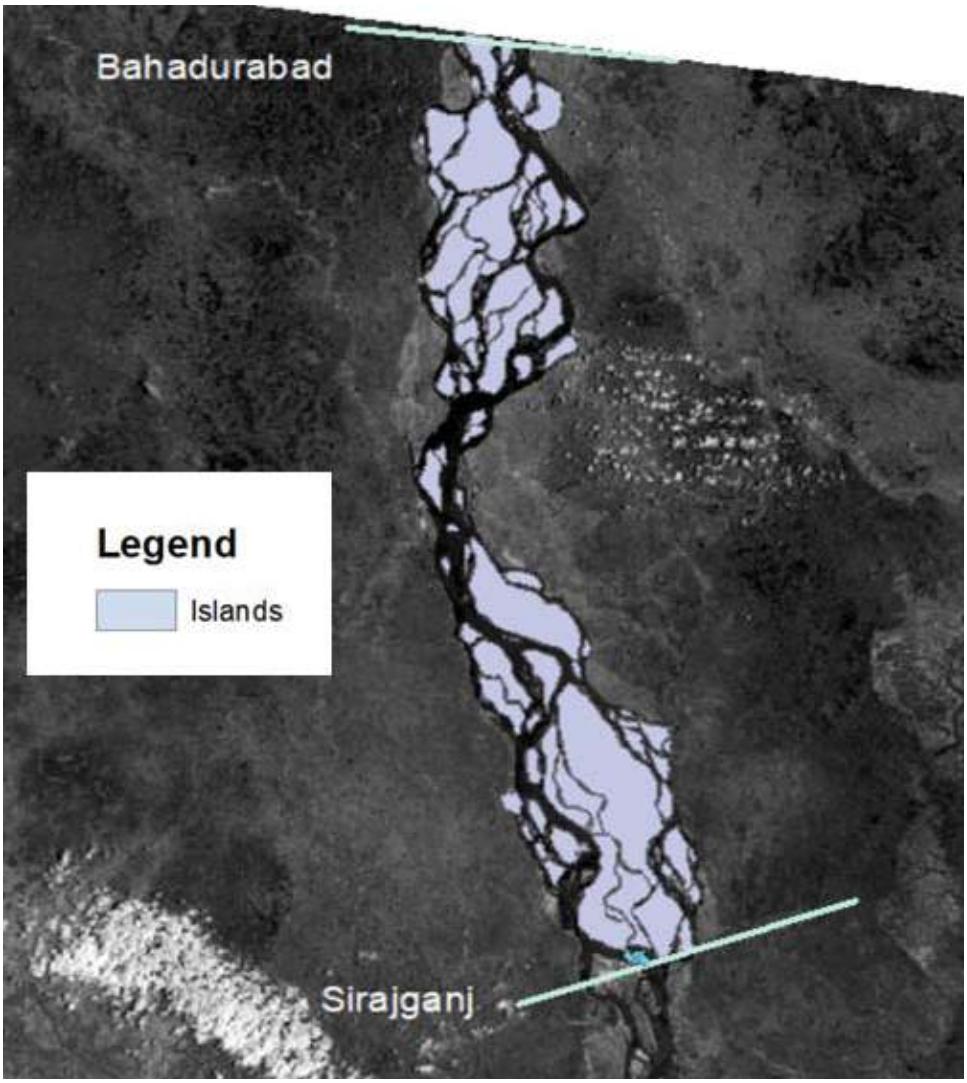
Figure A15: Number of Islands in 2006



Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

From the attribute table the number of islands was found to be 101.

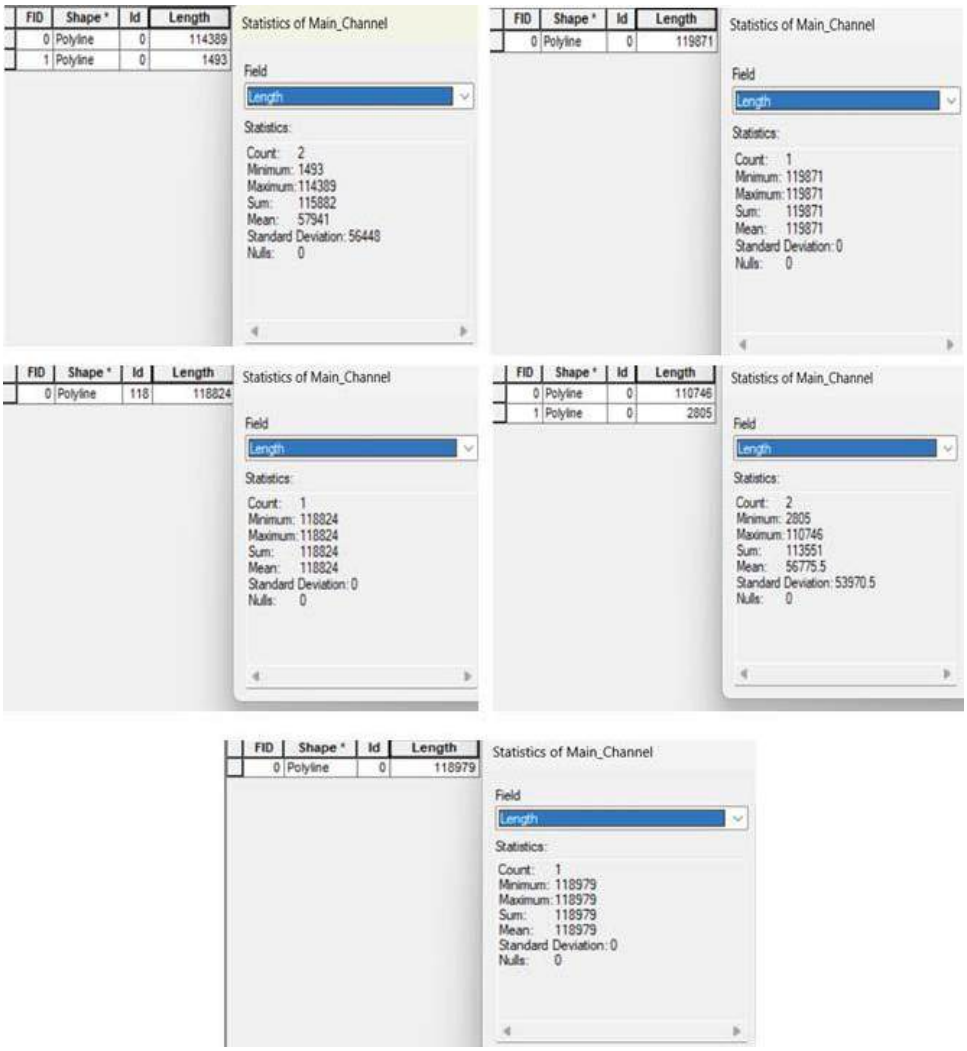
Figure A16: Number of Islands in 2007



Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

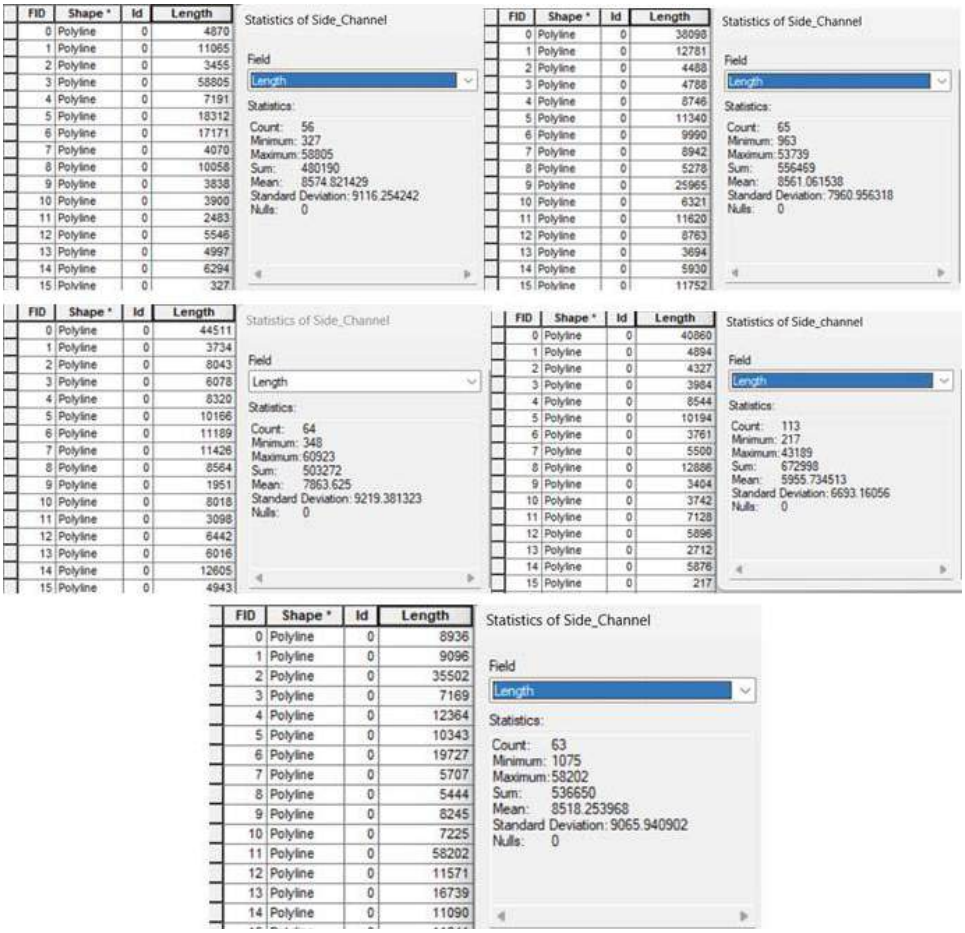
From the attribute table the total number of islands was found to be 88.

Figure A17: Number of Islands in 2011



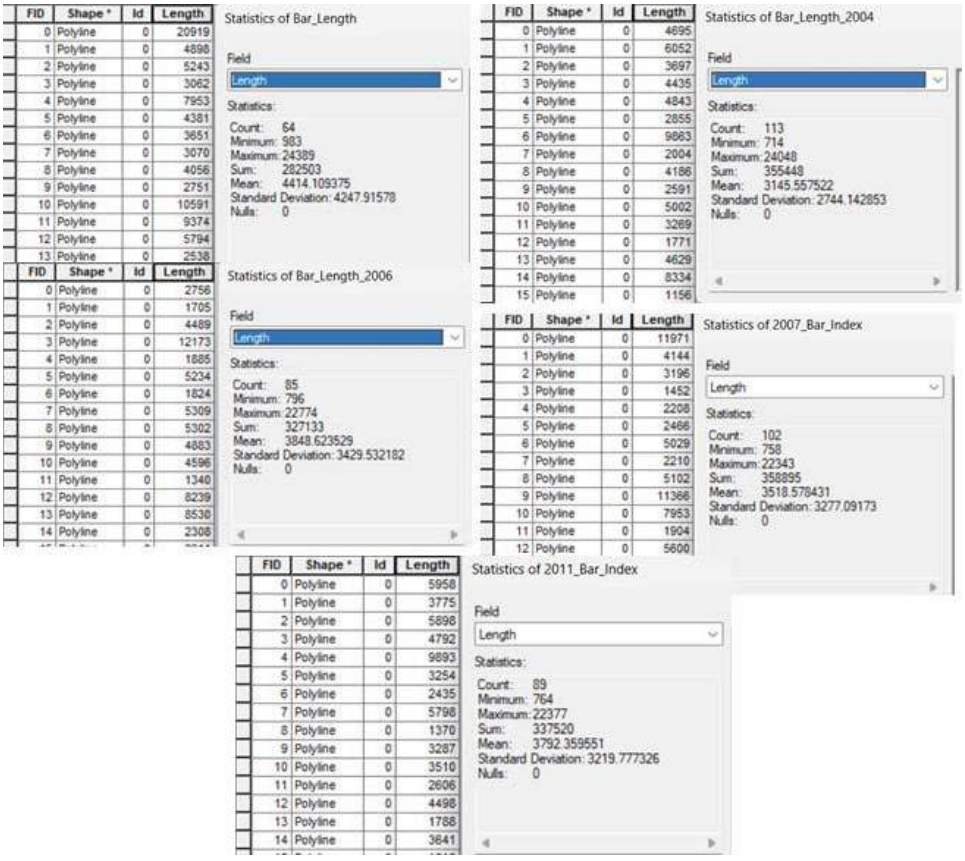
Source: Authors' own work. Satellite imagery obtained from USGS Earth Explorer (Landsat).

Figure A18: Attribute Tables for Main Channel Distances



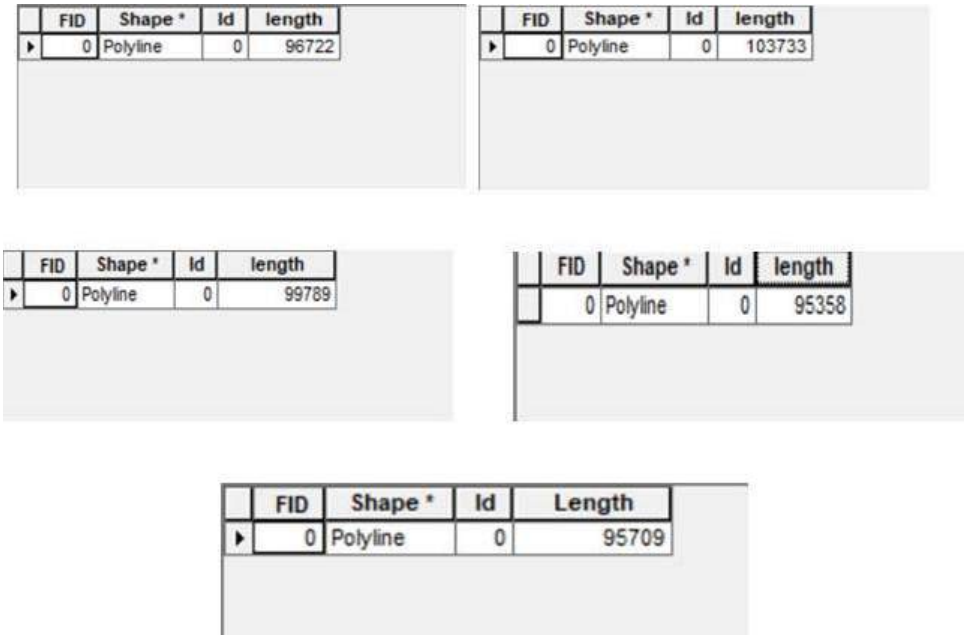
Source: Authors' own work. Generated in ArcGIS from USGS Earth Explorer (Landsat) satellite imagery.

Figure A19: Attribute Tables for Side Channel Distances



Source: Authors' own work. Generated in ArcGIS from USGS Earth Explorer (Landsat) satellite imagery.

Figure A20: Attribute Tables for Bar Length and Straight-line Distance



FID	Shape *	Id	length
0	Polyline	0	96722

FID	Shape *	Id	length
0	Polyline	0	103733

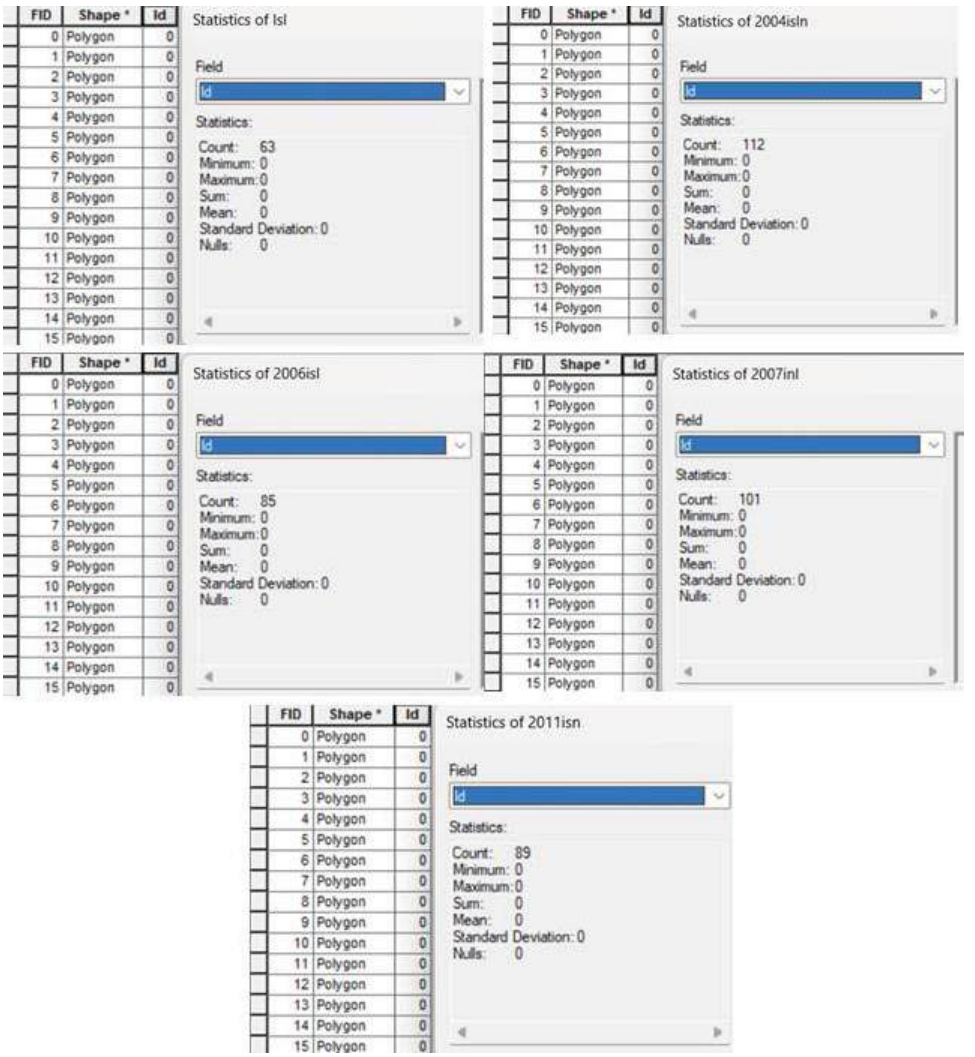
FID	Shape *	Id	length
0	Polyline	0	99789

FID	Shape *	Id	length
0	Polyline	0	95358

FID	Shape *	Id	Length
0	Polyline	0	95709

Source: Authors' own work. Generated in ArcGIS from USGS Earth Explorer (Landsat) satellite imagery.

Figure A21: Attribute Tables for Number of Islands



Source: Authors' own work. Generated in ArcGIS from USGS Earth Explorer (Landsat) satellite imagery.

Pakistan's Space Renaissance
A Pathway to Climate Resilience

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Abstract

Space technologies are being used as an important tool to tackle climate crises in the pre- and post-disaster management phases. This paper investigates the potential impact of Pakistan's space programme renaissance on increasing national climate resilience. This study uses an exploratory research design and qualitative methods, based on both primary and secondary data that are thematically analysed. This study employs the theoretical lens of technological determinism, which argues that technological innovation acts as the principal driver of social, political, and environmental transformation. It finds that Pakistan's expanding space-based infrastructure has strengthened anticipatory climate governance, particularly through near-real-time flood mapping, NDMA early warning reports, and the SACRED-SUPARCO disaster portal. The integration of domestic satellite data along with international imagery has expanded spatial coverage of climate-vulnerable regions, though continued dependence on foreign data highlights a partial capability gap. Overall, while Pakistan's technological capacity for climate monitoring has advanced considerably, institutional coordination and absorption capacity continue to shape the effectiveness of space-based contributions to climate resilience.

Keywords: Pakistan's space renaissance; Climate Change; Climate Resilience; Pakistan's National Space Policy; Technology and Climate.

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1. Introduction

Pakistan commenced its space journey by establishing the Space and Upper Atmospheric Research Committee in 1961 (International Astronautical Federation, 2025). This Committee was upgraded into the Space and Upper Research Commission (SUPARCO) by presidential order in 1987 (Mehmud, 2018, pp. 217-226). SUPARCO is designated as the National Space Agency of Pakistan in the National Space Policy of Pakistan. This committee successfully launched a series of Badr Rockets into space in the 1960s with the help of the U.S., Russia, and Britain (SUPARCO, 2022a). Pakistan continued its space cooperation with other space-faring nations, including China. The most notable cooperation in space materialised with China, which launched Pakistan's first satellite, Badr-1, on a Chinese Long March 2E Rocket. Badr-II was launched in 2001 with Russian cooperation. Both Badrs were designed with the help of UK companies (SUPARCO, 2022b). The early phase of SUPARCO, from the 1960s to the 2000s, initiated the development of remote sensing and communication satellites and established ground stations for receiving and processing satellite data. This phase halted due to political instability, shifting national priorities, and limited resources. Owing to a limited budget, SUPARCO struggled to keep pace with rapid technological advancements (Iqbal, 2020).

Pakistan's space programme underwent a revival phase in recent years, driven by both national pride and practical necessities. Pakistan launched a guiding framework for its space programme in the form of National Space Vision 2047 (Syed, 2017) and the National Space Policy of Pakistan (Pakistan's National Space Policy, 2024), which emphasise international cooperation along with indigenous development. It aims to achieve socio-economic benefit at the national level by harnessing space technologies. Pakistan is exploring space for peaceful purposes, including remote sensing, imagery, telecommunications, atmospheric testing, communications, disaster management, weather forecasting, and resource mapping (MoFA, 2025a). Among these uses, one of the most significant is to mitigate the effects of climate change through space technologies.

Pakistan's space revival is significant in combating one of its biggest contemporary challenges: climate change. Pakistan is the 5th most vulnerable country to climate change, according to Germanwatch Climate Risk Index (Abubakar, 2019; UN-Habitat, 2023; World Bank, 2022). Despite having the lowest contribution to carbon emissions, Pakistan is facing the implications of climate change in the form of recurrent floods, Glacial Lake Outburst Floods (GLOFs), droughts, torrential rains, and cloud bursts (National Institute of Public Administration, Peshawar, 2024). Public Policy Simulation Exercise on Climate Change and Its Implications for Pakistan during the 41st MCMC, held in 2024). The environmental, social, and economic effects of climate crisis are so huge that they cannot be quantified directly. Within five years, Pakistan faced two major floods, further underscoring the need for robust climate action and adaptation strategies (Relief Web, 2025). In this context, this paper discusses how space technologies are emerging as a critical tool for pre- and post-disaster management for climate-vulnerable countries like Pakistan. Remote Sensing and Earth Observation satellites provide essential information for monitoring climate change, crop monitoring, deforestation, air quality, water mapping, and urbanisation (MoFA, 2025b). Pakistan has actively integrated its satellite data for disaster management and is further taking measures to build climate resilience.

2. Literature Review and the Literary Gap

The space and climate nexus in Pakistan is an under-explored territory in literature because of its technicalities and less focus on research on space uses. However, there is limited literature on Pakistan's space programme in the context of socio-economic development. Ahsan and Khan (2019) trace the historical development of Pakistan's space programmes under SUPARCO, demonstrating its dependence on international funding and international partnership, particularly with China, contextualising it within South Asia's strategic and development context. They argue that Pakistan's revitalised interests in space are not shaped solely by security dynamics with India but also by socioeconomic needs for remote sensing applications in agriculture, water management, and disaster response, ultimately suggesting a Space 2.0 approach that highlights public-private partnerships and global cooperation (Ahsan & Khan, 2019). The main argument of the research is the framing of Pakistan's space assets, like PRSS-1 and PakTES-1A, as dual-use technologies that can yield both development advantages and strategic power. However, a significant weakness in their analysis is the lack of empirical evidence regarding how satellites have enhanced Pakistan's climate resilience or shaped disaster risk reduction strategies during climatic catastrophes. This gap highlights the need for further research connecting Pakistan's space capabilities explicitly to climate adaptation outcomes, particularly given the nation's crucial susceptibility to persistent floods, droughts, and GLOFs.

Going deeper into the literature, there is a paper that links satellite data to monitoring atmospheric CO2 levels in Pakistan. Mustafa et al. (2022) analysed the use of NASA's Orbiting Carbon Observatory-2 (OCO-2) satellite data and the Open-source Data Inventory for Anthropogenic CO2 (ODIAC) emission inventory to track human-induced C02 emissions across the 120 districts in Pakistan. The research emphasised that remote sensing can successfully monitor the spatial and temporal changes in emissions, particularly in Punjab, Sindh, and the China-Pakistan Economic Corridor, where industrial and agricultural activities are intensive (Mustafa et al., 2022). The authors contend that satellite observations provide important information for climate change mitigation and strategy, as their results show significant links between CO2 levels, NO2 output, and population density. Nonetheless, a significant drawback of the paper is its restricted precision in areas with cloud cover and mountainous terrain like Gilgit-Baltistan, along with discrepancies in low-emission zones where ODIAC depends heavily on nighttime light data, which limits its reliability at smaller scales.

Some recent studies underscore the significance of space technologies in Pakistan in disaster risk reduction. Akhtar and Mehboob (2024) argue that Pakistan has advanced notably in utilising space-based technologies in different sectors, ranging from socio-economic development to climate monitoring, including Earth Observation (EO), Geographic Information System (GIS), Artificial Intelligence (AI)/ Machine Learning (ML), and other high-performance computing, to enhance disaster risk reduction via programmes like PRSS-1, PRSC-EO1, SACRED, and NatCat. They emphasise that these technologies facilitate flood mapping, risk evaluation, and connection with the National Disaster Management Authority (NDMA), but also point out the significant shortcomings, such as the lack of Synthetic Aperture Radar (SAR) satellites, insufficient last-mile communication to the provincial authorities, and disjointed data integration among several agencies (Akhtar & Mehboob, 2025). Although their research offers an extensive overview of the current

institutional and technological capabilities, it is predominantly descriptive and focuses on the policy, missing empirical validation or quantitative assessment of the promptness, precision, and practical efforts of these space-oriented instruments. This gap highlights the need for additional research on how Pakistan's space programme can be implemented more efficiently to improve the national climate resilience.

Rauf and Chohan (2020) analyse the use of space technologies in Disaster Risk Management (DRM), particularly highlighting insights applicable to Pakistan, and positioning their research within the larger conversation about technological advancements for governance and resilience. Utilising international case studies from the USA, China, and India, the authors illustrate how remote sensing, satellite communication, and early warning systems have been incorporated into successful DRM frameworks (Rauf & Chohan, 2020). They assert that Pakistan's existing institutional and technological capabilities, as evidenced by entities such as SUPARCO and NDMA, remain underdeveloped, hindered by financial constraints, inadequate coordination, and a lack of necessary technical expertise and oversight. The study highlights the potential benefits of funding space-based infrastructure for risk evaluation, early warnings, and cooperation among organisations, while underscoring the need for local and global alliances to tackle resource shortages. This creates an opportunity for further study, particularly regarding how advanced technologies such as Synthetic Aperture Radar (SAR) satellites could strengthen Pakistan's capacity to cope with climate change and enhance its real-time monitoring effectiveness.

Existing scholarship provides valuable insights; there remains a notable paucity of research explicitly linking space-based technologies with measurable outcomes in climate adaptation and resilience in Pakistan. This paper differs from existing studies by providing an integrated, outcome-oriented investigation of how Pakistan's space renaissance affects its climate resilience and governance. Moreover, this study fills the theoretical gap by applying a theoretical lens of technological determinism to Pakistan's space and climate nexus. This study also fills a timely gap by covering the latest developments, such as EO and PRSC-S1, and their relationship with climate resilience indicators. This study gives a holistic account of Pakistan's renaissance, including domestic advancements and international cooperation used for pre-disaster and post-disaster management of the climate crisis.

3. Technological Determinism

This study employs the theoretical lens of technological determinism originating from the Cold War era, which argues the relationship between technology and politics. During this era, nuclear and space technologies were shaping global politics. James Moltz is the major proponent who applied technological determinism to space technologies. He believes that technological advancement influences national perception and policies. The central argument of this theory is that technological innovation acts as the principal driver of social, political, and environmental transformation (Moltz, 2018). In the context of space exploration, it asserts that technological advancements such as remote sensing satellites, Earth Observation systems, and communication satellites are likely to influence environmental policies and governance. Technology is the catalyst for cooperation, as space exploration is costly and complex. Hence, such cooperation on technological matters fosters peace, reducing the likelihood of conflict. Therefore, states collaborate on scientific research,

data sharing, and joint missions. Technological progress in space leads to global benefits or benefits for all. Space technologies help in flourishing new industries and uplifting society. Thus, it plays a significant role in achieving Sustainable Development Goals (SDGs).

Pakistan's space revival can be seen through the lens of technological determinism. Space Vision 2047 is a guiding map for Pakistan to harness space technologies for peaceful uses. Space Vision 2047 has a mission statement that says 'building, launching, and operating communication, remote sensing, weather, and navigation satellites and developing their applications and spin-off technologies for national security and socioeconomic development by 2047'. Pakistan has adopted technological determinism to achieve these goals. Pakistan has adopted collaboration with other space-faring nations, such as the US in the early phase and China in the revival phase. Pakistan's space programme has continued to overcome obstacles and move forward towards its goals. The National Space Policy of Pakistan emphasises the significance of international cooperation. Moreover, Pakistan is integrating space technologies to tackle governance issues such as disaster management and climate mitigation.

However, this study does not treat technological determinism as an automatic or linear causal model. While Pakistan's development of remote sensing and communication satellites expands its technical capacity for climate monitoring and disaster response, translating technological capability into effective climate governance depends on institutional coordination, bureaucratic capacity, and political prioritisation.

4. Research Methodology

This study adopts an exploratory research design to examine the role of Pakistan's space programme in mitigating the effects of the climate crisis. This study uses a qualitative research design.

This study is positioned in a post-positivist paradigm where its ontology is the subjectivity of reality, and epistemology is interpretivism. The primary research question is: How do Pakistan's space capabilities influence and enhance climate action and environmental sustainability?

To reach its research objectives, this study uses a qualitative case study design. Primary data is gathered on the basis of purposive sampling from official websites, statements, policy documents, and Pakistan's Foreign Office Press Releases. These documents were selected based on their explicit reference to satellite applications, environmental monitoring, disaster management, or climate-related technological initiatives. Secondary data is gathered from credible sources like journal articles, think tank reports, magazine articles, news, and books that discuss space technology and climate governance in developing states.

Collected data is analysed according to thematic analysis. Major recurring concepts related to space technologies and environmental sustainability are identified and explained in subsequent headings through open coding. Axial coding is used to group these codes into broader analytical categories such as flood early-warning, agricultural monitoring, environmental mapping, and institutional coordination. This study uses a theoretical lens of technological determinism to understand the spillover effect of space technology on

climate change mitigation. Reliability is ensured through a transparent coding framework and systematic documentation of source selection criteria. Data sources were verified for authenticity, and analysis followed a structured coding framework to minimise researcher bias. Thematic patterns were cross-checked multiple times for internal consistency. Validity is enhanced through data triangulation, comparing and cross-verifying information from diverse sources. Data is triangulated through comparing information from various sources, and only consistent facts and data are used.

This research will explore existing space technologies and infrastructure that are being used to tackle the climate crisis. It further recommends how Pakistan can expand according to its evolving needs.

5. Discussion and Analysis

5.1 Pakistan's Space Renaissance

As mentioned earlier, Pakistan's space programme dates to the 1960s, with various ups and downs. However, Pakistan's space programme entered the revival era post-2010 with renewed focus, increased funding, and international collaborations. In July 2011, Pakistan's Prime Minister Syed Yousaf Raza Gillani approved Pakistan's Space Program 2040, which aimed to harness 'the full spectrum of space technology to the people of Pakistan' (AFP, 2011). Later, this was renamed as 'National Space Programme 2047' (Syed, 2017). In 2011, Pakistan launched Pakistan Satellite (PAKSAT-1R), a communication satellite with the help of a Chinese Satellite Launch Vehicle (SLV) (Salman Siddiqui, 2011). Pakistan and China signed an agreement to develop and launch Pakistan's Remote Sensing Satellite (PRSS-1) (APP, 2018). Meanwhile, Islamabad also indigenously built another satellite, Pakistan Technology Evaluation Satellite (PakTes-1A). It is a remote sensing technology that serves as a demonstration for future innovations (Sehrish Wasif, 2018). Both these satellites were launched by the Chinese Long March SLV in 2018. PRSS-1 is the first Earth observation satellite providing high-resolution imagery for civilian uses like land and resource surveying, urban planning, and disaster management. Data from these satellites is used for the socio-economic benefits of the country.

SUPARCO carried out several key launches in 2024 and 2025. On May 3, 2024, Pakistan launched its first lunar nanosatellite, the iCube-Qamar, as a part of China's Chang'E 6 lunar mission. It was indigenously developed by the students at the Institute of Space Technology (IST), Pakistan (Guramani, 2024). It has two cameras that allow it to take moon photos. On May 30, 2024, a geostationary communications satellite, PAKSAT-MM1, was also launched (SUPARCO, 2024.) It provides high-speed internet and enhances broadcasting and telecommunications. Pakistan collaborated with China for the launch of this satellite. In January 2025, Pakistan launched the Electro-optical satellite (EO-1) for earth observation purposes (Reuters & Nadir Guramani, 2025). It provides high-resolution imagery for applications such as agriculture, urban planning, disaster management, and environmental monitoring. Another Remote Sensing Satellite (Congram, 2025), PRSC-S1, was launched on 31st July 2025 for Earth observation. Its primary function is to provide high-resolution imagery for environmental analysis, disaster mitigation, and tracking of CPEC projects. SUPARCO launched its first hyperspectral satellite in October 2025 (Khan, 2025). It is also

aimed at providing data for agricultural monitoring, mineral exploration, ecosystems, and environmental research.

In January 2024, Pakistan published its National Space Policy, which would serve as a framework for the country's space effort (Pakistan's National Space Policy, 2024b). It reaffirms Pakistan's position on the peaceful use of space technologies. It emphasises the socioeconomic benefits of space technologies that will reduce poverty. To address funding limitations, Pakistan's National Space Policy encourages collaborations between the public and private sectors. Pakistan's space programme exemplifies the conduct of a responsible space-faring nation that adheres to international space standards.

Pakistan's Space Vision 2047 includes international cooperation to achieve its goals. The major goals under Space Vision are satellite development, space applications, and human spaceflight. A key focus of this space programme is to harness space for civilian uses such as climate monitoring and disaster management. According to this programme, Pakistan plans to establish a constellation of Earth Observation satellites for water resource management, agricultural monitoring, flood tracking, and urban planning monitoring. This initiative also includes communication satellites, which will improve nationwide connectivity.

Sino-Pak space collaboration played a significant role in the revival of Pakistan's space programme. Besides providing launching facilities, China also facilitates Pakistan in technical assistance, training, and technology transfer in satellite development. There are future agreements between both countries on a manned moon mission as well. Pakistan has also signed up for the Beidou Navigation System of China (SUPARCO, 2024). This cooperation has accelerated the pace of advancement of Pakistan's space programme.

5.2 Pakistan's Climate Challenges: A National Overview

Environmental crises are a transnational threat that spares no country. But few countries are more vulnerable than others. The world has been witnessing a temperature rise of 1.6 degrees Fahrenheit since 1906. This global warming has multifaceted impacts worldwide. Pakistan serves as a poignant example of vulnerable nations in the face of climate change. Before the catastrophic floods of 2022, Pakistan was ranked as the eighth most vulnerable country and the 27th least prepared country (Government of Pakistan, 2021a) in the world to mitigate climate challenges. However, the devastating floods of 2022 and 2023, which submerged one-third of the country and caused an economic loss of USD 30 billion, fundamentally altered its ranking in terms of risk profile. The Climate Risk Index of 2025 ranked Pakistan as the first most affected country among the top 10 in 2022, surpassing even the highly exposed nations both in the Global North and South (Germanwatch, 2025). The World Bank projected that the total dangers posed by severe climate-related occurrences, environmental decline, and air contamination are expected to lower Pakistan's GDP by a minimum of 18 to 20 per cent by the year 2050 (World Bank, 2022).

5.3 Role of Space Technologies in Climate Change Mitigation

Space technologies are crucial for addressing climate change by aiding in the monitoring, analysis, and execution of efficient strategies. Remote Sensing data from satellites is crucial in understanding the impacts of urbanisation on climate change. Satellites are used in mapping

greenhouse gas emissions, urban energy use, and air pollutants, which are used to study the impact of climate change efforts at the city or district level (Milesi & Churkina, 2020). Moreover, there are other uses of RS and GIS data, such as agriculture, Forestry, Disaster Management, Water Resources, Cryosphere Modelling, Coastal and Marine Applications, Coastal and Marine Resources, and geology and mineral prospection. Furthermore, at the micro level, applications are being made integrating Artificial Intelligence (AI) into satellite data to enhance the potential for climate change mitigation. These applications are significant in enhancing renewable energy systems and creating smart solutions for sustainability.

5.3.1 Pakistan Space-Based Assets and Climate Resilience

Pakistan's space initiative, led by SUPARCO, evolved into a small yet varied collection of satellites used for communication, earth observation, remote sensing, and ground stations (Table 1). While the domestic assets represent significant progress, their contribution to climate change mitigation remains limited yet notable.

In this study, climate resilience refers to the capacity of institutions and communities to anticipate, track, respond to, and recover from climate-related hazards using space-based data and technologies. Pakistan's space technologies are effectively involved in leading a pathway towards climate resilience. SUPARCO has established a significant ground station capacity in Islamabad and Karachi, enabling the reception of both local satellite data and imagery from European sources like SPOT-6 and Pleiades (SUPARCO, 2025). This provides access to a vast collection of geospatial data that facilitates climate resilience in Pakistan. Firstly, satellite-based observations are utilised to give flood early-warning. NDMA releases the Disaster Early Warning Report every three months, which includes warnings about precipitation, temperature, landsliding, snow production, and fog outlook (NDMA, 2025). Early-warning helps in disaster preparedness, which helps in risk reduction, making Pakistan resilient against the climate crisis. Secondly, SUPARCO also has a dedicated portal, Disaster Watch by Space Application Centre For Response In Emergency and Disasters (SACRED-SUPARCO), that provides imagery and mapping of floods, GLOFs, monsoon patterns, smog, earthquakes, droughts, landslides, and forest fires. It was highly active during the 2025 flood and helped in early warning by importing data from international satellite systems as well (SUPARCO, 2024).

This map (Figure 1) shows how space imagery helps to identify which villages and infrastructure are flooded. SUPARCO's near-real-time data enables rescue, relief, and road access planning by mapping the extent of inundation and assessing damage severity.

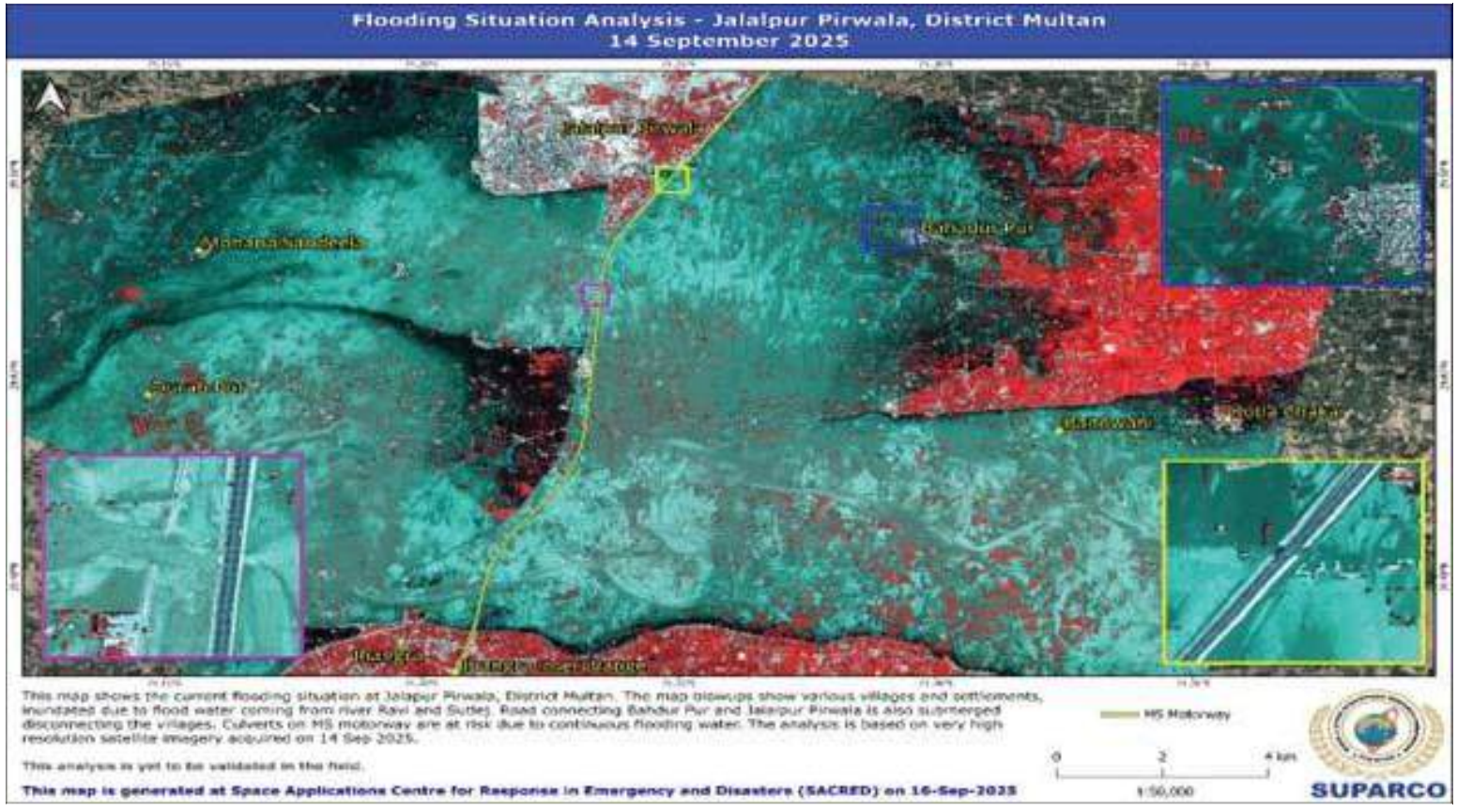
This map (Figure 2) shows how SUPARCO used space-based data to track flood progression and recession along the River Chenab. It provides crucial insight for disaster management authorities to plan recovery, assess damage, and predict flood behaviour.

Table 1: Major Pakistani Satellite Launches and Their Climate Applications

Satellite	Launch Year	Launch Partner / Vehicle	Satellite Type	Primary Functions	Relevance for Climate & Socio-Economic Resilience
PAKSAT-1R	2011	China (Chinese SLV)	Communication Satellite	Telecommunications, broadcasting, and internet connectivity	Supports disaster communication, emergency coordination, and digital connectivity during climate-induced crises
PRSS-1	2018	China (Long March SLV)	Remote Sensing / Earth Observation	High-resolution imagery for land surveying, urban planning, disaster management	Enables flood mapping, land-use monitoring, and climate risk assessment
PakTES-1A	2018	China (Long March SLV)	Indigenous Remote Sensing / Technology Demonstrator	Earth observation and technological experimentation	Builds domestic technical capacity and supports future climate-monitoring innovations
iCube-Qamar	2024	China (Chang'E-6 Mission)	Lunar Nanosatellite	Lunar imaging and scientific observation	Enhances indigenous space engineering capacity and academic–research integration (indirect long-term resilience contribution)
PAKSAT-MM1	2024	China (Collaboration)	Geostationary Communication Satellite	High-speed internet, broadcasting, and telecommunications	Strengthens the communication infrastructure crucial for disaster response and early warning dissemination
EO-1	2025	China (Launch Support)	Electro-Optical Earth Observation Satellite	High-resolution imaging for agriculture, urban planning, disaster management, and environmental monitoring	Improves precision agriculture, environmental surveillance, and disaster preparedness
PRSC-S1	2025	China (Launch Support)	Remote Sensing / Earth Observation	Environmental analysis, disaster mitigation, CPEC project monitoring	Enhances monitoring of climate-vulnerable regions and infrastructure resilience
Hyperspectral Satellite	2025	Indigenous (SUPARCO) China (Launch support)	Hyperspectral Earth Observation	Agricultural monitoring, mineral exploration, ecosystem, and environmental research	Enables advanced climate diagnostics, ecosystem health monitoring, and sustainable resource management

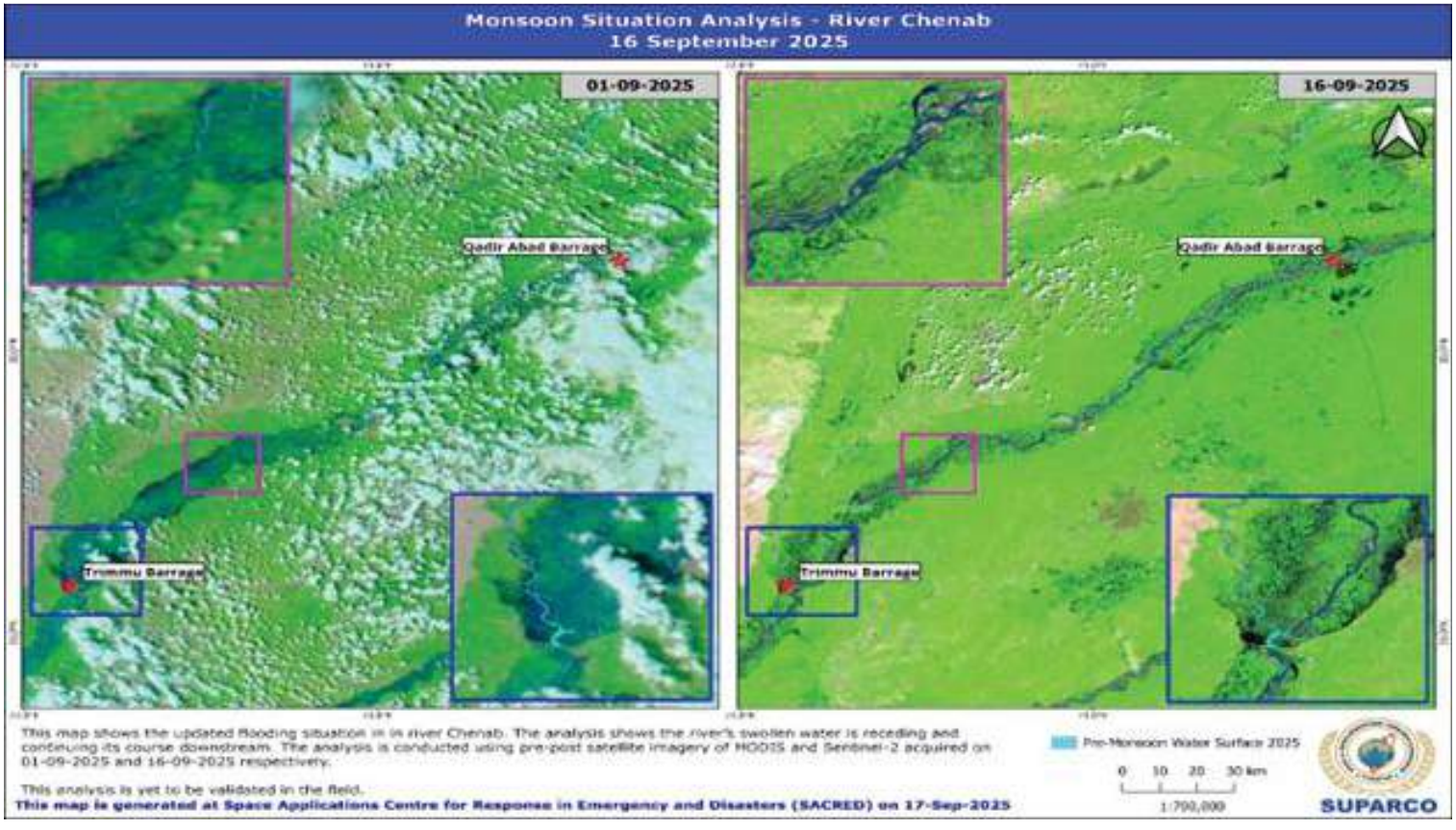
Source: Made by authors.

Figure 1: Flooding Situation Analysis



Source: From 'Monsoon 2025-Jalalpur Pirwala', by SUPARCO, 2025, Disaster Watch.

Figure 2: Monsoon Situation Analysis



Source: From "Monsoon 2025 Punjab – River Chenab," by SUPARCO, 2025, Disaster Watch.

SUPARCO has another web-portal, Pak-SCMS Bulletin, that releases crop monitoring reports predicting challenges according to satellite-based data. This helps states to adopt climate-smart agriculture (SUPARCO, 2025). Moreover, SUPARCO offers remote sensing and GIS services in areas closely related to climate change, such as agriculture, forestry, disaster management, cryosphere modelling, and coastal observation. Furthermore, aerial remote sensing enhances these initiatives by providing high-resolution, geo-referenced images for urban development and damage evaluation (SUPARCO, 2025).

Pakistan integrates diverse data sources that boost temporal coverage, enhance data reliability, and fill gaps in domestic satellite networks, thus reinforcing national climate monitoring and disaster response systems. Advisories and reports from SUPARCO and NDMA are then released as press releases and widely distributed through the media. Electronic and digital media are also used for this purpose. This information is also used by provincial and district governments to take necessary measures, such as evacuating, shifting people to safe areas, or preparing for emergency situations. It happened in the 2025 flood as well, where district government officials were actively involved in proactive measures and saved thousands of lives (Discover Pakistan, 2025). Technological determinism is an apt lens to explain Pakistan's commitment to use space technologies for the benefit of its people, which affects its national policies. However, the effectiveness of the measures of SUPARCO and NDMA depends upon the capacity and capabilities of governance institutions and mechanisms from the provincial to grassroots level.

5.3.2 Application of Space-Based Technology for Climate-Resilient Agriculture

The agricultural sector of a developing or underdeveloped country is the backbone of its state's GDP, and most of the population and workforce are heavily dependent on this sector. In the context of Pakistan, the agricultural sector is the most significant in Pakistan's economy and serves as its vital support. It represents 42.3 per cent of the workforce, 18.9 per cent of the GDP, and 80 per cent of overall export revenue (Government of Pakistan, 2021b). Pakistan's agriculture sector suffered from the floods of 2010, 2022, and 2025, resulting in damage of PKR 429 billion, PKR 800 billion, and approximately PKR 1 trillion, respectively (Ahmad Bukhari & Hassan Rizvi, 2017); (World Bank, 2022); (ReliefWeb, 2025).

Owing to the nature of risks to agriculture in Pakistan, there is a need to strengthen the integration of space-based data and AI models. The Agri Guard AI initiative represents an early-stage pilot illustration of space–AI integration in Pakistan's agricultural governance ecosystem. Mahroosh Umer, a Science, Technology, Engineering, Mathematics (STEM) student, led the creation of Agri Guard AI, which is an innovative platform designed to bolster climate-smart agriculture for smallholder farmers (Ahmed, 2025). She created a prototype of the platform with Glide, an interactive tool that enables farmers to visualise AI insights within actual farming scenarios. This model uses AI to process and analyse complex data from satellites and build a localised solution for the farmer. It also provides them with suggestions to improve soil health, optimise planting decisions, and help farmers access the carbon credit market. Her research is a pilot-illustration of Space-AI integration into conventional farming, enabling farmers to make informed, data-based choices daily. This model also serves as a practical and sustainable example for the agricultural sector of developing countries if applied efficiently. While Agri Guard demonstrates a strong example

of AI-satellite data integration, its adoption at the national level depends on governance institutions. Without formal incorporation into SUPARCO's long-term operational architecture or national agricultural policy frameworks, such initiatives risk remaining experimental rather than transformative.

6. Policy Recommendations

Pakistan set its path to space long ago and integrated space technologies for peaceful uses. In the context of challenges in incorporating satellite technologies in combating the climate crisis, here are a few recommendations to further enhance space use in the mitigation of climate change.

The immediate steps that Pakistan shall take to enhance the effectiveness of technology in climate resilience are as follows.

i) Enhance the coordination between national, provincial, district, and local level governance bodies in the effective implementation of proactive measures for risk reduction.

ii) Pakistan shall also adopt AI integration in space-based data to effectively and more efficiently assess the risk. Furthermore, this AI-powered prototype shall be adopted and launched at the national level by the government.

In the medium range, Pakistan needs to focus on technological development that is possible by following the steps.

i) Capacity building is the cornerstone of any ambitious programme. Pakistan is already working on capacity building. However, it should increase its focus on STEM education to nurture a skilled workforce. Space-related subjects should be added to all educational levels to enhance students' interest and to create a specialised talent pool.

ii) Targeted scholarships play a vital role in capacity building by easing financial stress and providing incentives. Students of STEM shall be given opportunities to collaborate with international students for the exchange of ideas and collaborative projects. Students shall be supported to study space-related subjects from international universities as well. It will bring a new wave of innovation in Pakistan's space programme.

iii) Human capital development is incomplete without subsequent training. To complement educational measures, specialised training workshops, internships, and research grants shall be offered to students. There should be an international outreach programme to provide international training to students. Hands-on learning opportunities and exposure to cutting-edge technologies and methodologies in space exploration will enhance professional capabilities.

iv) Public-private partnership is already at the heart of the financial management of Pakistan's space programme. The government should promote and financially support startups and innovation centres to enhance creativity and entrepreneurship. These focused centres will offer avenues for mentorship, resources, and networking opportunities.

In longer run, Pakistan needs to adopt the following policies:

i) Pakistan must continue to underline its worldwide commitment to the SDGs and the Paris Climate Agreement. Pakistan will continue to advocate for prudent space exploration for larger environmental and social goals. Space diplomacy is an effective instrument for addressing global concerns, particularly environmental catastrophe. To address climate concerns, Pakistan would participate through data exchange and joint space enterprises.

ii) Regional space diplomacy is an effective strategy for solving shared challenges and issues associated with the climate crisis. Pakistan must expand regional links and increase its joint capacity to address the environmental challenge. This could include collaborative satellite missions, shared ground stations, and integrated data analysis platforms. Pooling resources and skills will help to develop more efficient disaster management, agricultural planning, and water resource management techniques, all of which are vital to the region's climate resilience.

Conclusion

In a nutshell, Pakistan is using space-based technology to address environmental concerns such as water resource management and climate change mitigation. High-resolution satellite imagery and remote sensing data from Pakistani satellites and international partners are useful for monitoring water bodies, assessing groundwater levels, and identifying areas at risk of water scarcity. Various national institutions are involved in releasing early warnings for risk reduction. Pakistan has deeply integrated space technologies in pre-disaster and post-disaster management, which enhances its resilience against the climate crisis. The combination of these technologies with artificial intelligence and machine learning algorithms improves environmental monitoring and prediction capabilities, allowing for more precise and efficient decision-making processes. As we face increasingly complex environmental challenges, the collaboration between space technology and advanced analytical tools offers a viable path for developing novel solutions and policies to combat climate change and ensure sustainable resource management across multiple sectors.

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References

Abubakar, S. M. (2019, December 4). Pakistan 5th most vulnerable country to climate change, reveals Germanwatch report. *DAWN.COM*. https://www.dawn.com/news/1520402

Ahmad Bukhari, S. I., & Hassan Rizvi, S. (2017). Impact of 2010 Floods on Pakistan's Agriculture. *Journal of Environmental & Analytical Toxicology, 07*(01). https://doi.org/10.4172/2161-0525.1000424

Ahmed, A. (2025, August 18). Pakistani girl wins Global AI prize with sustainable farming tech. *Gulf News*. https://gulfnews.com/world/asia/pakistan/pakistani-girl-wins-global-ai-prize-with-sustainable-farming-tech-1.500236332

Ahsan, A., & Khan, A. (2019). Pakistan's Journey into Space. *Astropolitics, 17*(1), 38–50. https://doi.org/10.1080/14777622.2019.1578933

Akhtar, H., & Mehboob, M. (2025). Leveraging Space Science and Technology for Climate-Induced Disaster Management in Pakistan. *CISS Insight Journal, 13*(1). https://journal.ciss.org.pk/index.php/ciss-insight/article/view/410

An, N., Mustafa, F., Bu, L., Xu, M., Wang, Q., Muhammad Shahzaman, Bilal, M., Ullah, S., & Feng, Z. (2022). Monitoring of Atmospheric Carbon Dioxide over Pakistan Using Satellite Dataset. *Remote Sensing, 14*(22), 5882–5882. https://doi.org/10.3390/rs14225882

APP, N. S. |. (2018, July 9). Pakistan launches a remote sensing satellite in China. *DAWN.COM*. https://www.dawn.com/news/1418966

Camgram, J. (2025, July 31). *Pakistani Satellite Soars From Xichang! [Kuaizhou-1A Flight-30]*. China in Space. https://www.china-in-space.com/p/pakistani-satellite-soars-from-xichang

Discover Pakistan. (2025). *NDMA in Action | Flood Situation in Pakistan 2025 | Climate Change Effects* | Zoom In. In YouTube. https://www.youtube.com/watch?v=KS-dH4ptcjuc

Eckstein, D., Künzel, V., & Schäfer, L. (2016). *Global Climate Risk Index 2018*. https://www.germanwatch.org/sites/default/files/publication/20432.pdf

Fareed, M., & Qadir, S. (2025). *Post Winter Report 2024-25*. https://www.ndma.gov.pk/public/storage/publications/May2025/t4zNbmHpz9aReNlHNGaW.pdf

Germanwatch. (2025). *Global Climate Risk Index*. Germanwatch.org. https://www.germanwatch.org/en/cri

Government of Pakistan. (2021a). *Updated Nationally Determined Contributions 2021*. https://unfccc.int/sites/default/files/NDC/2022-06/Pakistan%20Updated%20NDC%202021.pdf

Government of Pakistan. (2021b). *National Climate Change Policy of Pakistan 2021*. https://policy.asiapacificenergy.org/sites/default/files/Updated%20National%20Climate%20Change%20Policy%20%282021%29_0.pdf

Guramani, N. (2024, May 10). Pakistan's iCube-Qamar beams back first images from moon's orbit. *DAWN.COM*. https://www.dawn.com/news/1832658

International Astronautical Federation. (2025). *IAF: Pakistan Space and Upper Atmosphere Research Commission*. Iafastro.org. https://www.iafastro.org/membership/all-members/pakistan-space-and-upper-atmosphere-research-commission.html

IPCC. (2023). *Sixth Assessment Report — IPCC*. Ipcc.ch; IPCC. https://www.ipcc.ch/assessment-report/ar6/

Iqbal, G. (2020, September 11). The Fall and Rise of Pakistan's Space Ambitions. *South Asian Voices*. https://southasianvoices.org/the-fall-and-rise-of-pakistans-space-ambitions/

Khan, Z. A. (2025, October 6). Pakistan to launch first modern hyperspectral satellite in Oct. *SAMAA TV*. https://www.samaa.tv/2087339612-pakistan-to-launch-first-modern-hyperspectral-satellite-in-oct

Mehmud, S. (2018). *Space Technology and Its Military Application*. Usmcu.edu. https://www.usmcu.edu/Outreach/Marine-Corps-University-Press/MCU-Journal/JAMS-vol-15-no-1/Space-Technology-and-Its-Military-Application/

Milesi, C., & Churkina, G. (2020). Measuring and Monitoring Urban Impacts on Climate Change from Space. *Remote Sensing, 12*(21), 3494. https://doi.org/10.3390/rs12213494

Ministry of Foreign Affairs (MoFA). (2025a). *Peaceful Applications of Space Technology in Pakistan: An Overview*. Mofa.gov.pk. https://mofa.gov.pk/vienna-peaceful-applications-of-spacetechnology

Ministry of Foreign Affairs (MoFA). (2025b). *Pakistan Successfully Launches Remote Sensing Satellite*. Retrieved from: https://mofa.gov.pk/press-releases/pakistan-successfully-launchesremote-sensing-satellite

Moltz, J C. (2018). *The Politics of Space Security*. Stanford University Press. https://www.sup.org/books/politics/politics-space-security-0

National Institute of Publica Administration, Peshawar. (2024). *Public Policy Simulation Exercise on Climate Change and its Implications for Pakistan During 41st MCMC held* on2024. https://nipapeshawar.gov.pk/KJPPM/PDF/CIP/js1.pdf

NDMA. (2025). *NEWSLETTER Towards a Disaster Resilient Pakistan NDMA INSIGHTS.* https://www.ndma.gov.pk/storage/publications/January2026/gkQw7FGYIhrlWEAhKFKR.pdf

Pakistan Flood Impacts on Agriculture & Food Security - Updated September 18th, 2025 - Pakistan. (2025, September 19). https://reliefweb.int/report/pakistan/pakistan-flood-impacts-agriculture-food-security-updated-september-18th-2025

Pakistan Flood Situation Update - 11 September 2025. (2025, September 11). Unocha.org. https://www.unocha.org/publications/report/pakistan/pakistan-flood-situation-update-11-september-2025

Pakistan Floods 2022 PDNA Main Report. (2022). Worldbank.org. https://thedocs.worldbank.org/en/doc/4a0114eb7d1cecbbbf2f65c5ce0789db-0310012022/

Pakistan Remote Sensing Satellite (PRSS-1) | SUPARCO. (2018.). Suparco.gov.pk. https://suparco.gov.pk/major-programmes/projects/prss-1/

Pakistan: Flash Floods - Jun 2025. (2025, July 24). Relief Web. https://reliefweb.int/disaster/fl-2025-000100-pak

Pakistan's National Space policy. (2024). Ibanet.org. https://www.ibanet.org/national-space-policy-pakistan

PakSAT-MM1 | *SUPARCO*. (2024.). Suparco.gov.pk. https://suparco.gov.pk/major-programmes/projects/paksat-mm1/projects/

Qureshi, S., Malik, S. A. A., Zia, U.-U. R., & Zulfiqar, M. (2025). *Climate-Smart Housing in Pakistan: Exploring Climate-Resilient Solutions for Urban Development. ICAME 2025, 23*. https://doi.org/10.3390/engproc2025111023

Rauf, A., & Chohan, U. W. (2020). Role of Space Technologies in Disaster Risk Management: Lessons for Pakistan. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3530032

Reuters, & Nadir Guramani. (2025, January 17). Pakistan launches its first homemade observation satellite EO-1. *Dawn*. https://www.dawn.com/news/1885863

Salman.siddiqui. (2011, August 11). PAKSAT 1R China launches Pakistan s first communications satellite. *The Express Tribune*. https://tribune.com.pk/story/229797/paksat-1r-china-launches-pakistan%E2%80%99s-%E2%80%98first%E2%80%99-communications-satellite

Sehrish.wasif. (2018, July 9). Pakistan launches two satellites using Chinese rocket. *The Express Tribune*. https://tribune.com.pk/story/1753260/pakistan-launches-two-satellites-using-chinese-rocket

Space Technology Applications | *SUPARCO*. (2025.). Suparco.gov.pk. https://suparco.gov.pk/major-programmes/space-technology-applications/

SUPARCO. *Space Technology Applications* | *SUPARCO*. Suparco.gov.pk. https://suparco.gov.pk/major-programmes/space-technology-applications/

SUPARCO. (2022a). *Suparco.gov.pk*. https://suparco.gov.pk/major-programmes/

SUPARCO. (2022b). *Suparco.gov.pk*. https://suparco.gov.pk/major-programmes/

SUPARCO. (2024). *DisasterWatch - SACRED-SUPARCO*. Sgs-Suparco.gov.pk. http://disasterwatch.sgs-suparco.gov.pk/

SUPARCO. (2025). *PAK-SCMS Bulletin | SUPARCO*. Suparco.gov.pk. https://suparco.gov.pk/crop-management/

Syed, B. S. (2017, December 22). Pakistan to retain full spectrum deterrence policy. *Dawn*. https://www.dawn.com/news/1378106

The signs of global warming are everywhere, and are more complex than just climbing temperatures. (2025). Eiu.edu.lb. http://www.eiu.edu.lb/newsroom/the-signs-of-global-warming-are-everywhere-and-are-more-complex-than-just-climbing-temperatures

UN-Habitat Pakistan | Un-Habitat Pakistan Country Report 2023. (2023). Unhabitat.org.pk. https://unhabitat.org.pk/un-habitat-pakistan-country-report-2023/

What's Happening at the IPCC? | unfoundation.org. (2025). Unfoundation.org. https://unfoundation.org/what-we-do/issues/climate-and-energy/climate-science/whats-happening-at-the-ipcc/?gad_source=1&gad_campaignid=19548803646&gbraid=0AAAAAD9kiAdI0K-8L5IV4gwpfk0Glb-vb&gclid=Cj0KCQiAgP_JBhD-ARIsANpEMxwdUwgK2jmEXUQ2gHaDwZH1DqPx8_rgK64iUkDpTWK-PKE1r2qYSeTsaAmyAEALw_wcB

World Bank. (2022). *Pakistan Urgently Needs Significant Investments in Climate Resilience to Secure its Economy and Reduce Poverty: World Bank Pakistan Climate & Development Report*. World Bank. https://www.worldbank.org/en/news/press-release/2022/11/10/pakistan-urgently-needs-significant-investments-in-climate-resilience-to-secure-its-economy-and-reduce-poverty

Locally Led Flood Resilience Through Nature-based Solutions

A Study of Kolkata's Hydraulic Ingenuity

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Abstract

Flood resilience in low-lying cities has historically been implemented through community-led, nature-based practices. Although contested by the contemporary development boom, natural water networks with compromised potential continue to contribute to city drainage. Kolkata, an eastern Indian megalopolis, capitalised on its lower-Gangetic swampy terrain, rivers, and canal network, as well as the Ramsar-designated East Kolkata Wetlands, to combat urban flooding. A World Bank study (2011) assesses that by 2050, nearly 40 per cent of its urban area and 47 per cent of its population will be exposed to flood vulnerability. Kolkata's climate risks are amplified by an unprecedented 53 per cent loss of its canal system over the last decade, which increases urban flood risks. Politically driven, unregulated reclamation of wetlands, excessive grey infrastructural dependence, unscientific planning, and poor governance have led to dramatic shrinkage, diminished carrying capacity, and relegation of the canals to mere sewers. This study examines how Locally Led Adaptation (LLA) facilitates the restoration of Kolkata's lost drainage regime using Nature-based Solutions (NbS). An interdisciplinary method is adopted to restore historic hydro-spatial linkages through geospatial mapping, locally led cultural approaches, back-tracing indigenous knowledge, and inclusive planning as a scalable roadmap towards flood-resilient urban transformation.

Keywords: Urban flood resilience; Flood vulnerability; Locally led adaptation; Nature-based solutions; Hydraulic ingenuity; Kolkata canals.

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1. Introduction

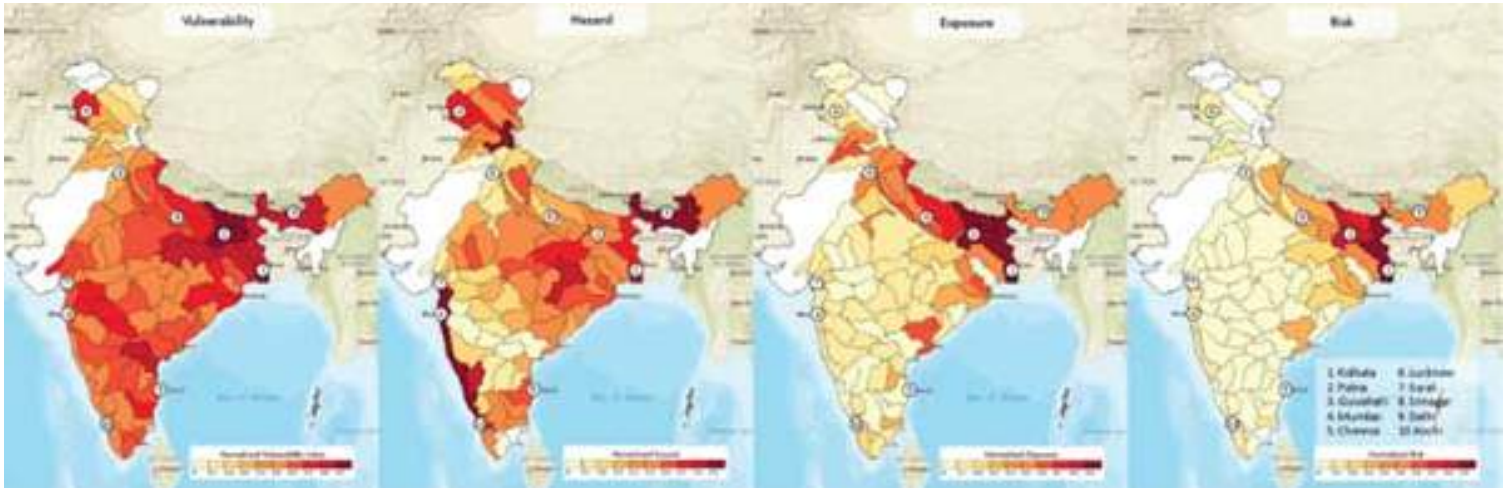
We are living in the Urban Age and the Anthropocene, an era in which human activities have become the dominant force reshaping planetary systems and disrupting long-standing hydrological balances (Anthony et al., 2025). Since the mid-twentieth century, rapid urbanisation, population expansion, and the consequent transformation of natural landscapes have significantly reduced the earth's capacity to absorb, store, and regulate water (Humbal et al., 2023). As impermeable surfaces replace wetlands, floodplains, and vegetated areas, cities increasingly face extreme water-related risks (Sohn et al., 2020). Today, more than half of the global population resides in urban areas, and this proportion is expected to rise to nearly 70 per cent by 2050, adding an estimated 1.75 billion new urban residents by 2030 alone (McDonald et al., 2008; Tratalos et al., 2007; SCBD, 2012; Müller et al., 2013; UNDESA, 2019). Urbanisation, increased impermeability, and loss of natural areas increase exposure to flooding, especially with intensifying climate change (Zhang et al., 2025). Urban flooding is no longer a periodic phenomenon but a recurring reality across the global South, including India's coastal and inland cities. Indian cities, including those situated along rivers, coasts, or deltas, face severe climate-induced hazards (Figure 1) (Verma et al., 2025). Extreme rainfall, cloudbursts, pluvial flooding, storm surges, and extreme heat are regular occurrences in cities like Kolkata, Mumbai, Chennai, Delhi, and Hyderabad. The consequences are visible in recurring disasters, inundated streets, paralysed transport networks, waterlogging due to dysfunctional drainage, and disproportionate impacts on the urban poor.

Using hazard, exposure, and vulnerability, the flood risk map of India showcases 10 most flood-prone cities, based on the common framework adopted by the United Nations in the Global Assessment Reports.

Flood risk in cities is shaped by the interaction of hazard, exposure, and vulnerability, rather than by a single climate event (Cea and Costabile, 2022). Many Indian cities have rapidly expanded into encroached wetlands, floodplains, and canal banks, significantly increasing their exposure. In cities like Kolkata, Mumbai, and Chennai, hazards include intense rainfall, cyclonic storm surges from nearby coasts, tidal flooding, and monsoon-driven overflow in rivers and canals. Vulnerability further amplifies risk (Murali et al., 2020). Marginal, informal settlements along canal edges or drainage basins experience repeated floods each year (Mukherjee and Bardhan, 2021). Fragmented governance, limited integration of indigenous and local knowledge, dependence on grey infrastructure, and weak enforcement further aggravate the challenges (Anwana and Owojori, 2023; Woroniecki et al., 2022). Therefore, flood risk becomes highest where hazards are strong, exposure is unavoidable, and vulnerability is deeply rooted. Only by addressing all three elements together can cities build long-term flood resilience. The National Adaptation Plan of India also highlights the need for inclusive, multi-level governance and community participation in urban adaptation, with particular emphasis on protecting vulnerable populations and enabling climate-resilient livelihoods—directly resonating with this study's emphasis on locally led adaptation, institutional coordination, and the role of ecosystem services in supporting urban poor and SMEs (NDMA, 2025).

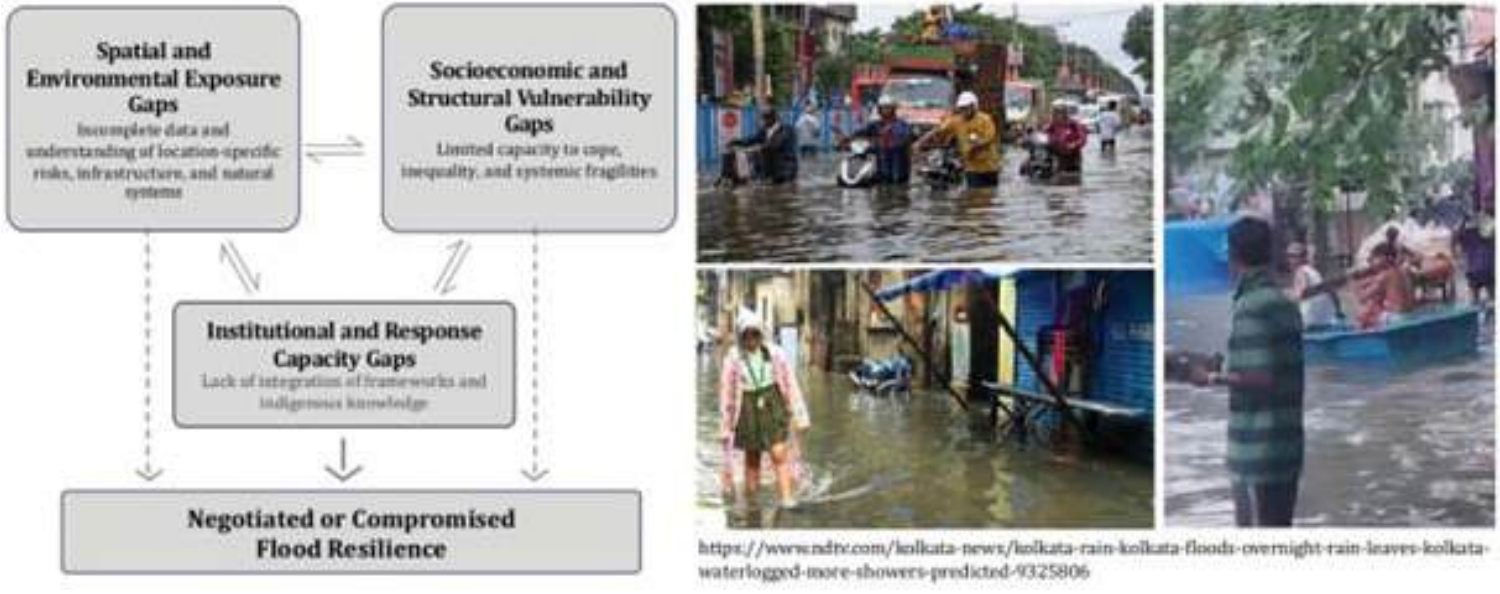
In Indian cities, development ambitions actively dismantle the very nature-based urban systems that historically protected and sustained them. Canal networks, wetlands, rivers,

Figure 1: Flood Risk Map of India



Source: (India Flood Atlas, n.d.).

Figure 2: Interlinked Gaps That Constrain Effective Flood Resilience in Kolkata



Source: Compiled by authors.

and drainage channels that once enabled natural flood management are being fragmented, polluted, and encroached upon (Singh et al., 2023). As climate change intensifies, the interaction and reinforcement of these gaps result in negotiated or compromised flood resilience, where adaptation becomes reactive, uneven, and exclusionary, rather than preventive, equitable, and systemic (Bhanye, 2025; Denton et al., 2014). The conceptual model (Figure 2) illustrates how three interacting systemic gaps continue to undermine urban flood resilience.

In this context, there is an urgent need to re-establish hydro-ecological integrity through local knowledge, community-inclusive governance, and nature-based solutions, moving from a state of compromised resilience to a future where urban growth and ecological security are mutually reinforcing. The study aims to frame an integrated flood resilience strategy for the deltaic city of Kolkata by incorporating the LLA principles and NbS.

2. Literature Review

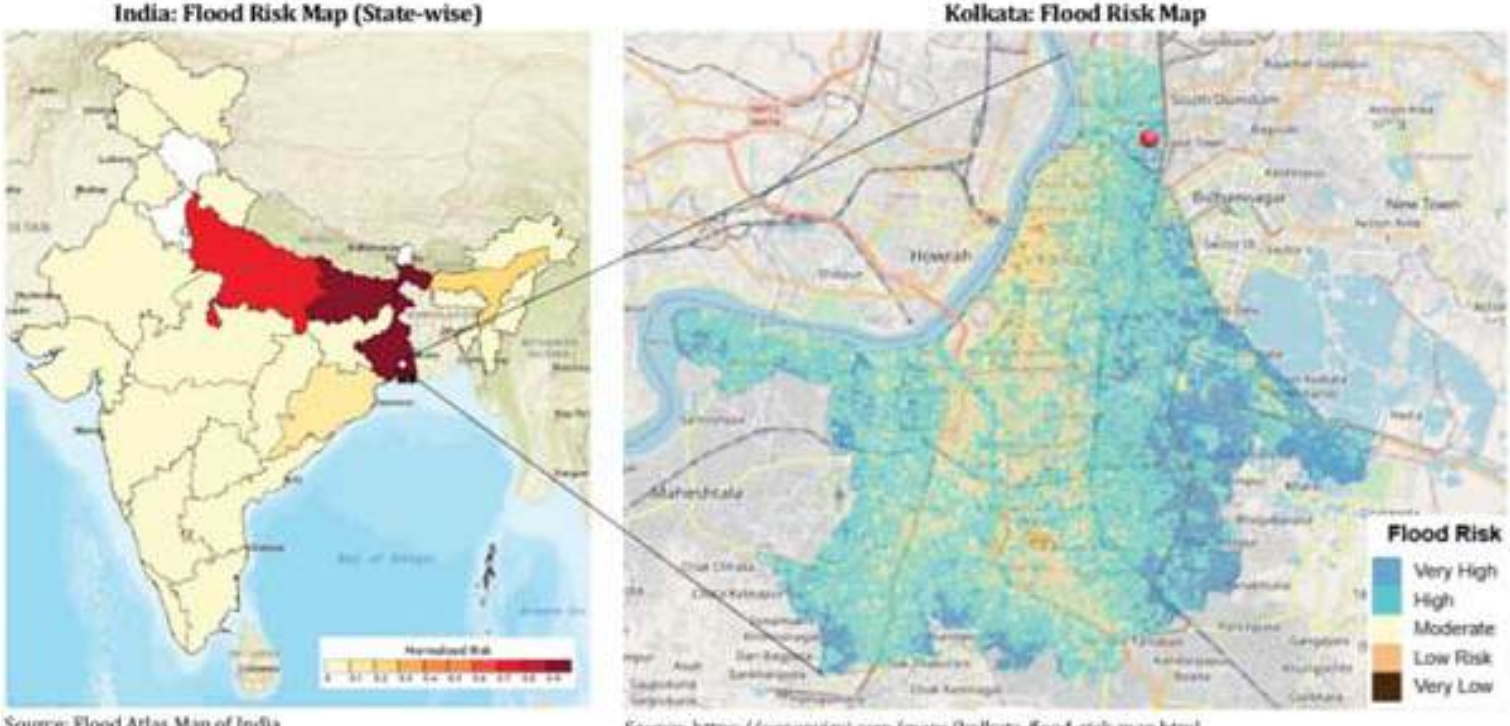
Kolkata is the capital of the Indian state of West Bengal. Covering an area of 206 sq. km, it is a primate city in the east, with a population of 4.49 million (WBIDC, n.d.). It is one of India's most densely populated megacities, with over 24,000 people per sq. km (Government of India, 2011). The compact footprint of the city, high population density, and ageing infrastructure significantly affect its flood resilience systems (Bose and Mazumdar, 2003).

Situated in the lower Ganga-Brahmaputra Delta in a low-lying marshy land (Figure3). Kolkata's urban identity is inextricably linked to its hydraulic ingenuity (Mukherjee, 2024). The river Bhagirathi–Hooghly, a distributary of the Ganga, historically shaped its growth, economy, and culture over three centuries (Paul and Bardhan, 2021). While all other European traders and colonisers selected the eastern bank of the river, the British wisely selected the western bank. This judicious decision not only facilitated its locational advantage as a port city but also provided a reliable source of fresh water. Equally significant is the River Adi Ganga, Ganga's paleochannel, which served as the primary waterway for trade, transportation, and stormwater drainage until the mid-18th century (Bhattacharya et al., 2023; Paul and Bardhan, 2022). It formed the ancient fluvial route linking inland Bengal to the Bay of Bengal via numerous tidal creeks and channels. Kolkata is further supported by an extensive network of 12 major interconnected canals linked to a larger network beyond its administrative boundaries (Bhattacharya et al., 2023). These canals, originally tidal creeks, were engineered and expanded by the British planners and engineers for drainage, transportation, and urban sanitation (Bhattacharya et al., 2024; Paul and Bardhan, 2022).

They also introduced an efficient gravity-based tidal drainage, leveraging the natural slopes and tidal patterns. They form the hydrological lifeline that connects the city to the East Kolkata Wetlands (EKW), a Ramsar site that converts municipal wastewater into productive, sewage-fed fisheries and peri-urban agriculture, supporting livelihoods while providing essential ecosystem services, such as regulating floods and purifying water (Figure 4). The combined network of the canals with the rivers Bhagirathi-Hooghly and Adi Ganga formed the engines of Kolkata's socio-economic, ecological, and spatial development, contributing towards its sustenance and flood resilience.

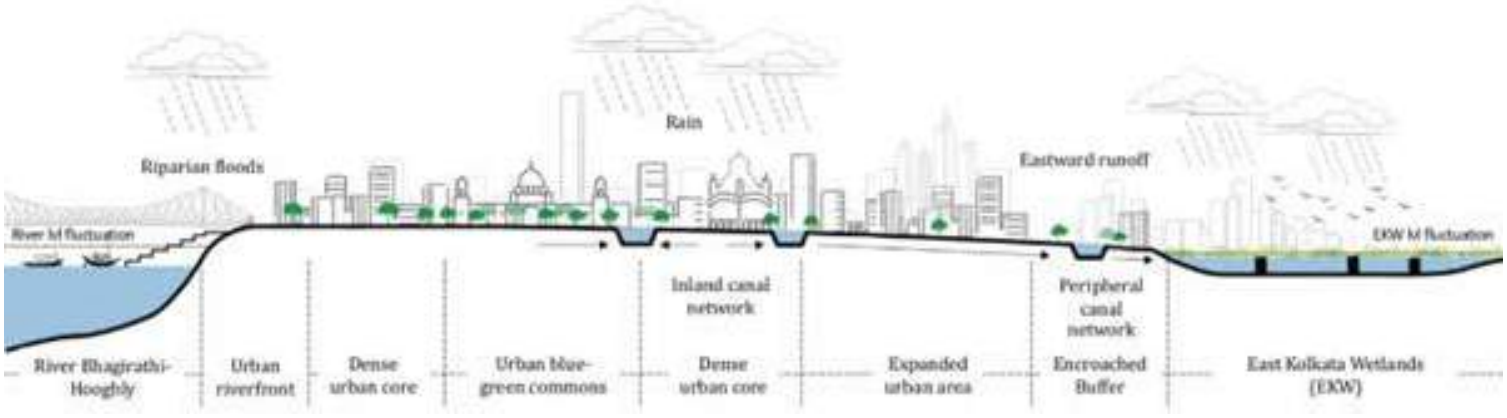
Kolkata's low elevation, proximity to the Bay of Bengal, and exposure to heavy south-western monsoon rains, cyclonic storm surges, tidal inundation, and cloudbursts make it vulnerable

Figure 3: Location Map of Kolkata Showing Its Flood Risks



Source: Authors' compilation.

Figure 4: The Hydraulic Ingenuity of Kolkata – Its Lifelines and Their Interconnection



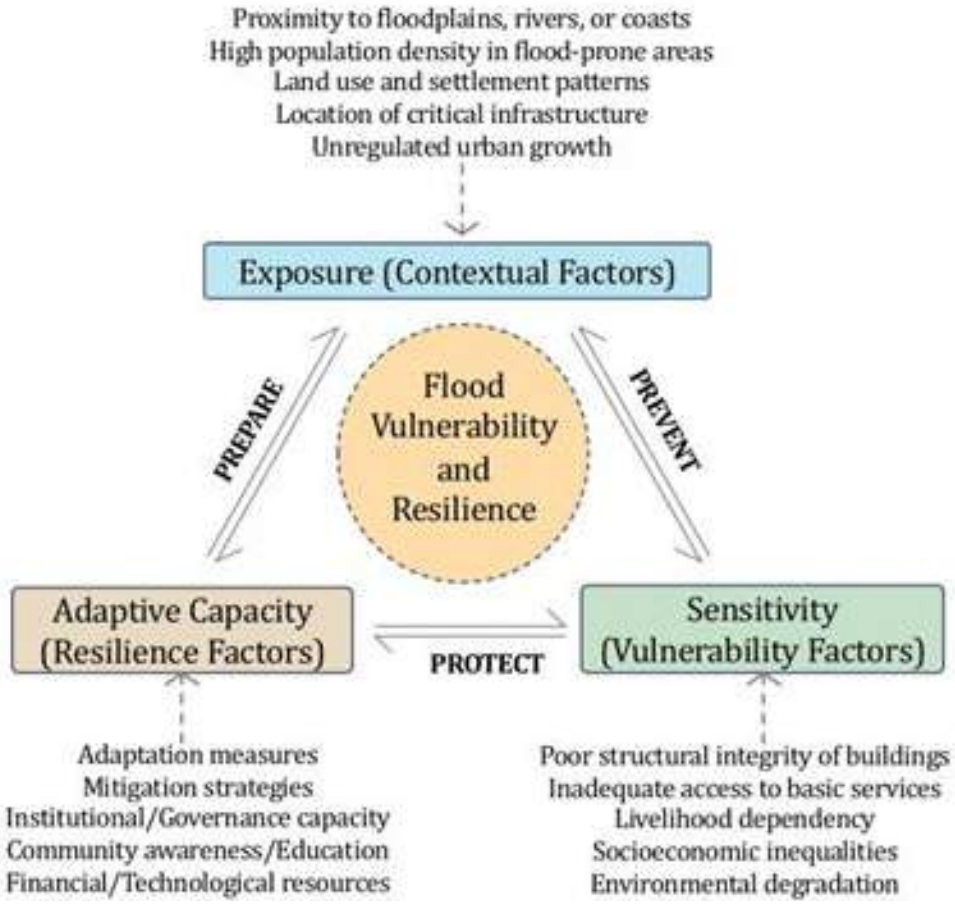
Source: Authors' compilation.

to inland flooding (Sen, 2010). As climate change intensifies, the dynamics between rainfall and sea-level rise alter tidal patterns, exacerbating flooding (Lei et al., 2025). Kolkata has experienced repeated climatic disasters and flood occurrences over the past two decades, highlighting its growing vulnerability and exposing the limitations of its ageing drainage and canal infrastructure.

Kolkata's unique hydrological network, comprising rivers, canals, wetlands, lakes, and ponds, remains crucial to its ecological stability and climate resilience (Mondal et al., 2022). Yet these systems face increasing deterioration due to:

- Unregulated land transformation in low-lying flood-prone zones
- Blocked canals reduce stormwater discharge
- Population pressures along vulnerable canal banks

Figure 5: The Conceptual Framework



Source: Authors' illustration.

- Poor governance and institutional fragmentation
- Climate change is intensifying extreme rainfall, cyclonic surges, and high tides

Kolkata's future resilience depends on restoring and revaluing its hydraulic ingenuity, the very systems that enabled its existence. Revitalising Kolkata's historic systems of engineered drainage through nature-based solutions and inclusive planning is not only an environmental imperative but also a vital priority for climate adaptation, to ensure the city's long-term resilience.

3. Theoretical and Conceptual Framework

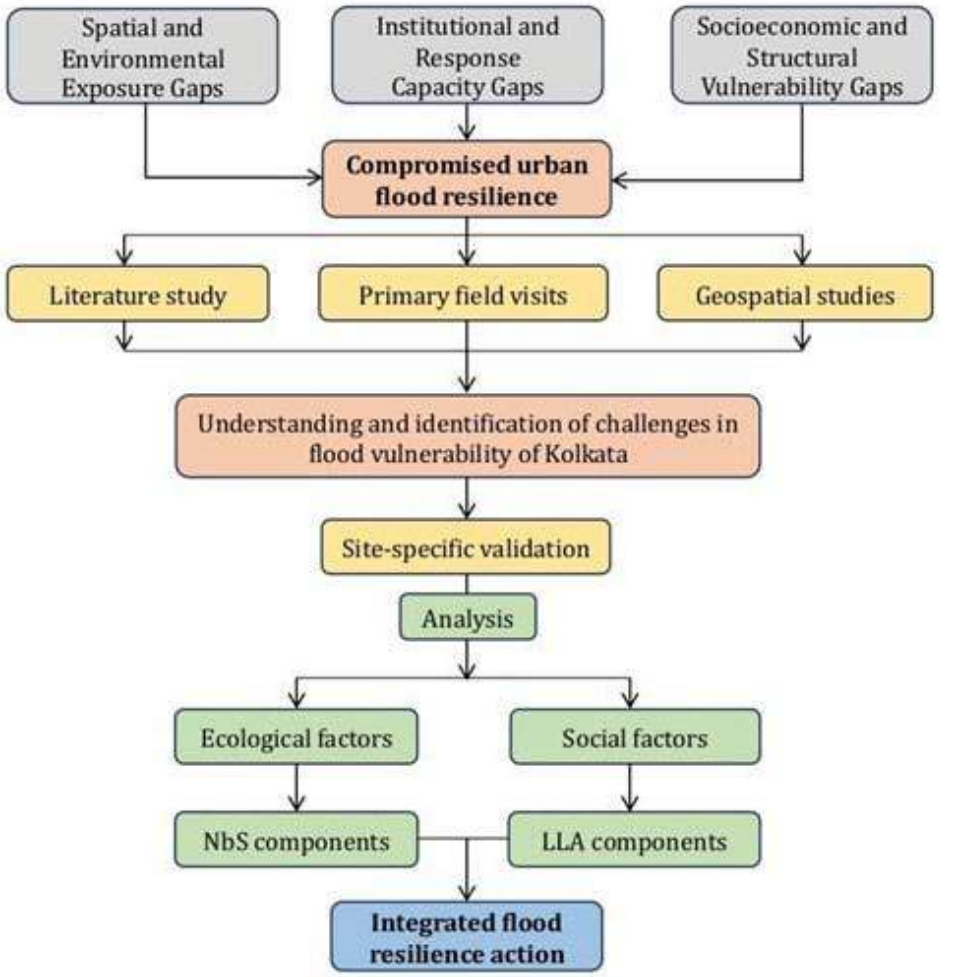
The conceptual framework of this study provides a holistic approach to flood management and community well-being. At the core of this framework lies the understanding of flood vulnerability and resilience, governed by the interplay of three major components - Exposure, Sensitivity, and Adaptive Capacity, as illustrated in Figure 5.

4. Research Methodology and Data

The paper begins by identifying the multi-scale and multi-sectoral gaps that result in compromised urban flood resilience in the city of Kolkata (Figure 6). The criticalities of Kolkata's flood exposure and the underlying parameters contributing to its vulnerability were studied through the mapping of historical data and a multi-layered GIS analysis (Figure 7). Historical and archival maps were studied to understand the spatio-temporal growth of the city. Digital Elevation (DEM) Maps, Normalised Difference Vegetation Index (NDVI), Normalised Difference Water Index (NDWI), Normalised Difference Built-up Index (NDBI), and Land Use and Land Cover (LULC) maps were studied for a detailed understanding of the urban sprawl, encroachment pattern, loss of wetlands and vegetation. Flood hotspot identification through overlay of inundation maps, waterlogging records, and historical flood footprints (including Kolkata Municipal Corporation, World Bank, and India Flood Atlas datasets). Extensive field visits were conducted to understand the basin characteristics, the aqua-terrestrial edge conditions, and the activity patterns of regular users. A semi-structured interview was conducted with the people residing in the informal settlements along the canal bank. A clear mapping of ecological and social factors was analysed to identify the human-nature connection, assess exposure and vulnerability, and measure coping strategies. Previous government efforts to restore the canals by the Kolkata Municipal Corporation (KMC), the Kolkata Environmental Improvement Investment Program (KEIIP), the Irrigation and Waterways Department, the Ganga Action Plans, and the Namami Gange Program were studied to identify conservation efforts and understand institutional and response gaps.

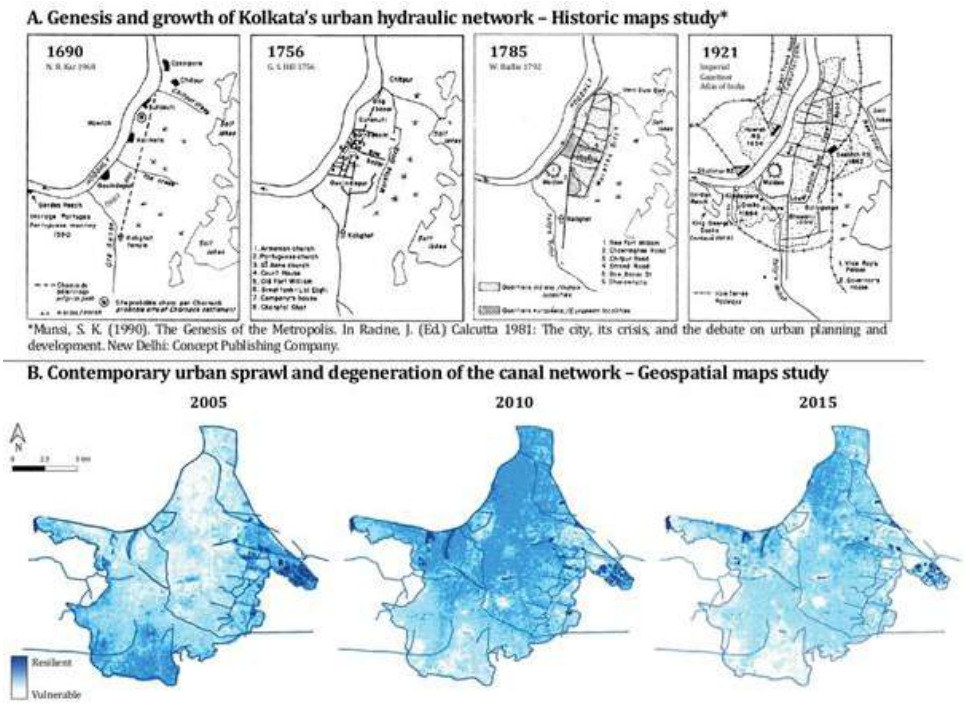
After understanding and identifying the challenges and previous records of flooding incidents, three critical areas were identified for context-specific application of the proposed strategies.

Figure 6: Research Methodology



Source: Authors' illustration.

Figure 7: The Origin, Growth, Expansion, and Degeneration of Kolkata



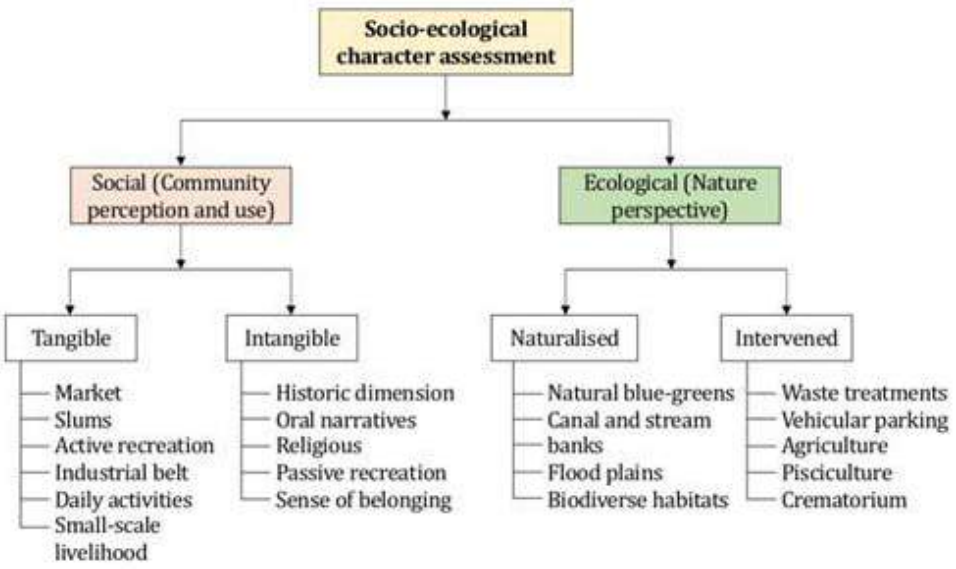
Source: Authors' illustration.

5. Analysis and Findings

The degradation of Kolkata's waterways reflects a long history of inadequate planning and management. The marshlands and canal edges were continuously reclaimed for urban development. The Adi Ganga lost much of its flow due to diversions, metro rail pillars, and roadside embankments. Siltation, solid waste dumping, erosion, and poor outfall management degraded canal conveyance and tidal flushing. Inflows of untreated sewage and industrial pollutants have drastically depleted dissolved oxygen, eliminated aquatic biodiversity, and halted navigability. Instead of functioning as a blue-green flood barrier, most canals now behave as choked sewers, elevating exposure and vulnerability of already-marginalised communities whose homes are precariously situated at the water's edge.

A detailed inventory and primary survey revealed a range of socio-ecological characteristics along various stretches of the waterways (Figure 8). The ecological study describes the distinct types of landscapes associated with the canals, which are relatively homogeneous in character and occur repeatedly in the study area, providing a good spatially referenced framework for developing planning and landscape management strategies. The social study revealed the tangible and intangible aspects which describe the association and user experiences. It can be concluded that the canals form an intrinsic part of the regular lives of the people of Kolkata, along with their immense ecological significance. Yet, they suffer

Figure 8: Socio-ecological Assessment of the Canal-bank Characters from Primary Survey



Source: Authors' illustration.

from environmental degradation and remain disconnected from the urban form of the city, as well as from socio-cultural connectedness with the people.

The canal and riverbanks vividly portray a bleak picture of encroachment, ecological remnants, and detachment from the socio-physical life of the city's residents (Figure 9). The waterways, which were once vegetated, navigable, and pristine, now reflect a patchwork of historical engineering, characterised by concrete embankments, siltation, and waste dumps. Some of the edges are still vegetated in a few stretches, retaining a rural character, but pollution has not spared these sections either. The ghats and jetties retain their traditional multifunctional roles in transport, drainage, and local community life; however, the canal network overall embodies a state of degradation, congestion, and lost ecological function.

Kolkata faces recurring phenomena of climate-induced flooding and chronic waterlogging which profoundly affect the lives, livelihoods, and socio-cultural fabric of the city, beyond physical damage to infrastructure (Parasuram et al., 2017). Repeated flooding poses a persistent stress compounding structural vulnerabilities related to poverty, informality, and weak urban governance. Urban poor and marginalised communities, particularly the informal settlements located along canal banks, low-lying reclaimed wetlands, railway edges mostly bear the consequences (Khan et al., 2024). A large share of Kolkata's poor depends on informal, daily-wage, or location-dependent livelihoods, such as street vending, rickshaw pulling, domestic work, construction labour, waste picking, small workshops, and home-based enterprises. Flooding disrupts access to their workplaces, leading to immediate income losses with no immediate social protection buffers. Damage to livelihood possessions, such as tools, carts, raw materials, and stock, further establishes cycles of indebtedness and

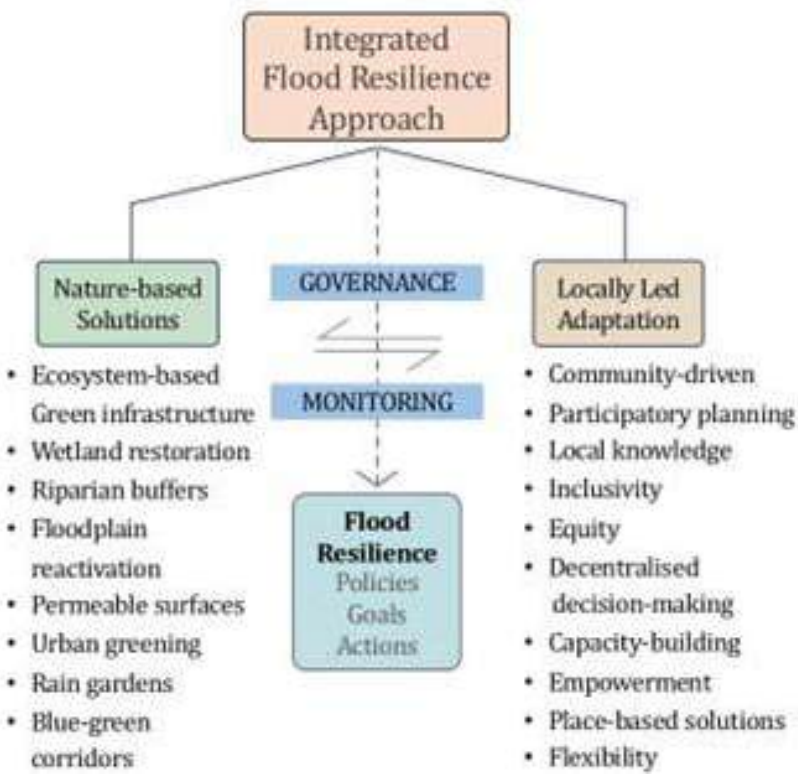
Figure 9: The River-and-Canal Network of Kolkata Shows Its Varied Characters and Challenges

Source: Authors' compilation.

economic insecurity (Delina et al., 2023). In wetland-adjacent areas, ecological degradation driven by encroachment and pollution undermines traditional livelihoods linked to sewage-fed pisciculture and agriculture, and informal food systems, reducing ecosystem-based adaptive capacity (Bunting et al., 2010). Floodwaters mixed with sewage, solid waste, and industrial effluents expose low-income communities to heightened health risks, including waterborne and vector-borne diseases (Rusca et al., 2021). Prolonged waterlogging disrupts access to safe drinking water, sanitation, and healthcare services, increasing physical and mental health stress.

Flood impacts in Kolkata are distinctly gendered (Rai et al., 2023). Women play critical yet under-recognised roles in household and community-level adaptation, acting as first responders (Azad & Pritchard, 2023). Women from low-income households face increased unpaid burdens related to water collection, food preparation, childcare, elder care, and household hygiene during floods. Women engaged in the informal and domestic sectors experience income losses while managing heightened household responsibilities. Limited access to safe sanitation and feminine hygiene facilities during floods exposes women, particularly expectant mothers and adolescent girls, to health, safety, and dignity risks, particularly in overcrowded homes or temporary shelters.

Figure 10: Integrated Flood Resilience Approach Proposed in the Study



Source: Authors' illustration.

Various government agencies have attempted restoration initiatives, mostly engineered techniques over the past five centuries, including desilting, pumping station upgrades, bioremediation trials, and enforcement of pollution controls. Several national programmes have focused on enhancing infrastructure and improving water quality. Yet these efforts often struggle to sustain long-term outcomes, largely due to fragmented governance, limited community integration, and the absence of a holistic, nature-based restoration strategy. A shift from hard-engineering fixes to NbS aligned with LLA models is crucial for sustaining ecological, social, and economic resilience (Figure 10).

To operationalise the approach, a 3-P strategy - *Protect, Prepare, and Prevent* is adopted for integrated flood resilience. 'Protect' focuses on restoring ecological buffers, improving canal health, and revitalising natural systems that absorb and regulate floodwaters. 'Prepare' enhances community awareness, early-warning systems, and institutional capacity to respond effectively during flood events. 'Prevent' aims to reduce exposure by guiding land-use planning, enforcing development controls, and designing safer urban environments. Together, these pillars integrate ecological restoration, social readiness, and proactive planning to create a resilient, adaptive, and risk-informed approach to urban flood management. Table 1 elaborates this approach under the verticals of LLA and NbS.

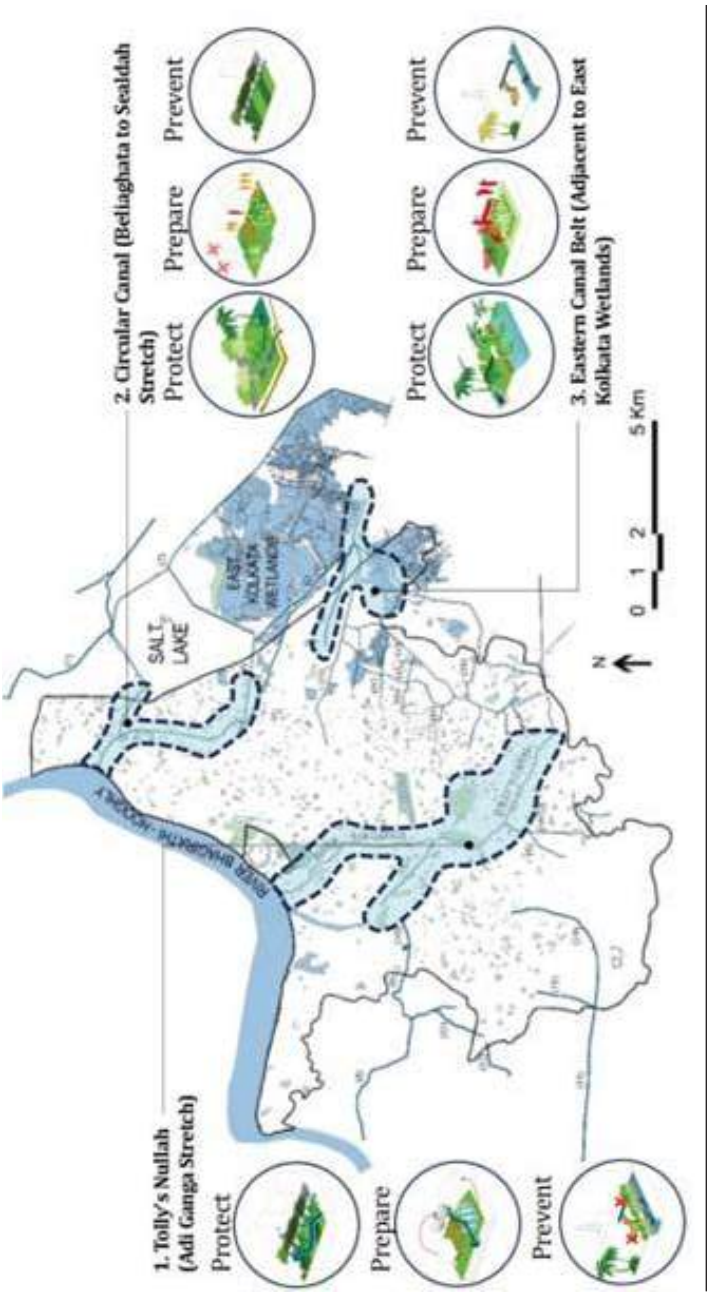
Table 1: Strategic Approach Towards an Integrated Flood Resilience

3-P Strategy	LLA Approach (Locally Led Adaptation)	NbS Approach (Nature-Based Solutions)
PROTECT *(Restore ecological buffers and canal health)*	• Community-driven restoration of clogged canals (e.g., involving ward committees in canal desilting) • Use of local knowledge to identify canal-wetland linkages • Empower informal communities to monitor water quality and report encroachments	• Riparian vegetation buffers along canal edges using native species • Re-naturalisation of canal banks with plant-based erosion control • Restore hydrological flows between canals and wetlands
PREPARE *(Enhance social preparedness and institutional capacity)*	• Formation of ward-level flood preparedness committees • Participatory mapping of flood-prone canal zones using local knowledge • Awareness drives in schools and neighbourhoods about canal health and flood safety	• Use of wetlands and canal-retention ponds as community learning spaces for climate education • Green corridors and eco-parks along canals as multi-functional spaces that support learning and resilience
PREVENT *(Reduce exposure through planning and design)*	• Inclusive planning with informal sector and canal-side communities to co-design safe housing zones • Decentralised water governance (empowered ULBs with citizen voices) for flood planning near canals	• Introduce sponge city features along canal banks (bioswales, rain gardens) • Promote permeable surfaces and green infrastructure near canal catch-ments • Use restored canals as stormwater reservoirs to prevent urban flooding

Source: Authors' analysis.

In the next step, three ecologically distinct and socially diverse stretches are selected from the broader canal network for application of the 3-P strategies proposed in the research. The selection of Tolly's Nullah, the Circular Canal, and the Eastern Canal area is driven by their hydrological roles, socio-ecological contexts, and strategic importance within Kolkata's broader flood resilience framework. The context-specific strategies are explained in Figure 11 and Table 2.

Figure 11: Segment-wise Flood Resilience Strategy for Kolkata's Waterways Using 3-P Strategy



Source: Authors' compilation.

Table 2: Context-specific Application of the Proposed Strategies in the Selected Stretches

Stretch 1 - Tolly's Nullah (Adi Ganga Stretch)			
Issues: • Severely encroached, polluted, and silted • Loss of flood-carrying capacity • High informal settlements along banks			
Strategy	**Intervention**	**Feasibility**	**LLA/NbS Benefit**
Protect	Re-introduce native vegetation on embankments	Moderate – requires community buy-in and desilting	Improves bank stability and water quality
Prepare	Ward-level water monitoring groups for pollution and blockages	High – can use local schools or clubs	Empowers community stewardship
Prevent	Create off-line detention ponds where the canal width allows	Low–moderate – needs land availability	Temporary flood storage reduces pressure on the main channel
Stretch 2 - Circular Canal (Beliaghata to Sealdah Stretch)			
Issues: • Heavily channelised and concretised • Rapid runoff during rainfall • Limited ecological function			
Strategy	**Intervention**	**Feasibility**	**LLA/NbS Benefit**
Protect	Establish floating wetlands in canal segments	High – feasible with support from NGOs or CSOs	Enhances water quality, biodiversity
Prepare	Install real-time water level indicators shared via mobile apps	Moderate – needs tech support and training	Improves early action, citizen science
Prevent	Green retrofitting of canal banks using coir matting and vegetation	High - adaptable with pilot projects	Slows water flow, eco-friendly erosion control
Stretch 3 - Eastern Canal Belt (adjacent to East Kolkata Wetlands)			
Issues: • Vital for urban flood buffering • Wetland connectivity at risk due to land conversion			
Strategy	**Intervention**	**Feasibility**	**LLA/NbS Benefit**
Protect	Legally reclassify buffer lands around the canal as eco-sensitive zones	Moderate – needs policy engagement	Long-term ecological protection
Prepare	Develop a wetland–canal curriculum in local schools + citizen monitoring	High – already active NGOs in EKW	Builds ecological literacy, advocacy
Prevent	Construct shallow spillways to reconnect the canal to the wetland buffer areas	Moderate – depends on encroachments	Reduces canal overflow into the city, natural storage

Source: Authors' analysis.

Flood risk management in Kolkata is currently constrained by fragmented governance, overlapping institutional policies, and limited coordination among multiple agencies responsible for drainage, transport, wetland and disaster management (Mukherjee et al., 2025). Effective flood resilience therefore requires not only technical interventions but also institutional reform and collaborative governance mechanisms that integrate NbS and LLA into everyday urban management. A key step towards improving institutional responses is the establishment of a dedicated inter-agency flood resilience coordination mechanism at the metropolitan scale. This platform should bring together the Kolkata Municipal Corporation (KMC), the Kolkata Metropolitan Development Authority (KMDA), the Irrigation and Waterways Department, the West Bengal Pollution Control Board, the West Bengal State Disaster Management Department, and representatives from ward-level institutions and community organisations. Clearly defined roles, shared performance indicators, and coordinated planning cycles can reduce duplication and address gaps in drainage management, wetland protection, and emergency response. Regular data sharing among agencies, particularly on rainfall, tide levels, canal capacity, solid waste management, and flood-prone hotspots, can support anticipatory action rather than reactive responses. Integrating GIS-based flood risk mapping and real-time monitoring into municipal decision-making would further enhance institutional preparedness.

NbS must be formally embedded within Kolkata's statutory planning instruments, including drainage master plans, land-use plans, and wetland management frameworks. This requires moving beyond pilot projects towards citywide guidelines for canal restoration, wetland conservation, permeable surfaces, and decentralised water retention systems. Institutional responsibility for NbS implementation should be clearly assigned, with budgetary allocations and long-term maintenance plans. Aligning NbS with routine municipal functions, such as desilting schedules, solid waste management, and street design, can improve coordination between departments and reduce institutional silos. Ecosystem-based flood management should be recognised not as an environmental add-on but as core urban infrastructure.

Strengthening ward-level institutions is critical for overcoming governance fragmentation at the smallest administrative level. Ward-level committees, community-based organisations, women's groups, and informal worker collectives should be formally involved in identifying flood risks, maintaining local drainage systems, monitoring canal conditions, and managing community assets. Decentralised decision-making, supported by technical guidance from municipal agencies, can improve responsiveness and accountability. Community stewardship models for canal edges, neighbourhood ponds, and open spaces can support NbS implementation while enhancing livelihood opportunities and social ownership. Ensuring representation of women and marginalised groups in these processes is essential for equitable and effective adaptation.

6. Conclusion: Recommendations and Policy Implications

Kolkata's flooding challenge is no longer a question of drainage capacity alone; it reflects a deeper disconnect between the city, its hydrological ecology, and the communities who live along its waterways. This study demonstrates that a lasting resilience will emerge only when Kolkata repositions its canals, wetlands, and riverfront not as infrastructural remnants but as living, multifunctional systems central to climate adaptation. Revitalising the city's

historic hydraulic ingenuity requires an integrated approach that combines technological innovations in drainage management and flood forecasting with socially inclusive, institutionally coordinated, and ecologically grounded responses. By integrating LLA with NbS and aligning these efforts with the objectives of India's National Adaptation Plan (NAP) for urban resilience, Kolkata can address long-standing vulnerabilities while strengthening social equity, ecological integrity, and institutional effectiveness. The proposed integrated flood resilience approach, guided by the 3P framework—Protect, Prepare, Prevent—offers a pathway to reconnect fragmented governance, restore urban wetlands and canal networks, and embed NbS and LLA within future city planning. Collectively, these strategies underscore that resilience cannot be engineered solely through grey infrastructure. It must be co-created, context-specific, supported by inclusive governance structures, and reinforced by ecological restoration. Strengthening Kolkata's flood resilience ultimately depends on transforming fragmented, sectoral governance into a collaborative, locally led institutional framework that integrates community knowledge, ecological stewardship, and coordinated urban planning. The lessons emerging from Kolkata also offer valuable insights for other low-lying, deltaic cities grappling with similar hydrological and social complexities.

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References

Anthony, E., Syvitski, J., Cohen, K.M., Saito, Y., Zăinescu, F., Vespremeanu-Stroe, A., Nicholls, R.J., Marriner, N., Amorosi, A., Maselli, V., Minderhoud, P.S.J., Tamura, T., Day, J., Woodroffe, C.D., Preoteasa, L., Tatui, F., Sabatier, F., Morhange, C., Besset, M., Kemp, P., & Chen., Z. (2025). A 7000-year record of human influence on Global River Deltas: Geomorphology, stratigraphy, the Anthropocene overprint and future. *Earth-Science Reviews*, 271. https://doi.org/10.1016/j.earscirev.2025.105302.

Anwana, E. O., & Owojori, O. M. (2023). Analysis of Flooding Vulnerability in Informal Settlements Literature: Mapping and Research Agenda. *Social Sciences*, 12, 40. https://doi.org/10.3390/socsci12010040.

Azad, M. J., & Pritchard, B. (2023). The importance of women's roles in adaptive capacity and resilience to flooding in rural Bangladesh. *International Journal of Disaster Risk Reduction, 90*, 103660. https://doi.org/10.1016/j.ijdrr.2023.103660.

Bhanye, J. (2025). A review study on community-based flood adaptation in informal settlements in the Global South. *Discover Sustainability, 6*, 595. https://doi.org/10.1007/s43621-025-01449-6.

Bhattacharya, S., Mukherjee, J., Choudry, A., & Ghosh, R. (2023). Reifying "river": Unpacking pluriversal possibilities in rejuvenation surrounding the Adi Ganga of Kolkata. *Front. Water*, 5. https://doi.org/10.3389/frwa.2023.1070644.

Bhattacharya, S., Mukherjee., J., Banerji, D., & Chatterjee, S. (2024). (En)countering an urban riverscape: Ethno-graphic explorations on the Adi Ganga. *Cities*, 151. https://doi.org/10.1016/j.cities.2024.105105.

Bose, S., & Mazumdar, A. (2023). Urban flood risk assessment and mitigation with InVEST-UFRM model: a case study on Kolkata city, West Bengal state (India). *Arabian Journal of Geosciences*, 16. https://doi.org/10.1007/s12517-023-11486-y.

Bunting, S., Pretty, J., & Edwards, P. (2010). Wastewater-fed aquaculture in the East Kolkata Wetlands, India: Anachronism or archetype for resilient ecocultures?. *Reviews in Aquaculture*. 2. 138-153. https://doi.org/10.1111/j.1753-5131.2010.01031.x.

Cea, L., & Costabile, P. (2022). Flood Risk in Urban Areas: Modelling, Management and Adaptation to Climate Change. A Review. *Hydrology, 9*(3), 50. https://doi.org/10.3390/hydrology9030050.

Delina, L. L., Paolo, N. P. L., Gaviola, J., & Guiam, R. C. (2023). Living with climate and state fragility in a "chaotic paradise:" securitizing livelihoods in the Philippines' Cotabato River Basin, *Climate Risk Management, 42*, 100558. https://doi.org/10.1016/j.crm.2023.100558.

Denton, F., Wilbanks., T. J., Abeysinghe, A. C., Burton, I., Gao, Q., Lemos, M. C., Masui, T., O'Brien, K. L., & Warner, K. (2014). Climate-resilient pathways: adaptation, mitigation, and sustainable development. In: *Climate Change in Impacts,*

Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, & L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1101-1131.

Government of India. (2011). Census of India. https://censusindia.gov.in/census.website/. Retrieved on November 18, 2025.

Humbal, A., Chaudhary, N., & Pathak, B. (2023). Urbanization Trends, Climate Change, and Environmental Sustainability. In: Pathak, B., Dubey, R.S. (eds) Climate Change and Urban Environment Sustainability. *Disaster Resilience and Green Growth*, Springer, Singapore. https://doi.org/10.1007/978-981-19-7618-6_9.

India Flood Atlas. (n.d.). *India Flood Atlas*. Retrieved on 29 September 2025. https://indiafloodatlas.in/.

Khan, M. A., Dakyaga, F., Chilinde, G., & Juah, D.M. (2024). Urban marginality: Everyday practice of building resilience to flood in the informal Settlement of Dar es Salaam. *GeoJournal, 89*, 103. https://doi.org/10.1007/s10708-024-11117-3.

Lei, C., Liang, G., Huang, S., & Zhang, P. (2025). Combined impacts of heavy rainfall, high tides, and sea level rise on multi-source pollution in coastal urban watersheds: a whole-of-system assessment. *Journal of Cleaner Production, 516*. https://doi.org/10.1016/j.jclepro.2025.145787.

Mcdonald, I. R., Kareiva, P., & Forman, T.T. (2008). The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biological Conservation, 141*(6), 1695-1703. https://doi.org/10.1016/j.biocon.2008.04.025.

Mondal, B. K., Kumari, S., Ghosh, A., & Mishra, P. K. (2022). Transformation and risk assessment of the East Kolkata Wetlands (India) using fuzzy MCDM method and geospatial technology. *Geography and Sustainability, 3*(3), 191-203. https://doi.org/10.1016/j.geosus.2022.07.002.

Mueller, N., Gerber, J., Johnston, M., Ray, D.K., Ramankutty, N., & Foley, A.J. (2013). Correction: Corrigendum: Closing yield gaps through nutrient and water management. *Nature*, 494, 390. https://doi.org/10.1038/nature11907.

Mukherjee, A. B., & Bardhan, S. (2021). Flood vulnerability and slum concentration mapping in the Indian city of Kolkata: A post-Amphan analysis. *Water Science, 35*(1), 109–126. https://doi.org/10.1080/23570008.2021.1957641.

Mukherjee, J. (2024). "Living systems infrastructure" of Kolkata: exploring co-production of urban nature using historical urban political ecology (HUPE). *Environment and Urbanization, 34, 32*. https://doi.org/10.1177/09562478221084560.

Mukherjee, S., Kar, S., & Bhattacharyya, T. (2025). Integrated catchment and coastal management for resilient urban flood mitigation under climate change. *Frontiers in Water, 7*. https://doi.org/10.3389/frwa.2025.1574309.

Murali, M., Riyas, M. J., Reshma, K. N., & Kumar, S. (2020). Climate change impact and vulnerability assessment of Mumbai city, India. *Natural Hazards, 102*(2), 575-589. https://doi.org/10.1007/s11069-019-03766-2.

National Disaster Management Authority (NDMA). (2025). *Guidebook on integrating disaster risk reduction into national adaptation plan on climate change.* Ministry of Home Affairs, Government of India. Retrieved on January 30, 2026. https://ndma.gov.in/sites/default/files/PDF/Reports/Guidebook_on_NAP_CC.pdf.

Parasuram, P., Narayanan, P., Pelling, M. A., Solecki, W., Ramachandran, P., & Ramachandran, R. (2017). Climate Change Adaptation Pathways in Kolkata. *Journal of Extreme Events, 3*(3). https://doi.org/10.1142/S2345737616500214.

Paul, S., & Bardhan, S. (2021). Integrating a heritage river in the urban form through landscape interventions: studies on Adi Ganga, Kolkata. *ISUF 2020 Virtual Conference Proceedings*. https://doi.org/10.26051/0D-YASW-QGHA.

Paul, S., & Bardhan, S. (2022). Framework for Quantitative Assessment of Urban-Blue-and-Green-Spaces in a High-density Megacity. *International Review for Spatial Planning and Sustainable Development*. http://dx.doi.org/10.14246/irspsd.10.3_280.

R. Rai, B. Satpathy, & A. K. Singh. (2023). Gender-based Variations in Perception of Flood Impacts- A Micro Study. *Indian Journal of Extension Education, 59*(2), 69-73. https://doi.org/10.48165/IJEE.2023.59215.

Rusca, M., Gulamussen, N. J., Weststrate, J., Nguluve, E. I., Salvador, E. M., Paron, P., & Ferrero, G. (2022). The Urban Metabolism of Waterborne Diseases: Variegated Citizenship, (Waste) Water Flows, and Climatic Variability in Maputo, Mozambique. *Annals of the American Association of Geographers, 112*(4), 1159–1178. https://doi.org/10.1080/24694452.2021.1956875.

Secretariat of the Convention on Biological Diversity (SCBD). (2012). *Report of the Global Workshop on National Experiences in implementing the Strategic Plan for Biodiversity 2011-2020*. UK Department for Environment, Food and Rural Affairs (Defra), & Ministry of the Environment, Brazil.

Sen, D. (2010). Flood Hazards in India and Management Strategies. In: Jha, M.K. (eds) *Natural and Anthropogenic Disasters*. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-2498-5_7.

Singh, H., Nielsen, M., & Greatrex, H. (2023). Causes, impacts, and mitigation strategies of urban pluvial floods in India: A systematic review. *International Journal of Disaster Risk Reduction, 93*. https://doi.org/10.1016/j.ijdrr.2023.103751.

Sohn, W., Kim, J.H., Li, M.H., Brown, R., & Jaber, F. (2020). How does increasing impervious surfaces affect urban flooding in response to climate variability?. *Ecological Indicators, 118*. https://doi.org/10.1016/j.ecolind.2020.106774.

Tratalos, J., Fuller, A.R., Warren, H.P., Davies, G. R., & Gaston, J. K. (2007). Urban form, biodiversity potential and ecosystem services. *Landscape and Urban Planning, 83*(4), 308-317. https://doi.org/10.1016/j.landurbplan.2007.05.003.

United Nations Department of Economic and Social Affairs (UNDESA). (2019). *UN DESA Annual Highlights Report 2019-2020*. https://www.un.org/en/desa/highlights-report-2019-2020. Retrieved on November 15, 2025.

Verma, P., Khan, A., Nisar, Z., & Safiullah, A. (2025). Urban Flood Resilience in India: A Comprehensive Review of Challenges, Assessment Strategies, and Future Directions. *Journal of Environment and Bioscience, 39*, 69-76. https://doi.org/10.59467/JEBS.2025.39.69.

West Bengal Industrial Development Corporation. (n.d.). *Kolkata - The Capital City*. https://www.wbidc.com/why-west-bengal/kolkata. Retrieved on September 29, 2025.

World Bank. (2011). *India - Vulnerability of Kolkata metropolitan area to increased precipitation in a changing climate*. World Bank. http://hdl.handle.net/10986/2818

Woroniecki, S., Spiegelenberg, F. A., Chausson, A., Turner, B., Key, I., Md. Irfanullah, H., & Seddon, N. (2022). Contributions of nature-based solutions to reducing people's vulnerabilities to climate change across the rural Global South. *Climate and Development, 15*(7), 590–607. https://doi.org/10.1080/17565529.2022.2129954.

Zhang, Q., Li, C., Wen, D., Kang, J., Chen, T., Zhang, B., Hu, Y., & Yin, J. (2025). Global South shows higher urban flood exposures than the Global North under current and future scenarios. *Nature Communications Earth & Environment, 6*. https://doi.org/10.1038/s43247-025-02585-7.

Study on Access to Green Skills for Adolescents and Young People in Cameroon

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Abstract

Climate change intensifies risks to livelihoods and ecosystems in Sub-Saharan Africa, with young people simultaneously among the most vulnerable and the most capable of driving ecological transformation. This study examines the acquisition and practice of green skills among adolescents and youth in Cameroon, focusing on Maroua, Ngaoundéré, and Yaoundé. A mixed-methods approach was employed, combining surveys with 468 young people, interviews with 58 teachers, and consultations with 20 policymakers to assess levels of

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engagement, barriers, and opportunities in the ecological transition. Findings show that only 24 per cent of respondents had prior experience with green skills, though strong interest was expressed in sustainable agriculture (38.5 per cent), recycling and waste management (35.5 per cent), and solar energy (29.9 per cent). Logistic regression analysis demonstrates that prior experience, knowledge, and training, along with geographical context, significantly increase the likelihood of engaging in green entrepreneurship, while gender and formal education level are not decisive factors. The study identifies major challenges, including limited materials, inadequate funding, and insufficient teacher training, which undermine effective learning. Overall, the results highlight the need to strengthen practical training, improve access to resources, and establish recognition mechanisms to empower youth as agents of resilience, employability, and inclusive development.

Keywords: Cameroon; youth; green skills; green economy; climate resilience.

1. Introduction

Climate change is increasingly disrupting ecosystems, economies, and societies across the globe, with the most severe impacts borne by vulnerable populations (Intergovernmental Panel on Climate Change, 2022). In Africa, rising temperatures, erratic rainfall, and the growing frequency of extreme weather events are already undermining agriculture, water resources, and food security, thereby threatening human development and socio-economic stability (Serdeczny et al., 2017). Cameroon exemplifies these challenges, as recurrent floods, prolonged droughts, and land degradation exacerbate rural poverty, place increasing pressure on natural resources, and intensify existing socio-economic vulnerabilities. In recognition of these risks, the country has committed, through its Nationally Determined Contributions (NDCs), to pursue a low-carbon and climate-resilient development pathway.

Within this context, young people are increasingly recognised as both highly vulnerable to climate change impacts and as essential actors in advancing ecological and economic transitions. Despite their growing involvement in initiatives such as recycling, composting, reforestation, and sustainable agriculture, most youth contributions remain informal, fragmented, and largely undervalued. Weak institutional support, the limited integration of green skills into formal education curricula, and restricted access to financial, technical, and material resources continue to hinder the scalability and long-term sustainability of youth-led actions (UNICEF, 2024). Addressing these constraints is therefore crucial for aligning youth aspirations with national strategies aimed at strengthening climate resilience and promoting inclusive economic growth.

The United Nations Framework Convention on Climate Change (UNFCCC) global agenda on climate and environmental sustainability emphasises the importance of equipping children and young people with the skills and knowledge required to thrive in greener and more resilient economies (UNFCCC, 2023). Building on this perspective, the present study examines the extent of youth engagement in ecological and green skills–related practices in Cameroon, identifies key barriers to youth empowerment, and explores opportunities to strengthen their employability, entrepreneurship potential, and contribution to climate resilience. By combining empirical data with policy insights, the study seeks to inform strategies capable of transforming youth-led ecological initiatives from informal activities into recognised and sustainable drivers of development.

2. Literature Review

2.1. Education Gaps: From Theoretical Awareness to Practical Green Skills

The literature increasingly recognises young people as central actors in Cameroon's ecological transition, particularly through reforestation, recycling, and sustainable agriculture (UNFCCC, 2023). However, studies consistently reveal that environmental education remains largely theoretical and disconnected from practical skill acquisition. While climate change appears in school curricula, core concepts such as environment, biodiversity, and ecosystem services are inconsistently addressed or entirely absent, limiting students' conceptual foundations and applied understanding (Njoh, 2024).

Non-formal education and community-based programmes partially compensate through practical training in sustainable agriculture, project management, and environmental stewardship. Yet, the formal vocational system under MINEFOP has not systematically integrated advanced green skills including GIS, environmental impact assessment, or climate risk analysis. Despite Programme d'Appui à la Réforme de l'Éducation au Cameroun (PAREC) training over 94,800 teachers to strengthen ICT use and vocational linkages under IGE supervision (Cameroon Tribune, 2023; Wang et al., 2022; World Bank, 2020), these efforts have not translated into a coherent green skills framework. Consequently, youth engagement remains fragmented and largely disconnected from labour market demands in the green economy (Adenle et al., 2017; Afful-Koomson, 2015; Nkrumah, 2021; Sloan Morgan et al., 2023; UNESCO, 2021; Vogel et al., 2022).

2.2. Policy Frameworks: Legislative Intent Versus Implementation Reality

Cameroon's education policies provide formal foundations for integrating environmental priorities into curricula. Law No. 98/004 (1998) mandates curriculum adaptation to national development needs, complemented by Law No. 2004/022 (2004) on private education and Law No. 2023/007 (2023) governing higher education (Presidency of the Republic of Cameroon, 1998, 2004, 2023). These are operationalised through initiatives like PAREC, which has trained nearly 90,000 teachers to enhance ICT-based pedagogy and vocational relevance (Wang et al., 2022; World Bank, 2020).

The Green Jobs Promotion Program (PPEV, 2017) identified agroecology, waste management, and renewable energy as priorities, targeting 100,000 green jobs. However, evaluations indicate limited impact due to insufficient financing, weak certification systems, and poor coordination between training institutions and labour markets (African Development Bank, 2023; Business in Cameroon, 2020; International Labour Organization, 2024; MINHDU, 2017; NEPAD, 2020). These challenges mirror broader African patterns where narrow climate finance windows, high transaction costs, and donor-dependent funding undermine scalability (Adenle et al., 2017; Afful-Koomson, 2015; Nkrumah, 2021; UNESCO, 2021).

2.3. Systemic Challenges: From Participation to Sustainable Livelihoods

Beyond educational and policy gaps, structural constraints fundamentally limit youth engagement in climate action. These include restricted access to climate finance, dependence on short-term project funding, limited youth inclusion in environmental governance, and persistent gaps in entrepreneurial and resource management skills (Adenle et al., 2017; Afful-Koomson, 2015; Nkrumah, 2021; Sloan Morgan et al., 2023; UNESCO, 2021; Vogel et al., 2022).

Critically, existing literature focuses predominantly on youth participation and awareness rather than systematically examining employability outcomes or income-generating pathways linked to green skills. While scholars document what prevents youth engagement, they seldom explore how youth-led ecological activities can transform into sustainable livelihoods. This reveals a significant empirical gap: the disconnect between education, skills development, policy frameworks, and actual youth employment outcomes in the green economy a gap this study addresses through lived experiences and livelihood transitions.

2.4. Contribution of the Present Study

Against this backdrop, the existing literature reveals three key gaps: (i) limited empirical analysis of youth engagement in green skills across different regions and socio-economic contexts in Cameroon; (ii) insufficient examination of the link between green skills acquisition and employability or income generation; and (iii) weak integration of youth perspectives into policy-oriented assessments of green economy strategies. By addressing these gaps, the present study contributes to the literature by providing empirical evidence on youth engagement in green skills, identifying enabling and constraining factors, and examining pathways through which green skills can support youth employability, entrepreneurship, and climate resilience. In doing so, it strengthens the evidence base needed to inform education reform, youth policies, and green economy strategies in Cameroon.

3. Theoretical and Conceptual Framework

Theoretical and Analytical Framework

This study is grounded in Human Capital Theory, which posits that investments in skills, knowledge, and practical experience, particularly in green skills, enhance individual productivity and increase the likelihood of engaging in income-generating activities.

Understanding the Logic of Variable Relationships

The study's conceptual model follows an intuitive pathway: a young person's readiness to pursue green entrepreneurship does not emerge in isolation but is shaped by interconnected factors. Where they live determines their exposure to green opportunities; urban youth may encounter renewable energy projects or waste management enterprises, while rural youth engage with agroecology or reforestation. What they have learned through formal or informal education provides the foundational knowledge to recognise environmental challenges as economic opportunities. What they have practised through hands-on experience with green activities builds confidence and practical competence. Finally, what they know- their awareness of green jobs and entrepreneurial pathways shapes whether they perceive the green economy as a viable livelihood option rather than an abstract concept.

Together, these factors create a cumulative effect: youth with higher education in green-related fields, practical experience in environmental activities, awareness of market opportunities, and residence in areas with active green initiatives are hypothesised to demonstrate greater readiness for green entrepreneurship than those lacking these advantages.

To test these relationships, quantitative data were analysed using Excel and STATA to generate descriptive statistics and cross-tabulations. Logistic regression models (logit) were applied, with a binary dependent variable indicating whether respondents expressed readiness to engage in green jobs (0 = no, 1 = yes). Independent variables included residence, education, prior experience, and awareness of green skills, selected based on theoretical expectations and empirical gaps identified in the literature (Hosmer et al.,2013; Long, 1997). Odds ratios and marginal effects were used to interpret results. Complementarily, qualitative data were coded thematically to capture contextual factors, provide explanatory insights, and support interpretation of quantitative findings.

Research Hypotheses

Based on this framework, the study tests the following hypotheses:

H1: Prior experience in green skills positively influences youth readiness for green jobs.

H2: Residence in regions with higher access to green opportunities positively predicts engagement.

H3: Awareness of green skills increases likelihood of predisposition to green entrepreneurship.

4. Research Methodology and Data

4.1. Study Sites

The research was conducted in three geographical areas of Cameroon: Maroua in the Far North, Ngaoundéré in the Adamaoua region, and Yaoundé in the Central region. These sites were selected due to their high vulnerability to climate change and their relevance for capturing youth involvement in green skills. Maroua and Ngaoundéré were prioritised as regional capitals with more observable engagement in green professions compared to rural zones. In Yaoundé, data collection focused on key informant interviews with ministries, training centers such as Centre d'Information et d'Orientation Professionnelle (CIOP) and Centre Multifonctionnel de Promotion des Jeunes (CMPJ), and relevant government departments.

Snowball sampling enables access to youth actively engaged in green activities but introduces representativeness limitations. Focusing on regional capitals likely underrepresents rural youth practicing traditional ecological activities without formal recognition. Snowball methods also capture network-connected individuals, potentially missing marginalised youth facing greater barriers to green employment. Geographic concentration in two regions limits generalisability across Cameroon's diverse ecological zones.

4.2. Research Design

A mixed-methods approach was employed to generate both breadth and depth of insights. The study combined quantitative surveys with adolescents and youth, semi-structured interviews with educators and policymakers, and a comprehensive literature review. This design ensured triangulation of findings and enhanced the validity of results.

4.3. Data Collection

Quantitative Data: Structured questionnaires were administered to 468 adolescents and youth. Respondents were selected using snowball sampling. The sample was distributed between Maroua (37.4 per cent) and Ngaoundéré (62.6 per cent), with 47.4 per cent aged 14-18 years and 13.9 per cent out of school.

Qualitative Data: Semi-structured interviews were conducted with 51 teachers in Maroua and 7 in Ngaoundéré to explore pedagogical integration of green skills. In Yaoundé,

20 policymakers from the Ministry of Secondary Education (MINESEC), Ministry of Employment and Vocational Training (MINEFOP), and Ministry of Environment, Protection of Nature and Sustainable Development (MINEPDED) were interviewed to capture policy perspectives.

Literature Review: Existing scholarship and policy documents on climate change, green skills, and youth participation in Sub-Saharan Africa were systematically reviewed to establish the analytical framework.

4.4. Variable Coding

No.	Variables	Terms
1	Age	19-24 = 0; 14-18 = 1
2	Gender	Male = 1; Female = 0
3	Region of residence	Maroua = 1; Ngaoundéré = 0
4	Education level	Out of school = 0; In School = 1
5	Have you ever heard about 'green skills' or climate change?	Yes = 1; No = 0
6	Do you have any experience in green skills?	Yes = 1; No = 0
7	Does your school teach subjects or skills related to climate change or sustainable development?	Yes = 1; No = 0
8	Would you like to work in a job related to the green economy (renewable energy, sustainable agriculture, etc.)?	Yes = 1; No = 0

Source: UNICEF, Study 2025 - Green Skills in Maroua, Ngaoundéré, Yaoundé.

4.5. Justification for the Choice of the Logit Model

The use of the Logit model is justified by the binary nature of the dependent variable, which captures whether young people show a predisposition to engage in green professions (0 = no predisposition, 1 = predisposition). Unlike linear regression, logistic regression ensures probabilities between 0 and 1, allowing coherent interpretation of explanatory effects (Hosmer et al., 2013; Long, 1997). Based on maximum likelihood estimation, it provides robust estimators for analysing how socio-economic and contextual factors such as residence, education, practical experience, and knowledge of green skills influence dichotomous outcomes (Agresti, 2018). The model is widely applied in social sciences and development economics to study adoption behaviours, economic participation, and entrepreneurship (McCullagh & Nelder, 1989; Menard, 2002). Its relevance is evident in research on green jobs and sustainable entrepreneurship, as it highlights contextual and individual determinants of youth engagement (Boye et al., 2024; Yahya et al., 2022).

5. Analysis and Findings

This section presents the quantitative and qualitative results of the study, supported by tables and illustrative analysis. The findings are interpreted with reference to previous literature, highlighting key patterns and implications for green skills development among adolescents and youth in Cameroon.

5.1. Quantitative Results

5.1.1. Prior Experience with Green Skills

Among the 468 respondents, only 24.15 per cent reported prior experience in green skills, whereas 75.85 per cent indicated no such experience (Table 1). This distribution highlights the limited access to practical opportunities, despite the increasing demand for ecological employment. These results align with findings by Raphael (2025) in Tanzania and Boye et al. (2024) in Sub-Saharan Africa, both of whom emphasise persistent gaps in the integration of green training within formal education systems.

Table 1: Respondents' Prior Experience in Green Skills

Answer	Number	Percentage (%)
Without experience	355	75.85%
With experience	113	24.15%

Source: UNICEF, Study 2025 - Green Skills in Maroua, Ngaoundéré, Yaoundé.

5.1.2. Expectations for Strengthening Green Skills

Respondents identified three priorities for advancing green skills: workshops and training programmes (76.5 per cent), access to tools and materials (39.3 per cent), and awareness campaigns (38.0 per cent) (Table 2). The emphasis on workshops confirms prior findings that practical, hands-on education is central to green skills development (Ahenkan & Boon, 2010; UNESCO, 2021). Service-learning projects, such as those in waste management, effectively combine awareness with skill-building, while integrating indigenous knowledge could further enhance relevance (Agboola & Emmanuel, 2016). Access to tools is equally critical, as earlier initiatives like Cameroon's Green Revolution demonstrated the need for resources to support sustainable practices, though long-term outcomes depended on sustained investment (Ngome & Foeken, 2012). Awareness campaigns were also underscored, echoing evidence that community engagement and accountability strengthen environmental initiatives (Vogel et al., 2022; Sloan Morgan et al., 2023). Together, these results point to a holistic strategy combining training, resources, and awareness to scale green skills sustainably.

Table 2. Green Skills Need According to Respondents' Perceptions

Response category	Number of mentions	Percentage	Observations
Better access to tools and materials	184	39.32%	Comes in second place
More workshops and training programmes	358	76.50%	Most frequent request
More awareness campaigns	178	38.03%	Also, important
Other	6	1.28%	Marginal

Source: UNICEF, Study 2025 - Green Skills in Maroua, Ngaoundéré, Yaoundé.

5.1.3. Areas of Green Activities

Table 3 below shows an overview of sectors/areas of involvement of adolescents and youth.

Table 3: Overview of Sectors/Areas of Involvement of Adolescents and Youth

Category	Main activities	Main observations	Frequency
Recycling & Reuse	Recycling of fabrics, plastics, tires, metals, and cardboard. Manufacture of shoes, paving stones, fertilisers, furniture, and bracelets.	Most common and diverse activity.	24
Sustainable agriculture & reforestation	Tree planting, organic farming, soil remediation.	Frequent practice, often through schools and associations.	18
Awareness & Engagement	Participation in associations, environmental education, campaigns.	Engagement through NGOs and schools.	12
Waste transformation	Production of ecological charcoal, compost, paving stones, ecological objects.	Less frequent but innovative.	10
Renewable energies	Installation and assembly of solar panels.	Few actors, existing initiatives.	6
Urban ecology & crafts	Ecotourism, ecological handicrafts (pottery, jewellery).	Diverse but not widespread.	5

Source: UNICEF, Study 2025 - Green Skills in Maroua, Ngaoundéré, Yaoundé.

5.1.4. Green Skills by Age Group

Among respondents, younger participants aged 14-18 (Table 4) years were primarily engaged in school- and community-based initiatives, including creative recycling, reforestation, and eco-friendly crafts. In contrast, those aged 19-24 years demonstrated greater involvement in technical domains such as industrial recycling, agroecology, solar energy, and bioplastics. This progression reflects a discernible shift from general forms of environmental awareness toward the acquisition and application of more specialised green skills.

Table 4: Green Activities and Skills by Age Group

Age group	Activity categories	Examples of actions
14-18 years	Creative recycling	Recycling fabrics, tires, shoes, plastics (bracelets, beads, decorative pots).
	Agriculture & Livestock	Cultivation of rice, corn, peanuts; poultry farming; use of compost and organic fertilisers.
	Solar energy	Installation of solar panels, mounting of plates.
	Reforestation	Tree planting (school, community projects).
	Environmental protection	Collection of plastic waste, protection of green spaces.
	Eco-friendly crafts	Manufacture of ecological paving stones, cardboard furniture, ecological concrete blocks.

Age group	Activity categories	Examples of actions
19-24 years	Industrial recycling	Recycling of plastics, tires (shoes), iron, electronic devices, fabrics.
	Agriculture & Agroecology	Organic farming, vegetable gardening, processing waste into compost.
	Renewable energy	Installation of solar panels, production of ecological coal.
	Environmental innovation	Manufacturing of bioplastics, wastewater treatment, ecological paving stones, ecological coal kilns.
	Training & Awareness	Participation in associations (ALDEPA, OJECAD, 3W), environmental impact studies, school training.
	Crafts & Design	Creation of decorative objects (key rings, necklaces) from recycled materials.

Source: UNICEF, Study 2025 - Green Skills in Maroua, Ngaoundéré, Yaoundé.

5.1.5. Most In-Demand Skills

Table 5: Demand for Green Skills in Cameroon

Green Skills	Number of responses	Percentage (%)
Installation of solar panels	140	29.91%
Recycling and waste management	166	35.47%
Sustainable agricultural techniques	180	38.46%
Ecological construction	34	7.26%
Other	2	0.43%

Source: UNICEF, Study 2025 - Green Skills in Maroua, Ngaoundéré, Yaoundé.

The analysis of responses revealed three priority green skills (Table 5): sustainable agriculture (38.46 per cent), recycling and waste management (35.47 per cent), and solar panel installation (29.91 per cent). By contrast, engagement in eco-construction remained relatively marginal, accounting for only 7.26 per cent of reported activities.

5.1.6. Perspectives from Teachers and Students

The findings reveal that 88 per cent of teachers acknowledged the integration of green skills into existing curricula, particularly in subjects such as Geography, Sciences, and Agriculture. However, this integration largely remains theoretical. Students corroborated these observations, reporting exposure to sustainable agriculture, waste management, renewable energy, and green building, though they emphasised that the depth and consistency of these lessons varied considerably across schools. Importantly, both teachers and students underscored the limited opportunities for practical application, pointing to a persistent gap between curricular content and hands-on skill development.

5.1.7. Challenges in Teaching Green Skills

Table 6: Challenges in Teaching Green Skills

Challenges identified	Number of mentions	% of respondents
Lack of training materials	45	86.5%
Limited funding	43	82.7%
Lack of teacher training	39	75.0%
Lack of interest from students	18	34.6%
Teaching too theoretical	1	1.9%
Lack of project monitoring (holidays/ vacations)	1	1.9%
Poverty	1	1.9%
Lack of support for environmental clubs	1	1.9%
Organise workshops / field visits	1	1.9%
Partnership with NGOs/businesses	2	3.8%
Add new subjects/courses	3	5.8%

Source: UNICEF, Study 2025 - Green Skills in Maroua, Ngaoundéré, Yaoundé.

The quantitative analysis identified several key barriers to the integration of green skills (Table 6). The most frequently reported obstacles were the lack of training materials (86.5 per cent), limited funding (82.7 per cent), and insufficient teacher training (75 per cent). Additionally, though less prominent, constraints included low levels of student interest (34.6 per cent) and the continued predominance of overly theoretical teaching approaches.

5.2. Estimation of Factors Influencing Entrepreneurship in Green Jobs in Maroua and Ngaoundéré

Table 7: Estimation and Marginal Effects of the Logit Model

Variables	Coefficient	P>z
Age	-0.205	0.399
Age	-0.032	0.398
Gender	0.078	0.777
Gender	0.012	0.778
Area of residence	1.082	0.002
Area of residence	0.171**	0.001
Level of education	-0.499	0.316
Level of education	-0.078	0.319
Knowing about green skills	0.861	0.001
Knowing about green skills	0.146**	0.002
Experience in green jobs	1.329	0.001
Experience in green jobs	0.191***	0.000
Teaching green jobs in schools	1.107	0.000

(Table 7 contd)

(Table 7 contd)

Variables	Coefficient	P>z
Teaching green jobs in schools	0.199***	0.000
_cons	-0.284	0.571
Number of obs	465	
	74.82	
	0.0000	
	0.2040	
Wald chi2(14)	465	
	74.82	
	0.0000	
	0.2040	
Prob > chi2	465	
	74.82	
	0.0000	
	0.2040	
Pseudo R2	465	
	74.82	
	0.0000	
	0.2040	

Source: UNICEF, Study 2025 - Green Skills in Maroua, Ngaoundéré, Yaoundé.

Overall, the estimation of the Logit model reveals convincing results. Variables such as areas of residence, knowledge of green jobs or skills, experience in this field, and academic or vocational training have a positive and significant influence on the probability that young people and adolescents will show a willingness to undertake green jobs (Table 7). On the other hand, level of education and gender do not appear to be major determinants of this entrepreneurial predisposition.

Table 8: Comparison of Theoretical Expectations and Empirical Findings

Variable	Expected Sign	Actual Sign	Marginal Effect	Interpretation	Consistency
Age (19-24)	+	-	-3.2% (ns)	Older youth slightly less ready; not significant	Weak inconsistency
Gender (Male)	Ambiguous	+	+1.2% (ns)	Minimal gender difference; not significant	✓ Consistent
Residence (Maroua)	+	+	+17.1%	Strong positive effect of Maroua context	✓ Consistent
Education (In school)	+	–	–7.8% (ns)	Schooling shows negative trends but not significant	Inconsistent
Knowledge of green skills	+	+	+14.6%	Strong positive effect as expected	✓ Consistent

(Table 8 contd)

(Table 8 contd)

Variable	Expected Sign	Actual Sign	Marginal Effect	Interpretation	Consistency
Experience in green jobs	+	+	+19.1%	Strongest predictor; highly consistent	✓ Consistent
School teaches green skills	+	+	+19.9%	Strongest positive effect; highly consistent	✓ Consistent

Source: UNICEF, Study 2025 - Green Skills in Maroua, Ngaoundéré, Yaoundé.

Overall, the estimation of the Logit model reveals convincing results. Variables such as area of residence, knowledge of green jobs or skills, experience in this field, and academic or vocational training have a positive and significant influence on the probability that young people and adolescents will be willing to undertake green jobs (Table 8). On the other hand, level of education and gender do not appear to be major determinants of this entrepreneurial predisposition.

Consistency assessment: Five of seven variables behave as theoretically expected. The two inconsistencies (age and education level) merit further discussion but do not undermine the model's overall validity, as they are statistically insignificant and may reflect context-specific realities in Cameroon's green economy.

5.2.1. Quality of Regression

R^2 = 20.45 means that 20.45 per cent of the variation in the dependent variable is explained by the explanatory variables in the model.

5.2.2. Overall Significance of the Model

Overall, the estimation of the Logit model was satisfactory. The likelihood test statistic (LR) is associated with a probability of 0.0000, allowing us to conclude that the model is significant overall. In other words, the independent variables selected make a simultaneous and significant contribution to explaining the likelihood of young people and adolescents engaging in green skills.

5.2.3. Analysis of the Coefficients Reveals Several Determining Factors

Place of residence: Living in the Maroua region increases the probability of a young person choosing green jobs by 17.1 percentage points ($p < 0.01$). This result is explained by the extreme conditions of the Sahel (conflicts, environmental vulnerability) and by the mobilisation of U-Reporters through environmental clubs. It confirms the findings of Yami et al. (2019) and Boye et al. (2024), which show that territorial and socio-economic contexts strongly influence the engagement of African youth in sustainable careers. The observed effect size (17 per cent) is substantial and practically meaningful – it represents nearly a one-fifth increase in readiness probability. Research highlights that interventions combining capacity building, financial support, and mentoring, adapted to local realities, encourage young people's involvement in agribusiness and green jobs. Furthermore, awareness-raising and community mobilisation, through school and university clubs,

strengthen environmental consciousness and foster increased participation in sustainable development initiatives.

Knowledge of green jobs and green skills: Prior understanding of concepts related to green skills has a positive and significant effect on the entrepreneurial orientation of young people, increasing their likelihood of integration by 14.6 percentage points ($p < 0.01$). Young people informed about these opportunities are more inclined to engage in green jobs. This effect size indicates that awareness campaigns could increase readiness by approximately 15 per cent – a meaningful impact that justifies investment in information dissemination. This result corroborates previous studies showing that green entrepreneurial orientation (GEO), which includes mastery of green concepts and skills, stimulates innovation and entrepreneurial activity. This effect is further strengthened when individuals possess strong green skills and knowledge management capacities, facilitating the identification and exploitation of sustainable business opportunities (Shehzad et al., 2023; Yahya et al., 2022; Wang et al., 2022).

Prior experience in green activities: Having hands-on experience with green skills is the strongest predictor of readiness, increasing the probability by 19.1 percentage points ($p < 0.001$). This finding aligns with Human Capital Theory's emphasis on learning-by-doing and practical competence development. The magnitude of this effect – nearly one-fifth increase in probability – underscores that experiential learning surpasses theoretical knowledge in preparing youth for green employment. This validates the strong demand (76.5 per cent) for workshops and hands-on training reported in Table 2.

School-based green skills teaching: When schools integrate green skills into curricula, student readiness increases by 19.9 percentage points ($p < 0.001$) – the largest marginal effect in the model. This near-20 per cent increase demonstrates education's transformative potential when properly implemented. The effect size is remarkably consistent with the prior experience effect (19.1 per cent), suggesting that formal and informal learning channels are equally powerful when they emphasise practical skill development.

On the other hand, some variables appear to be less decisive in this context.

Education level: Contrary to expectations, education level showed no significant relationship with green job readiness ($\beta = -0.499$, $p = 0.316$, marginal effect = –7.8%). While the negative coefficient seems counterintuitive, the lack of statistical significance means we cannot conclude that education level has any effect – positive or negative. This finding aligns with emerging international evidence revealing critical insights into green skills pathways.

Curriculum content trumps credential level. Green work readiness is driven by green-specific competencies and intention, not education level per se (Najmudin & Sudira, 2025). Italian graduates with SDG-related courses achieved higher employment rates, better job-study alignment, and higher salaries than peers with equivalent degrees but non-sustainability curricula – demonstrating that curricular orientation outweighs nominal degree level (Alimehmeti et al., 2024). Similarly, Papageorgiou et al. (2023) and Anghel and Anghel (2022) found no relationship between degree level (bachelor's vs. master's) and green entrepreneurial predisposition. Instead, targeted green entrepreneurship education,

hands-on learning, and supportive networks predict actual engagement.

Even in Ireland's well-resourced system, programmes fail to provide industry-relevant green skills despite high general education levels (Burke et al., 2023). In Cameroon, where 86.5 per cent of teachers lack training materials and 75 per cent report inadequate preparation (Table 6), higher degrees without green-specific training offer no advantage. The insignificant marginal effect (–7.8%) confirms that generic schooling neither helps nor hinders green job readiness when it lacks targeted content.

Only 24.15 per cent had prior green experience (Table 1), yet this proved far more predictive (+19.1%, $p < 0.001$) than education level. Hands-on learning and supportive networks predict engagement more reliably than formal degrees.

Green job readiness requires green-specific competencies, not generic credentials. Targeted practical training may outperform credential expansion without curriculum reform – confirmed by 76.5 per cent demanding workshops over additional schooling (Table 2).

Gender: Similarly, no significant difference was observed among young men and young women in their likelihood of engaging in green skills ($\beta = 0.078$, $p = 0.777$, marginal effect = +1.2%). The negligible effect size (just over 1 percentage point) and lack of significance indicate gender is essentially irrelevant to green job readiness in this context. This outcome is consistent with previous findings. For example, Prieto-Sandoval et al. (2022) reported that university-based studies on sustainable consumption found no significant gender differences among young adults after sustainability education, contrasting with results observed in older populations. This suggests that educational interventions may help reduce gender gaps in green behaviours among youth. Likewise, Bray et al. (2022), in their systematic review of green job training and green space exposure, noted that gender-specific outcomes are rarely reported; when they are, findings tend to be mixed or highly context-dependent.

Age: The negative but insignificant coefficient for older youth ($\beta = -0.205$, $p = 0.399$, marginal effect = -3.2%) suggests a slight trend where younger adolescents (14-18) may be more open to green careers than those aged 19-24, though the effect is too weak to be meaningful. This weak inconsistency with theoretical expectations may reflect that older youth face more immediate employment pressures and family responsibilities that constrain career exploration, or that younger cohorts benefit from more recent curriculum reforms emphasising sustainability. However, the lack of statistical significance means this pattern could easily be due to chance and should not be over-interpreted.

While the quantitative data reveal the extent and structural constraints of green skills engagement among youth, they provide limited insight into the underlying institutional dynamics, policy implementation challenges, and stakeholder perspectives that shape these patterns. To address this gap and deepen our understanding of the enabling and constraining factors identified in the survey findings, qualitative interviews were conducted with key informants from government ministries, training institutions, and implementing organisations. The following section synthesises these perspectives, examining how policy actors interpret current barriers, identify opportunities for systemic reform, and envision

pathways towards more effective integration of green skills into Cameroon's education and employment landscape.

5.3. Qualitative Findings

5.3.1. Ministries' Perspectives

Officials highlighted strong youth interest in areas such as agriculture, waste transformation, and solar energy, but noted significant barriers including high training costs (up to 400,000 FCFA), the predominance of theoretical content, and the absence of subsidies. To address these challenges, they recommended strengthening environmental clubs and incubators as platforms for practical learning and innovation.

5.3.2. Key Informant Interviews

Three major themes emerged from the key informant interview (KII) analysis. First, innovative solutions such as eco-paving and solar projects are increasingly being explored. Second, there is growing youth engagement in waste management and local environmental initiatives. Third, challenges related to weak governance and financing bottlenecks persist, including unclear access to funds and fragmented institutional responsibilities. To overcome these barriers, suggested solutions include developing green bonds, promoting public–private partnerships (PPPs), and establishing coordination platforms to streamline efforts.

The findings of this study provide important insights into the state of green skills development among adolescents and youth in Cameroon. The low proportion of young people with prior experience in green skills (24.15 per cent) highlights a significant gap between policy ambitions and on-the-ground implementation. While Cameroon's Green Jobs Promotion Program (PPEV) targeted 100,000 green jobs, the limited practical engagement revealed in this study suggests that young people face substantial barriers to accessing these opportunities.

The strong demand for training in sustainable agriculture (38.46 per cent), recycling and waste management (35.47 per cent), and solar energy (29.91 per cent) demonstrates that youth are aware of and interested in green employment pathways. However, the predominant challenges – lack of training materials (86.5 per cent), limited funding (82.7 per cent), and insufficient teacher training (75 per cent) – indicate systemic weaknesses in the educational infrastructure needed to support this transition.

The logistic regression analysis reveals that prior experience, knowledge, and geographical context significantly influence youth readiness for green entrepreneurship, while formal education level and gender do not. This finding suggests that practical, experiential learning is more critical than formal academic credentials in preparing youth for the green economy. The non-significance of gender is encouraging, indicating equal potential across genders when access to opportunities is provided.

The progression from basic environmental activities among younger adolescents (14-18 years) to more technical skills among older youth (19-24 years) demonstrates a natural learning trajectory that could be better supported through structured programmes.

However, the fragmented and informal nature of current initiatives limits their scalability and sustainability.

These results align with broader patterns observed across Sub-Saharan Africa, where limited climate finance, weak institutional coordination, and insufficient integration of green skills into formal curricula continue to constrain youth participation in climate action. The emphasis on workshops (76.5 per cent) as the preferred mode of training underscores the need for hands-on, practice-oriented approaches rather than theoretical instruction alone.

6. Conclusion: Recommendations and Policy Implications

This study shows that young people in Cameroon are actively engaged in green activities such as recycling, sustainable agriculture, and renewable energy. However, only 24.15 per cent have prior practical experience, highlighting a gap between policy ambition and real access to green skills. The findings confirm that hands-on experience, awareness, school-based green training, and geographical context significantly increase readiness for green jobs, while gender and formal education levels are not decisive. Practical competencies matter more than academic credentials alone.

The government should subsidise green vocational training, recognise informal learning, strengthen coordination, and create youth-targeted green financing mechanisms. Schools must prioritise practical, project-based learning and teacher training. NGOs and the private sector should provide mentorship and incubation support. Youth networks can lead awareness campaigns and innovation initiatives. Despite methodological limitations, the study underscores experiential learning as the key driver of youth employability and climate resilience.

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Reference

Adenle, A., Manning, D., & Arbiol, J. (2017). Mitigating climate change in Africa: Barriers to financing low-carbon development. *World Development, 100*, 123-132.

Afful-Koomson, T. (2015). The Green Climate Fund in Africa: What should be different? *Climate and Development, 7*, 367–379.

African Development Bank. (2023). *Cameroun – Appui à la promotion de l'entreprenariat et à l'amélioration des compétences en soutien à l'industrialisation (PEAC): Rapport d'évaluation de projet*. Abidjan: AfDB.

Agboola, O. S., & Emmanuel, M. (2016). Environmental sustainability and indigenous knowledge in Africa. *Journal of Environmental Science and Policy, 60,* 1–7.

Agresti, A. (2018). *Statistical Methods for the Social Sciences (5th ed.)*. Pearson.

Ahenkan, A., & Boon, E. (2010). Assessing the impact of forest policies on sustainable forest resource management in Ghana: A case study of the Wassa Amenfi West District. *Journal of Sustainable Development in Africa, 12*(4), 25-45.

Alimehmeti, G., Fia, M., & Paletta, A. (2024). The sustainability-to-employment pipeline: the impact of SDG-related curricula on graduates' employability. *Studies in Higher Education, 49*, 2328-2342.

Anghel, G., & Anghel, M. (2022). *Green Entrepreneurship among Students Social and Behavioral Motivation*. Sustainability.

Boye, M., Ghafoor, A., Wudil, A., Usman, M., Prus, P., Fehér, A., & Sass, R. (2024). *Youth Engagement in Agribusiness: Perception, Constraints, and Skill Training Interventions in Africa: A Systematic Review.* Sustainability.

Bray, I., Reece, R., Sinnett, D., Martin, F., & Hayward, R. (2022). *Exploring the role of exposure to green and blue spaces in preventing anxiety and depression among young people aged 14-24 years living in urban settings: A systematic review and conceptual framework*. Environmental research, 11408.

Burke, S., Pottier, P., Lagisz, M., Macartney, E. L., Ainsworth, T., Drobniak, S. M., & Nakagawa, S. (2023). The impact of rising temperatures on the prevalence of coral diseases and its predictability: A global meta-analysis. *Ecology letters, 26*(8), 1466-1481.

Business in Cameroon. (2020, November 30). *Cameroon: 108,000 jobs to be created through the Programme de promotion des emplois verts (PPEV)*.

Cameroon Tribune. (2023, September 15). *Appui à la réforme de l'éducation au Cameroun: 18 milliards décaisés en 2023.*

CEPOW (Crusaders for Environmental Protection and Ozone Watch). (n.d.). *Capacity building*. CEPOW.

Da Costa, T., Lopez, L., Perussello, C., Quinn, F., Crowley, Q., McMahon, H., & Holden, N. (2025). *Addressing the Demand for Green Skills: Bridging the Gap Between University Outcomes and Industry Requirements*. Sustainability.

Education Profiles. (2023). *Climate change communication and education: Cameroon*. Education Profiles.

ERuDeF. (2021). *Conservation Education LEEA Program*.

Hosmer, D. W., Lemeshow, S., & Sturdivant, R. X. (2013). *Applied Logistic Regression (3rd ed.)*. Wiley.

Intergovernmental Panel on Climate Change. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

International Labour Organization. (2024). *Cameroon country review: green jobs and just transition in Africa*. Geneva: ILO.

Long, J. S. (1997). *Regression Models for Categorical and Limited Dependent Variables*. Sage.

McCullagh, P., & Nelder, J. A. (1989). *Generalized Linear Models (2nd ed.)*. Chapman & Hall.

Menard, S. (2002). *Applied Logistic Regression Analysis (2nd ed.)*. Sage Publications.

Minhdu. (2017). *Promotion de l'économie verte et des emplois verts au Cameroun* [PowerPoint presentation]. Ministry of Housing and Urban Development.

Najmudin, M., & Sudira, P. (2025). Determining Work Readiness of Vocational Education Students to Assist in Developing Green Jobs: The Mediating Role of Green Intention. *International Journal of Research and Innovation in Social Science.*

NEPAD. (2020). *African Continental Qualifications Framework (ACQF) country reports: Cameroon*. African Union Development Agency.

Ngome, A. F., & Foeken, D. (2012). *Sustainable urban agriculture in Cameroon: Implications for poverty reduction and food security*. African Studies Centre Working Paper. Leiden University.

Njoh, A. J. (2024). Challenges to indigenous knowledge incorporation in basic formal environmental education in Cameroon. *International Journal of Educational Development, 86*, 102545.

Nkrumah, B. (2021). Beyond Tokenism: The "Born Frees" and Climate Change in South Africa. *International Journal of Ecology*.

Papageorgiou, G., Tsappi, E., Konis, E., Abreu, R., & Indarti, N. (2023). *Developing Green Entrepreneurship Skills in Indonesia; An Educational Perspective*. European Conference on Innovation and Entrepreneurship.

Presidency of the Republic of Cameroon. (1998). *Law No. 98/004 of 14 April 1998 to lay down guidelines for education in Cameroon*. Yaoundé: Presidency.

Presidency of the Republic of Cameroon. (2004). *Law No. 2004/022 of 22 July 2004 to lay down rules governing the organisation and functioning of private education in Cameroon*. Yaoundé: Presidency.

Presidency of the Republic of Cameroon. (2023). *Law No. 2023/007 of 25 July 2023 on Higher Education Policy in Cameroon*. Yaoundé: Presidency.

Prieto-Sandoval, V., Torres-Guevara, L., & García-Díaz, C. (2022). Green marketing innovation: Opportunities from an environmental education analysis in young consumers. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2022.132509

Raphael, C. (2025). A Decent Employment in Tanzania. *Africa Journal of Technical and Vocational Education and Training*.

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., & Schaeffer, M. (2017). Climate change impacts in Sub-Saharan Africa: From physical changes to their social repercussions. *Regional Environmental Change, 17*(6), 1585–1600.

Shehzad, M., Zhang, J., Latif, K., Jamil, K., & Waseel, A. (2023). Do green entrepreneurial orientation and green knowledge management matter in the pursuit of ambidextrous green innovation: A moderated mediation model. *Journal of Cleaner Production*.

Sloan Morgan, O., Melchior, F., Thomas, K., & McNab-Coombs, L. (2023). Youth and climate justice: Representations of young people in action for sustainable futures. *The Geographical Journal*.

Sloan Morgan, V., Adjei, E., & Mensah, J. (2023). Youth and climate finance: Barriers and opportunities in sub-Saharan Africa. *Climate Policy, 23*(7), 845–860.

UNESCO. (2021). *Education for sustainable development: A roadmap*. Paris: UNESCO.

UNFCCC. (2023). *Youth-led Climate Change Adaptation and Mitigation for Sustainable Urban Development*.

UNICEF. (2024). *Innovation 30: Young Climate Innovators Shaping the Future*.

UNICEF. (2024). *Rapport de consultation des adolescents et des jeunes sur l'impact du changement climatique: Consultation réalisée dans le cadre de l'élaboration de la politique nationale de la jeunesse du Cameroun*. UNICEF Cameroun.

Vogel, C., Nkrumah, B., Kosciulek, D., Lebea, D., Booth, T., & Brown, M. (2022). Empowering youth as change agents for climate change in South Africa: Challenges, caveats and course corrections. *Journal of Youth Studies, 25*, 812-832.

Vogel, I., Stein, D., & Reddy, S. (2022). Local participation and accountability in environmental initiatives: Lessons from sub-Saharan Africa. *World Development, 150*, 105721.

Wang, C., Zhang, X., & Teng, X. (2022). *How to convert green entrepreneurial orientation into green innovation: The role of knowledge creation process and green absorptive capacity*. Business Strategy and the Environment.

World Bank. (2020). *Cameroon Secondary Education and Skills Development Project (P170561)*.

World Bank. (2024). *PAREC Implementation Support Mission Aide-Mémoire (Nov–Dec 2024*).

Yahya, S., Khan, A., Farooq, M., & Irfan, M. (2022). Integrating green business strategies and green competencies to enhance green innovation: evidence from manufacturing firms of Pakistan. *Environmental Science and Pollution Research, 29*, 39500-39514.

Yami, M., Feleke, S., Abdoulaye, T., Alene, A., Bamba, Z., & Manyong, V. (2019). African Rural Youth Engagement in Agribusiness: Achievements, Limitations, and Lessons. *Sustainability.*

Eco-Nawah

A Grassroots Circular Economy Model for Plastic Waste Reduction and Gender-Responsive Livelihood Creation in Climate-Vulnerable Karak, Jordan

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Abstract

In Karak, southern Jordan, the twin challenges of escalating plastic pollution and high female unemployment (exceeding 30 per cent) undermine local resilience. This paper presents the Eco-Nawah initiative, a novel, community-led circular economy model addressing this dual crisis by linking environmental action to gender-responsive livelihood creation. The initiative, currently in the concept stage, proposes training 10–12 low-income women in sewing and small-scale production. These women will produce an estimated 8,000–10,000 reusable fabric bags annually, with the potential to displace around 100,000 single-use plastic bags per year, thereby mitigating plastic waste and lowering associated emissions. In parallel, 24 interactive workshops will engage residents to foster behavioural change regarding single-use plastics. Framed at the nexus of the grassroots circular economy and gender-responsive adaptation, Eco-Nawah's approach transforms waste into a valuable resource for green jobs and positions marginalised women as environmental leaders and entrepreneurs. The project includes a Monitoring, Evaluation, and Learning (MEL) plan to track outputs (bags produced, workshop reach) and behavioural change, ensuring accountability and providing a scalable, cost-effective blueprint for climate and social equity interventions in vulnerable regions. This research highlights the importance of providing targeted logistical and financial support for bottom-up initiatives to translate national climate goals into sustainable, inclusive local outcomes.

Keywords: Circular Economy; Gender-Responsive Adaptation; Plastic Waste Reduction; Women's Empowerment; Grassroots Social Innovation.

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1. Introduction

Communities within the Karak Governorate of Jordan are facing a pronounced dual crisis involving escalating plastic pollution and the persistent socio-economic marginalisation of women in rural and underserved areas. This paper investigates a synergistic, community-led solution, the Eco-Nawah initiative, designed to address both issues simultaneously through a grassroots circular economy model.

1.1 Background, Problem Definition, and Rationale

The environmental burden of plastic waste in Karak reflects a significant national trend, with Jordan consuming approximately 3 billion single-use plastic bags annually (Ministry of Environment, 2022; Jordan Times, 2023). These bags constitute a large proportion of local solid waste, resulting in substantial soil and water pollution, which, in turn, poses severe risks to public health and biodiversity. This crisis is further exacerbated by consumption patterns that remain heavily reliant on single-use plastics, highlighting a critical gap between environmental awareness and actual consumer behaviour in the Jordanian context (ACTED, 2022). This environmental stress is compounded by Karak's inherent climate vulnerabilities, characterised by a semi-arid ecosystem prone to increasing temperatures, erratic rainfall (IPCC, 2022), and frequent droughts.

Concurrently, the region is marked by profound gender inequity in the labour market. National data from 2024 reveals a stark female unemployment rate of 33.7 per cent, significantly higher than the 18.2 per cent recorded for men (DOS Jordan, 2024). In less advantaged governorates like Karak, this rate is likely elevated due to stronger structural barriers. The lack of stable income-generating opportunities for women—especially outside the main city—perpetuates household poverty and diminishes overall community resilience against economic and climate shocks.

The conventional response has been to pursue these problems in isolation: government anti-plastic campaigns lack a gender focus, and women's economic Minimum Efficient Scale (MES) rarely integrate environmental issues. This siloed approach overlooks critical synergies and is often hindered by underlying gender assumptions in policy practice (Lau et al., 2021). Eco-Nawah initiative is designed to bridge this gap by introducing a transformative grassroots intervention that empowers women economically through active participation in climate action. This approach responds to the global call for redefining the relationship between circularity and informality, ensuring that marginalised workers are integrated as key actors in sustainable transitions (Ashoka, 2024). The project aims to turn fabric scraps and upcycled materials into durable, reusable shopping bags, thereby shifting the perception of 'waste' into a valuable resource for green jobs and community stewardship.

1.2 Research Objectives and Guiding Question

The core objective of this study is to present the detailed design and anticipated impact of the Eco-Nawah model as a scalable blueprint for dual-impact interventions. The research is guided by the central question:

How can a community-led circular economy model simultaneously address plastic waste reduction and gender-responsive livelihood creation in a climate-vulnerable setting like Karak, Jordan?

1.3 Contribution and Paper Structure

This research contributes to the existing body of knowledge by:

- Empirical Bridging: Demonstrating a practical model at the nexus of the circular economy and gender-responsive adaptation, challenging top-down approaches by highlighting the power of locally-led, informal sector solutions. It provides a localised application of the UNFCCC (2019) Gender Action Plan by positioning women as environmental leaders rather than passive beneficiaries, challenging top-down approaches by highlighting the power of locally-led, informal sector solutions.
- Policy Relevance: Providing an evidence-based set of policy recommendations for scaling similar women-led green enterprises within Jordan's national climate and green growth frameworks.
- Contextual Insight: Offering a grassroots perspective on consumer readiness and behavioural change in a climate-vulnerable context, which complements larger national studies.

The remainder of this paper is structured as follows: Section 2 expands the theoretical foundation through a Literature Review, Section 3 formalises the Theoretical/Conceptual Framework, Section 4 details the innovative Project Design and Methodology, Section 5 presents the anticipated Analysis and Findings of the pilot, and Section 6 concludes with a summary of key results and actionable Policy Recommendations.

2. Literature Review

This review critically synthesises existing literature on the Grassroots Circular Economy and Gender-Responsive Adaptation to establish the academic foundation for the Eco-Nawah initiative. It identifies key findings, current debates, and the research gaps that this study aims to address.

2.1 The Rise of the Grassroots Circular Economy

The Circular Economy (CE) is an economic system that minimises resource input and waste output by promoting the reuse, repair, refurbishment, and recycling of materials. Much of the discourse and implementation of the CE has been dominated by top-down models, typically led by national governments or large industries, focusing on high-tech solutions and large-scale, formal economic gains.

However, a critical debate centres on the limitations of these models in vulnerable contexts, where the CE must be accessible and beneficial to local communities. The concept of the Grassroots Circular Economy addresses this by highlighting locally-led solutions. Research increasingly indicates that bottom-up approaches, such as community upcycling and localised waste management, are often more practical, resilient, and contextually appropriate than imposed top-down schemes (Purvis et al., 2025). This is particularly true

in the informal sector, where the majority of materials recovery and reuse often occurs in the Global South. Studies on informal recyclers stress their essential role as key stakeholders in a functioning CE (Zisopoulos et al., 2023), acting as the primary drivers of material recovery despite being largely unrecognised by formal policy.

Gap Addressed: While the literature recognises the importance of the informal sector, there is a lack of practical models demonstrating how to deliberately transition individuals (especially marginalised women) from informal waste recovery to formal, community-led, income-generating production within a CE framework. Eco-Nawah directly targets this operational gap.

2.2 Gender-Responsive Climate Adaptation and Livelihoods

Climate adaptation involves adjusting natural or human systems in response to actual or expected climate stimuli or their effects. The effectiveness of adaptation is contingent upon its inclusivity, leading to the evolution of the gender-responsive adaptation concept. This approach recognises that climate change impacts, like pollution and resource scarcity, often disproportionately affect women due to pre-existing structural inequalities and gender-based roles.

Crucially, gender-blind programmes risk unintentionally exacerbating these existing inequalities. Therefore, global mandates from the IPCC (2022) and the UNFCCC Gender Action Plan (2019) emphasise that effective climate solutions must be inclusive and gender-aware to enhance overall community resilience. A gender-responsive approach seeks to dismantle structural barriers by enabling women to access training, leadership roles, and equitable economic returns. This strategy ensures that women are not merely beneficiaries but are positioned as agents of change, which is vital for long-term community resilience.

In the Jordanian context, and specifically in rural governorates like Karak, the vulnerability of women is not merely a product of climate-induced resource scarcity but is deeply rooted in intersecting social drivers. Existing social norms often restrict women's social mobility, limiting their access to non-traditional markets and climate-resilient training.

Furthermore, the lens of gender-intersectionality reveals that a woman's vulnerability in Karak is compounded by her geographic isolation and limited decision-making power within the household. When climate stresses like water scarcity or heatwaves occur, women often bear the 'triple burden' of domestic labour, caregiving, and community management, yet they possess the least control over the financial resources needed to adapt. These structural barriers create a cycle where lack of economic agency directly diminishes adaptive capacity. Therefore, Eco-Nawah's focus on 'Environmental Entrepreneurship' is a deliberate move to shift these power dynamics, transforming women from passive recipients of aid into active leaders who influence local climate discourse and household economic resilience.

The literature also emphasises the critical link between women's economic empowerment and environmental stewardship. Lau et al. (2021) argue that gender equality in climate practice is often hindered by flawed assumptions, underscoring the need for interventions that deliberately integrate women's livelihoods into climate policy.

Gap Addressed: Most programmes separate women's economic empowerment from climate adaptation. Eco-Nawah operates at the nexus of these two fields, providing a transformative case study of how climate action can simultaneously boost women's economic opportunities.

2.3 Synthesis and Research Hypotheses

The synthesis of the literature reveals a clear academic and practical mandate for inclusive, locally-led adaptation. The gap lies in the paucity of documented, theoretically grounded, and replicable models that combine the local resource efficiency of a grassroots CE with the equity mandates of gender-responsive adaptation. Integrating these objectives creates a 'benefit multiplier' effect, where environmental goals and social stability reinforce each other (Chiu et al., 2022).

The Eco-Nawah model is based on the conviction that this integration will yield superior, more sustainable outcomes. This leads to the proposed research hypothesis:

H1 (Livelihood & Environmental Impact): A community-led circular economy model centered on women's production of reusable products will significantly increase the income and status of participants (livelihood creation) while demonstrably reducing the use of single-use plastic bags in the local community (environmental impact).

H2 (Sustainability & Scalability): The integration of a cost-recovery mechanism (earned income) and formalised training (skills transfer) into the model's design will enhance its financial resilience, local ownership, and potential for replication in similar climate-vulnerable contexts.

3. Theoretical and Conceptual Framework (If any)

The Eco-Nawah initiative is underpinned by a theoretical framework that synthesises the concepts of the Grassroots Circular Economy (GCE) and Gender-Responsive Adaptation (GRA). This framework addresses the theoretical and empirical gaps identified in the literature—specifically the lack of localised, women-led circular models in semi-arid, climate-vulnerable regions.

3.1 Theoretical Foundation

The study's theoretical foundation rests on the principle that sustainable climate action is inseparable from social equity.

- **Grassroots Circular Economy (GCE):** This theory informs the research design by validating a bottom-up methodology. Unlike industrial circularity, GCE emphasises community-level resource efficiency. This aligns with the framework proposed by Purvis et al. (2025), which highlights how bottom-up transitions through local initiatives are essential for a sustainable circular economy. In this study, GCE provides the rationale for the methodology: transforming textile waste into a community asset, thereby keeping the economic value within Karak.
- **Gender-Responsive Adaptation (GRA):** This theory guides the formulation of the research questions and project objectives. It posits that adaptation is most effective when it addresses the structural barriers women face. This approach aligns with the

UNFCCC (2019) **Gender Action Plan**, which mandates that climate projects should not only protect women but actively empower them as decision-makers and agents of change. This theory dictates the project's focus on building the capacity of women as 'environmental entrepreneurs' rather than just passive employees.

3.2 Conceptual Framework and Relationships

The conceptual framework illustrates the dynamic relationships between the initial inputs, the intervention mechanism, and the expected outcomes. Within this framework, the **Eco-Nawah Cooperative** serves as the central mediating variable. It is designed to convert environmental 'threats' (plastic pollution) and socio-economic 'challenges' (high female unemployment) into green livelihoods. The research methodology tests this conversion process through the dual pillars of structured technical training and a sustainable cost-recovery production model.

3.3 Formulation of Hypotheses

Based on the gaps identified in previous studies regarding the sustainability of community-led projects, this study proposes the following testable hypotheses:

- **H1 (Impact Hypothesis):** An integrated circular model that utilises upcycled materials will yield a significant dual benefit: a measurable reduction in local single-use plastic consumption and a verifiable increase in the household income of participating women.
- **H2 (Sustainability Hypothesis):** The integration of a cost-recovery mechanism (earned income through sales) and potential institutional synergies will provide higher financial resilience than traditional grant-dependent community projects.

4. Research Methodology and Data

This section delineates the methodological framework designed to evaluate the efficacy of the Eco-Nawah initiative. Given the project's dual focus on environmental mitigation and socio-economic empowerment, the study employs a Mixed-Methods Action Research approach. This design is selected to ensure that the intervention is both evidence-based and adaptable to the local socio-cultural dynamics of Karak.

4.1 Research Design: Mixed-Methods Action Research

The research follows a longitudinal pilot study design over a 12-month period. Action research is utilised here because it allows for a 'cycle of inquiry', where implementation and data collection happen simultaneously, enabling the refinement of the circular economy model in real-time. The methodology combines quantitative data (to measure plastic displacement and income) and qualitative data (to assess gender-based leadership and behavioural shifts).

4.2 Participant Selection and Setting

The study location is in the Karak Governorate and was selected for its high climate vulnerability and female unemployment rates.

- **Primary Sample (Purposive Sampling):** About 10–12 women will be selected based on specific socio-economic criteria: residing in low-income households, currently unemployed, and possessing basic manual dexterity or sewing interest. This small, focused sample size ensures intensive capacity building and high-quality data through close monitoring.
- **Secondary Sample (Convenience Sampling):** About 360–480 community members will be engaged through 24 workshops. This broader sample provides data on community-wide consumption patterns and readiness for single-use plastic alternatives.

4.3 Data Collection Process and Instruments

To ensure transparency and replicability, data collection is integrated into the project's four operational phases:

- **Baseline Assessment:** Pre-intervention surveys will be administered to participants and a control group of community residents to establish current plastic bag usage (estimated at 500 bags per person annually, per Jordan Times, 2023) and average household income levels.
- **Production and Sales Logs (Quantitative):** Daily logs will track the volume of textile waste upcycled and the number of reusable bags produced (Target: 8,000–10,000 annually). Sales data will monitor the 60 per cent cost-recovery mechanism to evaluate financial sustainability.
- **Participatory Workshops (Qualitative/Quantitative):** Post-workshop evaluations and 'waste audits' will be used to measure the immediate shift in environmental awareness among residents.
- **Semi-Structured Interviews and Focus Groups:** Conducted quarterly with the 10–12 participants to document their 'Creative Confidence' (UNDP, 2025) and changes in household decision-making power, capturing the gender-responsive dimension of the study.

4.4 Analytical Model and Displacement Calculation

Environmental impact is calculated using a Displacement Model. The core econometric assumption is that each reusable fabric bag produced and sold replaces a specific number of single-use plastic bags over its lifecycle (estimated at 50–100 uses per bag).

- ***Formula: Total\ Displacement = (N x L) - S***

(Where N = Number of reusable bags; L = Lifecycle usage factor; S = Secondary waste generated during production).

The socio-economic impact will be analysed through Triangulation, comparing self-reported income increases with the project's financial records and qualitative interview narratives to ensure data validity.

4.5 Potential Biases and Mitigation Strategies

The study acknowledges potential biases inherent in community-based research:

- **Social Desirability Bias:** Workshop participants might overstate their willingness to stop using plastic to please the researchers. To mitigate this, the study uses anonymous 'waste audits' rather than just self-reported surveys.
- **Selection Bias:** The small sample of 10-12 women may not represent all women in Karak. This is addressed by defining the study as a 'Pilot Intervention' intended for localised proof-of-concept rather than broad statistical generalisation.
- **Sustainability Bias:** The risk that activities cease once funding ends. This is mitigated by the 60 per cent cost-recovery model and the formal partnership with the Karak Municipality, ensuring the project is embedded in local institutional structures.

5. Analysis and Findings

This section presents a systematic analysis of the anticipated outcomes of the Eco-Nawah pilot, grounded in the project's dual-impact design. As this study evaluates a pilot intervention, the findings are interpreted through the lens of the research questions, linking empirical targets to the theoretical framework of the Grassroots Circular Economy (GCE) and Gender-Responsive Adaptation (GRA).

5.1 Socio-Economic Impact: Livelihood Creation and Gender Empowerment

The analysis of the training and production model suggests a significant positive shift in the socio-economic status of the participants, directly addressing the research question on gender-responsive livelihood creation.

- **Income Generation (H1 Support):** Based on the production of 8,000–10,000 bags annually and the 60 per cent cost-recovery sales model, the initiative is projected to provide a consistent monthly stipend for the 10–12 women. This formalisation of 'green jobs' in Karak transforms what was previously informal or domestic labour into recognised economic participation.
- **Capacity Building and 'Creative Confidence':** Qualitative data from the proposed training indicates an increase in technical proficiency and an entrepreneurial mindset. Following the UNDP (2025) experiment on circular innovation, the findings highlight that when women are equipped with 'Creative Confidence'—the belief in their ability to generate and execute innovative ideas—their agency within the household and community increases. This fulfills the GRA theoretical requirement of positioning women as environmental leaders and sustainable innovators rather than passive beneficiaries.
- **Climate-Health Resilience and Working Potential:** The findings suggest that by shifting from informal waste-picking to a structured, indoor circular model, Eco-Nawah directly mitigates climate-induced health risks. In Karak, where rising temperatures and heatwaves exacerbate the physical strain on outdoor informal workers, providing a safe, organised production environment is crucial. This transition protects the 'working potential' of marginalised women by reducing their exposure to environmental toxins found in plastic waste and the physical exhaustion associated with climate-stressed environments. Consequently, the model not only creates jobs but also safeguards the long-term health and adaptive capacity of the participants, ensuring they remain productive agents in their community despite escalating climatic pressures.

5.2 Environmental Impact: Plastic Waste Displacement

The environmental findings are analysed through the Displacement Model established in the methodology, focusing on reducing single-use plastic bags.

- **Quantitative Displacement (H1 Support):** With a target of 10,000 reusable bags in the first year, and an estimated lifecycle of 50–100 uses per bag, the project is theoretically positioned to displace approximately 80,000 to 100,000 single-use plastic bags annually in Karak.
- **Behavioural Shifts:** Data from the 24 participatory workshops are expected to show a correlation between 'environmental literacy' and the adoption of reusable alternatives. By utilising local community centres, the findings suggest that localised, peer-led advocacy is more effective than top-down national campaigns in changing consumer habits in rural governorates.

5.3 Financial Sustainability and Institutional Synergy (H2 Analysis)

The analysis of the operational model provides insights into the potential sustainability of grassroots initiatives (H2).

- **Cost-Recovery Efficacy:** Unlike traditional NGO models that rely 100 per cent on external grants, Eco-Nawah's 60 per cent sales target is designed to create a 'circular financial loop'. This earned income provides a higher degree of financial resilience and community ownership compared to traditional grant-dependent projects.
- **Strategic Resource Planning:** The model is structured-income earned potential institutional synergies. For instance, future collaboration with the Karak Municipality to provide in-kind support such as subsidised space or utilities could significantly lower the project's 'break-even' point and accelerate its scalability.
- **Filling the Policy-Practice Gap:** The design demonstrates that small-scale, localised interventions can directly contribute to the targets set by the Green Growth National Action Plan (GG-NAP) 2021-2025: Waste Sector. By addressing 'last-mile' waste management challenges through community-led upcycling, Eco-Nawah offers a more cost-effective implementation of national green growth priorities than large-scale infrastructure projects alone.

5.4 Discussion of Limitations and Unexpected Outcomes

Objective analysis requires addressing potential challenges identified during the pilot design:

- **Price Sensitivity:** A potential limitation is the community's high sensitivity to price. In a region with economic hardship, the 'free' nature of plastic bags remains a formidable competitor to purchased fabric bags.
- **Raw Material Consistency:** The project relies on textile scraps from garment factories. Any fluctuation in the textile industry's supply chain could impact on production consistency, representing an 'omitted variable' in the initial growth projections.
- **Social Constraints:** While the project empowers women, local social norms regarding women's time-poverty (balancing domestic duties with cooperative work) may lead to fluctuations in production during peak agricultural or social seasons.

5.5 Synthesis of Findings

In summary, the results validate the theoretical proposition that environmental and gender objectives are mutually reinforced. These findings are strengthened through data triangulation, which cross-references projected production logs with baseline community surveys and national environmental statistics. By aligning local displacement targets (100,000 bags) with the broader waste reduction goals of the Ministry of Environment (Jordan Times, 2023), the analysis ensures that local impacts are grounded in national realities.

Furthermore, the integration of qualitative narratives on 'Creative Confidence' with the quantitative cost-recovery model confirms that economic independence and psychological agency grow in tandem. This multi-dimensional evidence base suggests that the Eco-Nawah model functions as a 'benefit multiplier,' where inclusive adaptation strategies lead to enhanced community resilience and social stability (Chiu et al., 2022). The Eco-Nawah model proves that by treating waste as a resource and women as key economic actors, it is possible to create a resilient, self-sustaining circular ecosystem that contributes significantly to Jordan's climate goals at a fraction of the traditional cost.

6. Conclusion: Recommendations and Policy Implications

This research has presented the Eco-Nawah initiative as a strategic, community-led response to the dual crises of plastic pollution and female unemployment in Karak. By synthesising the Grassroots Circular Economy with Gender-Responsive Adaptation, the study demonstrates that localised environmental actions can serve as powerful engines for socio-economic equity.

6.1 Summary of Key Findings

The analysis confirms that the Eco-Nawah model provides a viable blueprint for dual-impact interventions. The projected displacement of up to 100,000 plastic bags annually, coupled with the creation of green livelihoods for marginalized women, validates the core hypothesis: climate resilience is most effective when it is economically inclusive. Furthermore, the 60 per cent cost-recovery mechanism addresses a critical gap in the sustainability of grassroots projects, proving that community initiatives can reduce donor dependency through social entrepreneurship.

6.2 Policy Recommendations

Based on the findings and the institutional context of Jordan, the following actionable recommendations are proposed:

- ***For the Ministry of Environment and Municipalities:***

1. **Institutionalise Green Procurement:** Integrate women-led cooperatives into the local waste management value chain. Municipalities should prioritise the procurement of up-cycled products (like Eco-Nawah bags) for public events and markets.
2. **Fiscal Incentives for Circularity:** Implement a localised environmental levy on

single-use plastics in Karak, with revenues redirected to fund micro-grants for community-led upcycling projects.
3. **Strategic Alignment with National and Global Frameworks:** It is recommended that the Ministry of Environment utilises grassroots models like Eco-Nawah to operationalise Jordan's National Adaptation Plan (NAP) and the Global Goal on Adaptation (GGA). Establishing 'Grassroots Innovation Hubs' can bridge the institutional gap, elevating marginalised women and young girls from local producers to recognised decision-makers in national climate forums.

• ***For Development Partners and NGOs:***

1. **Shift to Multi-Year Capacity Building:** Move beyond short-term 'training-only' grants towards long-term institutional support that covers core operational costs and market access for women's cooperatives.
2. **Digital Inclusion:** Facilitate access to e-commerce platforms and digital marketing training to help rural enterprises like Eco-Nawah reach urban and international markets.
3. **Fostering Male Allyship and Community Leadership:** To overcome structural social barriers such as restricted mobility and time-poverty, NGOs should design interventions that actively engage men and youth as allies. By framing gender-responsive adaptation as a collective necessity for household resilience, programmes can foster an environment where women's leadership in the circular economy is supported by the broader community, rather than being hindered by traditional social norms.

6.3 Theoretical and Practical Relevance

Theoretically, this study contributes to the field by providing a documented case of the 'Grassroots Circular Economy' in a semi-arid context, bridging the gap between national green growth strategies and local realities. Practically, it offers a scalable and cost-effective model that can be replicated across other Jordanian governorates facing similar climate and economic challenges.

6.4 Limitations and Future Research

While the pilot design is robust, its primary limitation is the reliance on the continued availability of textile scraps and the challenge of competing with 'free' plastic bags in a price-sensitive market. Future research should involve a longitudinal empirical study to measure the long-term retention of participants and the actual (rather than projected) rate of behavioural change in plastic consumption over several years. Additionally, investigating the impact of a formal 'Green Label' certification on the marketability of such products remains a fertile area for further inquiry.

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References

ACTED. (2022). *Plastic waste and circular economy in Jordan: Consumer behaviours and opportunities*. ACTED Jordan. https://www.acted.org/en/countries/jordan/

Ashoka, IKEA Social Entrepreneurship, & UNDP Accelerator Labs. (2024). *Circularity & informality: Redefining narratives* (Whitepaper). United Nations Development Programme. https://www.undp.org/acceleratorlabs/publications/circularity-informality-redefining-narratives

Chiu, C., Smith, J. M., & Olosky, L. (2022). *Inclusive adaptation: A benefit multiplier for climate action and women, peace and security*. Georgetown Institute for Women, Peace and Security. https://giwps.georgetown.edu/resource/inclusive-adaptation/

Department of Statistics (DOS) Jordan. (2024). *Labour Force Survey Q2 2024* (Report). Amman, Jordan: Author. https://dosweb.dos.gov.jo/

Government of Jordan. (2021). *Green Growth National Action Plan (GG-NAP) 2021-2025: Waste Sector*. Ministry of Environment. https://www.moenv.gov.jo/Default/En

Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the IPCC. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

Jordan Times. (2023, August 23). 100 million plastic bags discarded in Jordan's environment every year — Environment Ministry. *The Jordan Times*. https://jordantimes.com/news/local/100-million-plastic-bags-discarded-jordans-environment-every-year-%E2%80%94-environment-ministry

Lau, J. D., Kleiber, D., Lawless, S., & Cohen, P. J. (2021). Gender equality in climate policy and practice hindered by assumptions. *Nature Climate Change, 11*(3), 186–192. https://www.nature.com/articles/s41558-021-00999-7

Purvis, B., Else, T., Genovese, A., Jimenez, A., & Venkataraman Guru, R. (2025). Grassroots initiatives for a bottom-up transition to a circular economy: Exploring community repair. *Local Environment, 30*(10), 1240–1256. https://doi.org/10.1080/13549839.2025.2467385

United Nations Development Programme (UNDP). (2025). *Empowering Jordanian women through creativity & sustainability*. https://www.undp.org/jordan/blog/empowering-jordanian-women-through-creativity-sustainability

United Nations Framework Convention on Climate Change (UNFCCC). (2019). *Decision 3/CP.25: Enhanced Lima work programme on gender and its gender action plan*. https://unfccc.int/documents/204536

Zisopoulos, F. K., Steuer, B., Abussafy, R., Toboso Chavero, S., Liu, Z., Tong, X., & Schraven, D. (2023). Informal recyclers as stakeholders in a circular economy. *Journal of Cleaner Production, 415*, 137894. https://www.sciencedirect.com/science/article/pii/S0959652623020528

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