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Assessing the links between climate change resiliency and food security in northwestern region of Bangladesh

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Abstract: Climate change is intensifying threats to food security across the developing countries, pushing vulnerable nations like Bangladesh towards a breaking point – where resilience is no longer an option but a survival imperative. Despite growing concerns, however limited empirical research exists on how climate resilience influences food security across rural and urban farming households. This study examines climate resilience in northwestern Bangladesh and its impact on farming households' food security. Using multistage random sampling, 498 households across 16 villages in extreme climate zones were surveyed. A climate resilience index (CRI) was developed to assess resilience, and a binary logistic model analysed its effect on food security; the findings indicate a positive association between them. Other key determinants of food security include household income, non-farm employment, crop diversity, education level of the household head and farm size. Also, urban households exhibit greater resilience than rural ones, with 38.7% and 32.8% classified as food secure, respectively. Enhancing climate resilience through adaptive strategies can improve food security, while off-farm activities provide critical financial support. Policy interventions, such as government or NGO-led agricultural financing, could further strengthen food security.

Keywords: binary logistic model; composite index; farming households; multistage random sampling; principal component analysis; rural urban comparison

Global climate change (CC) has become extremely aggravated in the past few decades, and carbon emissions impart significantly on atmospheric warming (Al-Ghussain 2019; Abbass et al. 2022). Both global average surface temperature and air temperature are still increasing, with the 10 warmest years on record, having

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taken place since 2005 (Celik 2020; Verma 2021; Straffelini and Tarolli 2023). This is a strong threat to global food security systems – even in many developed countries, food insecurity remains and undermines their public health objectives. Before COVID-19, more than 820 million individuals were hungry and 110 million experienced acute food insecurity (Loopstra 2018; Pollard and Booth 2019; United Nations 2020). These conditions have been further exacerbated by the pandemic, particularly in low- and middle-income countries (Bloem and Farris 2022). With these worldwide and regional vulnerabilities, in which deltaic areas represent the epitome of environmental risks and human reliance on natural resources, agriculture is the sector most immediately and critically affected.

Agriculture is the leading provider of food supply and security (Pawlak and Kołodziejczak 2020) and CC endangers global food production through increasing CO_2, elevated temperature, altered precipitation and extreme weather, and heightened weed, pest and disease pressure, directly connecting CC to food insecurity (Lin 2011; Altieri et al. 2015). Bangladesh is a case in point, being sixth most climate vulnerable in the 2017 German Watch Global Climate Risk Index rating (Hossain et al. 2017). The cyclone of 2007 alone incurred a total damage worth USD 2.3 billion by wiping out more than two million homes and vital infrastructure such as schools, agricultural lands and transport networks (Chowdhury et al. 2021; Ahmed et al. 2022). These shocks may prompt households to switch to cheaper alternative food items, thus compromising diet quality (Islam et al. 2021a).

The projected 4 °C temperature rise is expected to severely reduce the yields of rice, wheat and other crops in Bangladesh (Islam et al. 2022a; Naz et al. 2022), that are consistent with 6% and 4% losses in wheat and maize yields, respectively, worldwide between 1980–2008 (Lobell and Gourdji 2012) as well as potential future losses of up to 11% without adaptation (Hasegawa et al. 2022). In such scenario, climate resilience, the ability to bounce back from disaster, emerges as the key for transformative subsistence agriculture into high-productive systems (Logan et al. 2013; Mitra and Shaw 2024), not just to ensure local food supplies but to forestall cascading effects through interlinked global food systems, emphasising the urgency of developing comprehensive resilience strategies and mobilising climate finance (Raj et al. 2022).

The reverberations of climate-induced yield losses extend well beyond the confines of individual farms, disrupting complex supply chains and emphasising the imperative need for the development of holistic resilience frameworks and deployment of climate finance. Research on climate-change adaptation in a wide range of agroecological settings including farming systems in South Asia (Abdur Rashid Sarker et al. 2013; Habiba et al. 2013; Ahmad et al. 2014; Alauddin and Sarker 2014; Islam and Hossen 2016; Acharjee et al. 2020; Islam et al. 2020b; Anik et al. 2021; Roy et al. 2021; Kamruzzaman et al. 2023; Tasnim et al. 2023) as well smallholder farmers in Africa and other developing and developed nations in the world (Hassan and Nhemachena 2008; Burke and Emerick 2016; Adeagbo et al. 2021; Aragón et al. 2021; Khan et al. 2022; Raihan 2023; Desmet and Rossi-Hansberg 2024), have long shown that increasing temperatures and variable rainfall are a threat to crop productivity. Farmers adopt various localised coping mechanisms such as crop diversification, plant drought-tolerant crops, adjusted sowing dates and water-saving techniques; however, the success of these strategies vary with knowledge, farm size, credit facilities and extension services availability, institutional infrastructure for development support and climate-smart technologies.

Concurrent studies on household food security (Ahmad et al. 2014; Cafiero et al. 2018; Habtewold 2018; Al Banna et al. 2021; Banna et al. 2022; Islam et al. 2022b; Sarker et al. 2022; Hadley et al. 2023) demonstrate that social and environmental shocks, such as poverty, price variability, and climate extremes affect not only food access but also the quality of diet. Critical determinants are income, farm size, education, and participation in social protection, with interventions that include focused cash transfers, extension (education around production methods), and community-based nutrition education working to improve food availability and utilisation.

Some research does, however, explicitly relate climate change to the context of food security (Das and Ansari 2021; Islam et al. 2021b; Brenton et al. 2022; Lam et al. 2022; Ahmed et al. 2025; Khalifa 2025), thereby demonstrating several mechanisms through which weather changes can reduce household level food security. Increasing temperatures and the effects of heat stress on both crops and farmers directly reduce household incomes and access to food (Vermeulen et al. 2012; Kroeger 2023) while changing rainfall patterns, droughts and extreme weather events disturb food supply chains and drive-up prices, quickly squeezing household purchasing power more than wages have grown in rural areas (Ahmed 2024). Poor assets, limited livelihood options and inadequate safety nets are known to force households which are already on the edge into high vulnerability and insufficient dietary intake during climatic perturbations (Randell et al. 2022). At a household level, low asset base, limited income earning opportunities,

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and poor social safety nets systematically push poor communities into a vulnerability trap for dietary insufficiency during climatic stress (Rahman et al. 2024).

However, the evidence from elsewhere in the developing world – such as sub-Saharan Africa and Central Asia – is that a combination of adaptive responses, most notably livelihood diversification, climate-smart agriculture and improved irrigation with targeted social protection, can strengthen household food security (Kompas et al. 2024). Studies in South Asian deltaic environments, including Bangladesh, indicate that those households practising crop and income diversification have greater household dietary diversity and access to food consumption resilience compared with subsistence-oriented households; however these benefits are unequally distributed and secure the largest gain for wealthier households versus poorer ones owing to challenges in market access and credit availability (Matsuura-Kannari et al. 2023). Further, this adaptive capacity is critically dependant on institutional support such as market information, improved seed provision, extension services and access to irrigation infrastructure – deficiencies that disproportionately constrain smallholders and landless households (Matsuura-Kannari et al. 2023). Therefore, household food security is multivariate and consists of four interlinked dimensions – dietary adequacy, income stability, asset availability, and adaptive capacity – some of which are likely to react differently against climate shocks with reference to the household attributes, institutional settings and access opportunities to the adaptive resources in deltaic farming systems (Tasnim et al. 2025).

Despite this wide array of literature, few papers have established a multidimensional, indicator-based climate resilience index and empirically tested the effect on an aggregate food security at household level. Our study bridges this gap by (*i*) creating a climate resilience index with principal component analysis of asset, livelihood and social-institutional indicators, and (*ii*) analysing how resilience capacity mediates the association between climate vulnerability and standardised food security outcomes. We also examine how socioeconomic factors – income, education, non-farm income and livestock ownership – affect this resilience-food security relationship.

By providing conceptual pathways of the mediating link of resilience, as well as practical suggestions to policymakers (from integrated governance structures and spatially targeted investments to finance earmarking for adaptation and monitoring systems), this research contributes towards a better understanding of climate-food dynamics and provides policy directions that can be scaled in Bangladesh and other developing countries which are vulnerable to climate shocks.

MATERIAL AND METHODS

Data and sample characteristics

Northwestern Bangladesh was identified as the best natural laboratory to address climate resilience-food security analysis, because it suffers by far the highest climate vulnerability in the country; mean summer temperatures of 36 °C have been recorded over the past 35 years and are still increasing, alongside an increasingly erratic pattern of precipitation (Rahaman et al. 2016; Tasnim et al. 2023), associated with the concomitant food insecurity (Sultana and Sabau 2023; Yasin et al. 2024).

Statistical representativeness was ensured by employing probability-based multistage sampling: two districts (Pabna, Natore) were randomly sampled from the Northwestern region; four upazilas (Pabna Sadar, Ishwardi, Lalpur and Bagatipara) were then selected and 16 unions followed final systematic household selection (n = 498 respondents, Table 1). Rural-urban stratification by district proximity (Pabna Sadar/Bagatipara urban, Ishwardi/Lalpur rural) resulted in equal representation (248 urban; 250 rural), accounting for differentials in market access that confound links between resilience and food security. This theoretically-informed spatial stratification enhances the analytical ability to study individual level impacts of climate resilience in various livelihood settings through Bangladesh's most climate-stressed agricultural region.

The interviewed 498 households from northwestern Bangladesh display extreme developmental paradoxes as they have 98.6% primary school access but only 45.6% completion of primary educational systems, suggesting systemic bottlenecks beyond infrastructure availability. Also, while 40.4% diversify income, only 48.6% have access to formal credit, implying informal adaptation covering up for institutional slack, and high-income inequality (coefficient of variation 72.9%) alongside near-universal basic services (98.8% market access and 97.4% electricity). Agricultural exposure is revealed by 7.2% landless and 13.7% with no livestock assets, while the adaptation to vulnerability is constrained by infrastructure bottlenecks with universal electricity access at the expense of limited transportation (57.4% road) and financial access. Such paradoxes imply that households exhibit resilience in the context of failed systems of development where capacity to adapt emerges despite, rather than due to, institutional support, key conditions for the examination of how individual climate resilience relates to household food security across constraint-bounded populations.

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Table 1. Sample characteristics

Variable	Mean ± SD	Range	*n* (%)
Demographics & economics			
Age (years)	49.0 ± 11.5	20–80	–
Family size	4.7 ± 1.6	1–14	–
Male household head	–	–	474 (95)
Female household head	–	–	24
Income (EUR)	1 045 ± 762	48–4 968	–
No education	–	–	195 (39.2)
Primary	–	–	227 (45.6)
Secondary or more	–	–	76 (15.3)
Agriculture & infrastructure			
Livestock hold	4.4 ± 2.8	0–10	–
Small farms	–	–	286 (57.4)
Medium farms	–	–	122 (24.5)
Large farms	–	–	54 (10.8)
Landless	–	–	36 (7.2)
Multiple income sources	–	–	201 (40.4)
Service access			
Service	Availability *n* (%)	Service	Availability *n* (%)
Primary school access	491 (98.6)	Market	492 (98.8)
Electricity	485 (97.4)	Health	447 (89.8)
All weather roads	286 (57.4)	Credit facilities	242 (48.6)

Source: Authors' own elaboration

Development and analysis of climate resilience index

The innovative climate resilience index (CRI) methodology is based on a systematic adaptation of the originally developed resilience instrument by Tambo and Wünscher (2017), a food insecurity measurement developed as a holistic resilient assessment tool considering climate impacts. This methodological innovation draws upon and improves an established ten-component framework, namely applying it from measuring food insecurity outcomes to quantifying the household-level ability of impacts that affect climate resilience in urban and rural areas.

The methodological contribution is, therefore, aimed at filling the gap of climate resilience frameworks without robust validation and harmonised measurement methodologies. By adapting Tambo's rigorously tested framework so that it becomes a measure of resilience and its application, an advanced measurement system for resilience remains grounded in theory, it becomes capable of quantifying the climate resilience (Tambo 2016; Tambo and Wünscher 2017). Through a stakeholder consultation process with development actors, agricultural specialists and community elders within the project areas as well as reviewing relevant literature (Tambo 2016; Tambo and Wünscher 2017; d'Errico and Di Giuseppe 2018), we develop a localised way of selecting indicators that allows a modified framework to move from focusing solely on food insecurity into being able to measure climate resilience (Table 2).

The methodological challenge highlighted by Tambo (2016) on the problem of transferring links between indicators and resilience in various scale levels is thus met by this innovative application. It is addressed here with an improved standardisation protocol that preserves the validity of indicators and allows for a cross-component incorporation to assess climate resilience. For variables that show positive associations with climate resilience (income diversification, food availability, adaptive capacity and coping strategies), we use our improved standardisation:

$$I_a = \frac{S_r - S_{min}}{S_{max} - S_{min}} \quad (1)$$

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Table 2. Description of the major/main and sub-components of climate resilience index (CRI)

Major components	Subcomponents	Explanation
Natural disaster and climatic variability	% of Hh reported environmental shock during the last 12 months	1 = yes; 0 = no
	% of Hh reported socioeconomic shock during the last 12 months	1 = yes; 0 = no
	% of Hh reported injury/death due to shocks during the last 12 months	1 = yes; 0 = no
	% of Hh reported having an early warning system	1 = yes; 0 = no
	% of Hh reported prepared for future likely CC impacts	1 = yes; 0 = no
Stability	% of Hh reported facing unsuitable land slopes (topography)	1 = yes; 0 = no
	% of Hh reported infertile soil	1 = yes; 0 = no
	% of Hh reported land under SWC	1 = yes; 0 = no
	% of Hh with the perception of CC impacts	1 = yes; 0 = no
Social capital	% of Hh reported sharing their resource	1 = yes; 0 = no
	% of Hh reported sharing technology	1 = yes; 0 = no
	% of Hh with membership to CBOs	1 = yes; 0 = no
	% of Hh involved in conflict management decision	1 = yes; 0 = no
Income and food access	annual *per capita* income	income in EUR
	HFIAS	HFIAS score
	% of Hh reported with a diversified diet	1 = yes; 0 = no
Health	illness score	number of ill persons
	% of Hh reported they used improved toilet	1 = yes; 0 = no
Water	% of Hh with Improved water	1 = yes; 0 = no
	% of Hh with sufficient water	1 = yes; 0 = no
	% of Hh reported they faced water conflict	1 = yes; 0 = no
Sociodemographic status	% of Hh reported female-headed households	1 = yes; 0 = no
	age of household head	age
	dependency ratio	the ratio of dependent members to worker
	% of Hh with literate household heads	1 = yes; 0 = no
	family size	size of the family
Livelihood strategy	diversity of income sources (% of Hh with more than one income source	1 = yes; 0 = no
	% of Hh exchanged information	1 = yes; 0 = no
	% of Hh who had taken any coping strategies to CC impact	1 = yes; 0 = no
	% of Hh reported technology utilisation	1 = yes; 0 = no
Assets	farm size	1 = small; 2 = medium; and 3 = large
	% of Hh who owned livestock	1 = yes; 0 = no
	% of Hh with access to the communication device	1 = yes; 0 = no
	% of Hh reported saving and loan associations	1 = yes; 0 = no
Access to basic services	% of Hh reported access to the market	1 = yes; 0 = no
	% of Hh reported access to health services	1 = yes; 0 = no
	% of Hh reported access to primary school	1 = yes; 0 = no
	% of Hh reported access to all-weather road	1 = yes; 0 = no
	% of Hh reported access to savings and credit	1 = yes; 0 = no
	% of Hh reported access to electricity	1 = yes; 0 = no

CC – climate change; CBO – community-based organisation; HFIAS – household food insecurity access scale score; Hh – households; SWC – soil and water conservation
Source: Authors' own elaboration from the literature

https://doi.org/10.17221/218/2025-AGRICECON

The indicators that have a negative impact:

$$I_a = \frac{S_{max} - S_r}{S_{max} - S_{min}} \quad (2)$$

where: I_a – the indicator's standardised value; S_r – the indicator's observed (mean) value for region *r*; *min* and *max* – the indicator's minimum and maximum values across the region.

After standardising each indicator or subcomponent, the following formula calculated the average value of each main component:

$$M_r = \frac{\sum I_{ai}}{N} \quad (3)$$

where: M_r – one of the main components of a region; I_{ai} – the indicator indexed by *i* that makes up each component; *N* – the number of indicators in each main component.

Standardising the values of the 10 components across all agroecologies allowed for their average to be used to determine the CRI's weighted average.

$$CRI_r = \frac{\sum_1^{10} WMiMri}{\sum_1^{10} WMi} \quad (4)$$

or Equation (5).

The ten-component model is conceptually based on the three-capacity resilience framework (absorptive, adaptive, transformative capacity) supported by the ever-expanding literature base (Constas et al. 2014). These elements – income and food access, basic services, safety nets, assets, adaptive capacity and stability – correspond to the sustainable livelihoods framework's five species of capital (Moser 1998; Asmamaw et al. 2019), which have been demonstrated necessary for household resilience.

Individual households' resilience index. An innovative approach is presented by constructing household level resilience indices using a principal component analysis (PCA) methodology based on an extensive 28-variable holistic framework of resilience. This is a methodological improvement by translating regional-level measurement of climate resilience into household level indices for statistical analysis of a relationship to household food security.

The PCA method overcomes a key limitation of existing resilience constructs, which are at the aggregate level and do not permit testing of the actual impact that individual household resilience has on outcomes such as food security. This limitation is addressed by stepwise variable expansion and by performing a PCA tailored to the quantification of resilience at the household level (Vyas and Kumaranayake 2006). The approach entails the operationalisation of a comprehensive 28-variable individual resilience framework, which includes demographic attributes (age, gender and family size), economic dimensions (income, income diversity and resource sharing), technological dimensions (access to technologies and technology sharing), social capital indicators (membership in community-based organisations (CBOs), community connections), infrastructure access variables (electricity availability, all-weather roads and market places), institutional connectivity factors (access to savings, credits facilities, access to health services, access to primary school), land & agriculture components (land under SWC practices, soil fertility status, slope suitability of the land, farm size, livestock ownership), natural resources situation of an area (water sufficiency, improved water source) and climate-specific factors (availability of early warning system/exposure to environmental shocks/climatic injury experience).

The 28-variable framework incorporates well-documented dimensions of resilience in climate adaptation literature: demographic variables represent human capital (Sen 1999); economic indicators represent the basis for financial capital and livelihood diversification (Ellis 2000); technological adoption – adaptive capacity (Smit and Wandel 2006); social capital measures of network effects (Putnam 2000); infrastructure access – physical capital availability (Moser 1998) and climate-specific factors feeding back into exposure and sensitivity dimensions (Klein et al. 2014). This broad set of variables covers the multi-dimensionality of resilience empirically confirmed in various settings (Asmamaw et al. 2019; Kuruppuarachchi et al. 2024). This flexible framework is a significant methodological step forward from existing approaches involving integration of systematic literature (Asmamaw et al. 2019; Murendo et al. 2020; Hu and Dong 2023; Kuruppuarachchi

$$CRI_r = \frac{WndcvNDCvr + WifaiFAr + WhHr + WwWr + WsbSBr + WsdpSDPr + WlvsLVSr + WasASr + WscSCr + WabsABSr}{Wndcv + Wifa + Wh + Ww + Wsb + Wsdp + Wlvs + Was + Wsc + Wabs} \quad (5)$$

where: CRI_r – the climate resilience index for each region; *Mri* – main component indicators; *WMi* – the weight of the main component *i*

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et al. 2024; Molla et al. 2024). The new PCA-based individual resilience index also allows for converting multi-dimensional concepts of resilience into a measure at the level of individual households.

$$RI_a = \frac{f1 \times (a^*_1 - a_{1)}}{S_1} + \frac{f2 \times (a^*_2 - a_{2)}}{S_2} + \ldots + \frac{fN \times (a^*_N - a_{N)}}{S_N} \quad (6)$$

where: RI_a – the resilience index for individual households; $f1$ – the PCA-generated component loading for one variable; a^*_1 – the one variable's observed value; S_1 and a_1 – the standard deviation and mean, respectively, of the first variable for all households.

Food security measurement

A methodological novelty for food security measurement is developed by a systematic amalgamation of five well-tested indicators into a complete measurement system that reflects several dimensions of household food security simultaneously. This methodology is an improvement compared to single-indicator analyses, which can be missing significant components of a food security situation and militate against the ability to classify in which states a relationship exists with climate resilience indicators.

The 5-indicator integration model is supported by food security literature indicating that diverse indicators represent different dimensions: MAHFP (months of adequate food provisioning) estimates the temporal availability of food, CSI (coping strategy index) captures behavioural adjustment to food stress, HDDS (household dietary diversity score) reflects quality in the utilisation of nutrients, FCS (food consumption score) consolidates access and frequency, and HFIAS (household food insecurity access scale score) captures lived experiential food insecurity (Maxwell and Caldwell 2008; Jones et al. 2013). This multifaceted approach responds to advice in the literature that 'no single indicator outperformed others across levels of severity' of food insecurity (Coates 2013) and is therefore essential for an exhaustive assessment.

The integrated system for measuring food security comprises:

i) *Months of adequate food provisioning (MAHFP) score.* The prevalence of food insecurity in a household is calculated by subtracting the number of months in which those requirements were not met from the total number of months in the previous year (Swindale and Bilinsky 2006a). For instance, if a family has gone hungry for three out of the last 12 months, their MAHFP score would be MAHFP = (12–3) = 9.

ii) *Coping strategy index (CSI) score.* The term 'coping strategy for food security' refers to the methods through which a household deals with the stress of not having enough food. We employ a total of 12 different coping methods and asked families how often they've used each one during the last week; responses ranged from 0 to 7. We next utilised a focus group discussion to rank the intensity of these coping mechanisms from least to most extreme: 1, 2, 3, and 4. Finally, we multiplied each response's frequency by weight to produce the coping strategy index score (Maxwell 1996).

iii) *Household dietary diversity score (HDDS).* After classifying food into the 12 different food groups (cereals, white tubers and roots, vegetables, fruits, meats, eggs, fish, legumes, nuts and seeds, milk and milk products, oils and fats, sweets, and spices), we questioned respondents about whether or not they had consumed a particular type of food in the previous 24 h and recorded their responses as either 0 or 1. Lastly, adding together all of the different food categories resulted in a score for the dietary variety of the family, which might range from 0 to 12 (Swindale and Bilinsky 2006a).

iv) *Food consumption score (FCS).* We initially classified all foods into nine categories and then asked respondents to rate their consumption of each category over the course of the preceding week using a scale from zero to seven. We then assigned the following values to the various food groups based on their relative weights: staples = 2, vegetables = 1, fruits = 1, meat and fish = 4, pulses = 3, milk = 4, oils = 0.5, sugar = 0.5 and condiments = 0. Summing all food groups provides a household food consumption score.

v) *Household food insecurity access scale score (HFIAS).* There are a total of nine inquiries on respondents' experiences with food insecurity, each of which consists of a conditional and a frequency inquiry. When asked whether they have had any problems connected to food insecurity in the last 30 days, respondents were instructed to identify whether or not they had. If the response to that question was 'yes', then the next question would ask how often this condition had occurred in the previous 30 days: rarely (once or twice), sometimes (3 to 10 times), or often (more than 10 times). All situations where the response to the related occurrence question is 'no' are coded as 0. We recorded responses as 1 = rarely, 2 = sometimes, and 3 = often. The sum of the frequency of occurrence during the past 30 days for the nine food-insecurity related conditions generated a HFIAS score.

https://doi.org/10.17221/218/2025-AGRICECON

We finally classified our respondents according to the five food security indicators (HDDS, CSI, MAHFP, FCS and HFIAS) by their international classification and found the number of respondents' food secured by different types of indicators in rural-urban separately (Mutea et al. 2019).

Binary logistic regression. A methodological novelty is presented in the use of binary logistic regression to assess a new research question: how individual climate resilience indices impact household food security status. To the best of our knowledge, this is the first structured statistical framework to analyse the effect of individual-level climate resilience on food security status at a large scale, filling one of the gaps in climate adaptation and food security research. The dependent variable is binary food security (1 = food secure, 0 = food insecure), generated from a multivariate 5-indicator metabolism of single-threshold methods approach. This methodological innovation makes policy-relevant analysis statistically effective on the examination of climate resilience impacts. The improved logistic regression model specification features the individual climate resilience index as the main explanatory variable:

$$Y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \varepsilon \quad (7)$$

where: Y_i – the dependent variable (1 = food secure; 0 = food insecure); β_0 – the intercept; β_s – the coefficients; ε – the error term; x_s – the explanatory variables.

Table 3 provides the explanatory variable and this flexible framework stands as a methodological development attained through an extensive review process and making use of the new measurement approach of climate resilience (Beyene and Muche 2010; Leza and Kuma 2015; Mutea et al. 2019; Sani and Kemaw 2019).

The analytical approach allows for direct investigation of the strength of association between individual household climate resilience capacity and food security outcomes after controlling for a broad range of socioeconomic, demographic and agricultural factors. This methodological approach offers the first systematic technique to quantify the relationship between climate resilience and food security at the individual household level, introducing new empirical evidence for climate adaptation policy and food security intervention.

Variable selection is widely confirmed throughout food security literature: household head education invariably emerges as statistically significant determinant for better information access and decision-making capacity (Beyene 2008; Bashir et al. 2012), family size exhibits negative relationships with food security through resource sharing effects (Owoo 2018), income-related measures capture purchasing power and alternate livelihoods effects (Barrett 2010), the use of agriculture-specific assets captures production productivity and wealth effects (Ellis and Freeman 2004) and infrastructure access facilitates market participation and service usage by households (Hoddinott 1999). The creation of the climate resilience index constitutes our methodological innovation, given an underlying theoretical rationale from the resilience literature that adaptive capacity at the household level influences people's outcomes with regard to food security via enhanced shock absorption and recovery (Constas et al. 2014).

The methodological novelty of the approach taken by this study arises not from its introduction of novel

Table 3. Binary logistic regression's exploratory variables

Explanatory variable	Code	Types of variables
Head of household's level of education	0 = illiterate; 1 = primary; 2 = secondary; 3 = S.S.C; 4 = H.S.C; 5 = tertiary	factor
Family size	population size of the family	continuous
Off-farm activities	1 = yes, 0 = otherwise	dummy
Total annual income	EUR	continuous
Resilience index	score of resilience index	continuous
Size of accessible land	0 = no farm; 1 = small; 2 = medium; 3 = large	continuous
Irrigation use	1 = yes; 0 = otherwise	dummy
Livestock number	various species of animals maintained	count
Number of crops growing	number of different types of crops grown	count

S.S.C. – Secondary School Certificate; H.S.C. – Higher Secondary Certificate

Source: Authors' own elaboration from the literature

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analytical tools but, rather, from the strategic mixing and adaptation of established methods with a view to gaining insight into an emerging research question: how individual climate resilience mediates household food security. The synthesis of such a methodology by integrating measurements of climate resilience with an assessment across comprehensive dimensions of food security and statistical analysis to derive not-yet-attainable empirical insights was previously infeasible without comprising the necessary rigor.

RESULTS AND DISCUSSION

Resilience index

This section describes the outcomes of the resiliency analysis at various stages. In the initial phase, the results of the indicator that contributes to each of the major components are presented in Table 4. Urban households experienced fewer environmental shocks, fewer socioeconomic shocks, and injuries or deaths than rural households. Around 36% of the urban households reported that they had prepared for future likely CC impacts compared to rural households (17%). Empirical studies show that urban households are typically less vulnerable to weather-related hazards than rural households due to better infrastructure, more financial means and better information systems (Su et al. 2022). For better communication with the district, urban households had an early warning system compared to rural, which is consistent with suggested rural-urban communication infrastructure differentials for Bangladesh's early warning systems. Studies confirm serious online divides between rural and urban areas, with rural populace trailing behind in terms of 38% internet penetration and facing access to smartphone technology due to infrastructure constraints as well as digital illiteracy challenges (Siddiquee and Islam 2020).

More of the rural households reported unsuitable land slopes as compared to urban due to vulnerable infrastructure and management. This result is consistent with the known fact that rural farmers are more topographically constrained, i.e. they are mostly located on steeper locations (> 15° slope) compared to urban housing units which preferably occupy flatter terrain (close to 5° slope) used for agriculture (Zhao et al. 2014; Yang et al. 2023). More urban respondents reported soil infertility and this could be attributed to the abuse of chemical fertiliser. An extensive study of 25 Dutch urban farming programmes revealed gross overuse of fertilisers (Wielemaker et al. 2019). Urban households had a better perception of CC impacts than rural because better communication facilities elucidating climatic fluctuations contributed to the urban households' ability to see them. Radio serves as the main channel for rural communities to get information on climate, while urban dwellers have access to several sources including TV, internet and government platforms. Although rural households are directly exposed to climate, they do not possess the scientific theories of climate processes that urban dwellers have due to the abundance of information flow, which results in marked gaps between city and countryside for perceptions of climate change (Bizeck 2024).

Even though rural households have fewer resources, they are more social and cooperative than urban residents, and the share of resources was found to be higher in the rural region than in the urban (Wijesingha et al. 2025). The share of technology was also found to be higher in rural regions than in urban. Although urban regions all have technological resources and this is not the case for rural, non-commercial mobile phone sharing in sub-Saharan Africa has already been extensively studied and it is apparently more frequent in rural than in urban contexts (Burrell 2010).

Annual *per capita* income positively impacted resiliency and was slightly higher in urban than in the rural region; clearly, urban farmers earn more than rural because of lower transportation cost. Likewise a study comparing rural and urban business performance showed that while rural firms in England had similar levels of turnover to urban ones, they were more likely to be profitable (Phillipson et al. 2019). The higher the household food insecurity access scale scores, the lower the resiliency of a household. The lower prevalence of food insecurity in urban areas was indicated by a higher standardised value in urban areas. Urban residents followed a more diversified diet than rural and an examination of household consumption patterns in Bangladesh showed that while dietary diversity was higher among urban households, the urban households obtained a smaller proportion of their dietary energy from staple foods relative to the rural households, pursuing a more diverse diet by obtaining food from multiple sources in the city (Islam et al. 2020a).

Due to higher life expectancy in urban areas, the indicator value for the average age of the household head was greater compared to rural areas. A recent study revealed that urban males have an average longevity advantage over rural males of 1.56 years, and urban females over rural females, 0.56 years at birth (Islam et al. 2017). For the same reason, the number of dependents in urban regions was more significant, which

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Table 4. Major and sub-components/indicators standardised value

Major components	Indicator	Indicator's standardised value	
		urban	rural
Natural disaster and climatic variability	% of Hh reported environmental shock during the last 12 months (–)	0.46	0.38
	% of Hh reported socioeconomic shock during the last 12 months (–)	0.70	0.64
	% of Hh reported injury/death due to shocks during the last 12 months (–)	0.93	0.90
	% of Hh reported having an early warning system (+)	0.29	0.20
	% of Hh reported prepared for future likely CC impacts (+)	0.36	0.17
Stability	% of Hh reported unsuitable land slopes(topography) (–)	0.92	0.76
	% of Hh reported infertile soil (–)	0.79	0.85
	% of Hh reported land under SWC (+)	0.33	0.38
	% of Hh reported they had a perception of CC impacts (+)	0.87	0.85
Social capital	% of Hh reported, share of resources (+)	0.38	0.41
	% of Hh reported share of technology (+)	0.50	0.94
	% of Hh reported they have a membership to CBOs (+)	0.03	0.01
	% of Hh with social conflict management and involved in the decision (+)	0.32	0.28
Income and food access	average annual per capita income (+)	0.18	0.17
	average HFIAS score (–)	0.87	0.83
	% of Hh reported they had diversified diet (+)	0.39	0.36
Health	average number of ill members (–)	0.56	0.18
	% of Hh used improved toilet (+)	0.83	0.76
Water	% of Hh used improved water (+)	0.88	0.86
	% of Hh with sufficient water (+)	0.88	0.72
	% of Hh with water conflict (–)	0.93	0.90
Sociodemographic status	% of Hh with female–headed households (–)	0.95	0.95
	average age of household head (+)	0.51	0.49
	dependency ratio (–)	0.77	0.81
	% of Hh heads with literacy (+)	0.56	0.66
	family size (–)	0.68	0.71
Livelihood strategy	% of Hh with more than one income source (+)	0.42	0.39
	% of Hh exchanged information (+)	0.49	0.48
	% of Hh with coping strategies (+)	0.41	0.32
	% of Hh with technology utilisation (+)	0.54	0.51
Assets	farm size (+) (1 = small; 2 = medium; 3 = large)	0.14	0.25
	% of Hh who owned livestock (+)	0.88	0.83
	% of Hh with an access communication device (+)	0.81	0.76
	% of Hh with saving and loan associations (+)	0.51	0.41
Access to basic services	% of Hh with access to market (+)	0.99	0.98
	% of Hh with access to health services (+)	0.92	0.87
	% of Hh with access to primary school (+)	0.99	0.98
	% of Hh with access to all–weather road (+)	0.61	0.53
	% of Hh with access to savings and credit (+)	0.53	0.44
	% of Hh with access to electricity (+)	0.99	0.96

(+) indicates a positive relationship with the resiliency index and thus estimated by Equation (1), (–) indicates a negative relationship with the resiliency index and thus estimated by Equation (2); CBO – community-based organisation; CC – climate change; Hh – households; HFIAS – household food insecurity access scale score; SWC – soil and water conservation
Source: Authors' own elaboration

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harms the resilience index; standardising gives a better value for rural compared to urban. As we mainly took data from the farming households, we found that 66% of urban and 56% of rural households are educated because, in urban areas, educated people have many opportunities except farming. The standardised value for the family size indicator was 0.68 for urban and 0.71 for rural areas because of greater life expectancy in urban areas, which also reflects the dependency ratio.

As there are more opportunities to work in urban areas, around 42% of urban respondents reported having more than one income source, compared to 39% of rural. According to a study, urban households in Bangladesh receive income from an average of 3.4 different sources, such as wages, small business, real estate and remittances, compared to the rural average of 2.7, indicating much greater income diversification in cities compared to rural areas (Genoni et al. 2021). The indicator's values for coping strategy and technology utilisation were more for urban than rural areas, as there were more opportunities for using modern technology in farming in urban region. The farm size indicator value was more for urban than the rural region. This is because of the more equal distribution of land in rural areas, as most of the rural farmers are marginalised farmers. More urban households own livestock than rural because, nowadays, the population of livestock raised in urbanised areas of Bangladesh is increasing profoundly (Al Abbasi et al. 2025). More rural households had access to communication devices compared to urban, which can be explained by the fact that rural households have limited access of other communication devices. As there were more banks and other financial institutions in urban areas, the saving and loan association indicator value in urban was more significant than in rural regions. Rural branches comprise 48% of all Bangladesh branches, but represent only 8% of the credit, while urban branches for their part comprise 52% of all branches, but they disburse more than 91% of all bank loans (Hossain et al. 2023). Access to market, health service, primary school, all-weather road, savings and credit, and electricity facilities were slightly more significant in urban areas than rural ones, as they were located near district headquarters. According to BANBEIS (Bangladesh Bureau of Educational Information and Statistics), that resulted in all-season road access to social services for 89% of urban dwellers and 64% of rural ones; more than 95% of urban households in the seven divisions, for instance, are within two kilometres of a primary or secondary school, compared to 72% of rural households (Bayes 2001; Khan 2009).

The calculated value of the major components and the overall CRI for rural and urban areas are depicted in Table 5 and Figure 1. The urban region was better positioned in natural disaster and climate variability. The value for stability, income and food access, health, water, livelihood strategy, assets, access to basic services, and social capital were greater in urban regions than in rural ones. The values of social capital and sociodemographic status were only higher for rural regions. Using Equation (5), we finally calculate the overall value of the climate resilience index for urban and rural areas and, according to our findings, the residents from urban areas were more resilient than rural ones. As also demonstrated in literature, urban populations have greater overall climate resilience – especially related with infrastructure and governance dimensions – while

Table 5. Value of different major components and the overall climate resiliency index (CRI)

Major components	Urban	Rural
Natural disaster and climatic variability	0.55	0.46
Stability	0.73	0.71
Social capital	0.31	0.41
Income and food access	0.48	0.45
Health	0.70	0.47
Water	0.90	0.83
Sociodemographic status	0.70	0.73
Livelihood strategy	0.46	0.43
Assets	0.59	0.56
Access to basic services	0.84	0.79
CRI	0.61	0.57

Source: Authors' own elaboration

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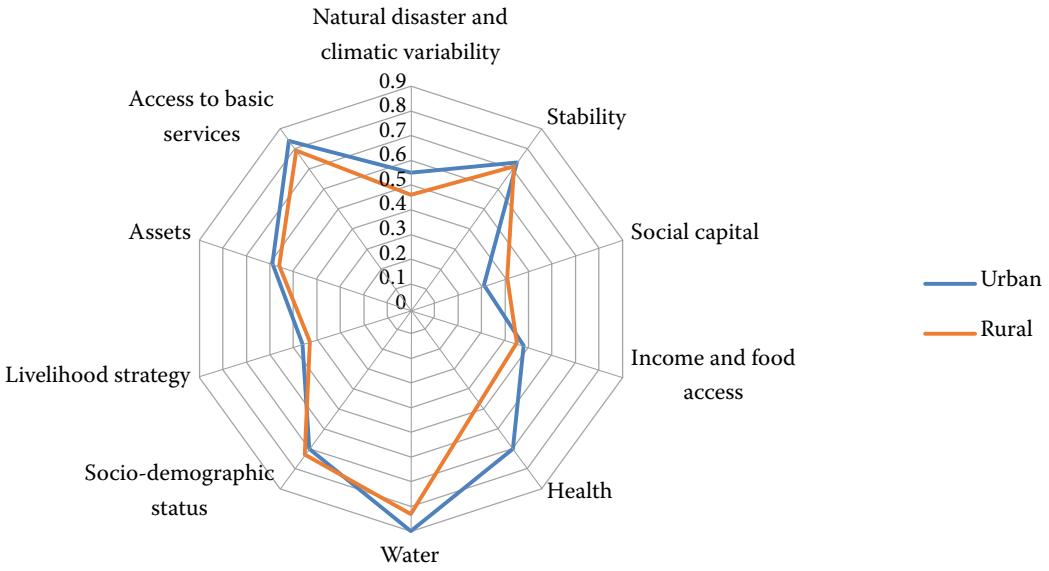

Figure 1. Spider diagram of the major components of climate resilience index (CRI)

Source: Author's own elaboration

rural communities depend more on traditional coping strategies and are exposed to higher environment-related risks (Li et al. 2025). Studies show that there is more effective governance seen in urban localities with municipal government delivering better services of disaster management and climate adaptation infrastructure than those in rural areas, as the rural authorities are responsible to only undertake a national action plan without any capacity for local initiative building (Hossain and Fernández-Güell 2023). Studies show urban populations have better access to several adaptive capacities including healthcare facilities, financial institutions and technological networks for effective climate risk management compared to those in rural areas with institutional service gaps (Chapagain et al. 2025). An extensive paper by Su et al. (2022) provides empirical evidence that urban households are more resilient than their rural counterparts under climate change impacts.

Food security status

The classification in Tables 6 and 7 is based on the World Food Programme and Food and Nutrition Technical Assistance Project recommendations. HDDS provides an evaluation of dietary diversity-related food security, which states that 53.6% and 54.8 % of the families are in a state of food security in urban and rural areas, respectively. Our HDDS findings are consistent with the reported convergence of dietary diversity documented globally in response to effective rural-urban market integration. Other research in Ghana finds no substantial households dietary diversity gaps between urban and rural communities (54% vs 56%) when the rurality has good level of market connectivity and transportation infrastructure (Kennedy et al. 2011). Validation studies also show that HDDS converge when 'rural-urban food supply chains are well-integrated and transportation costs are low', resulting in similarities in access to foods that nullify the usual urban dietary advantages (Swindale and Bilinsky 2006b). These described convergence trends corroborate our observation of the similar level of food security based on dietary diversity between urban (53.6%) and rural (54.8%) respondents as a signpost of well-performing local food system operation. As many as 94% and 90% of urban and rural families had an acceptable FCS, a measure of weighted food dietary variety. This high FCS prevalence mirrors research from across the world, indicating that acceptable FCS rates are over 85% in urban and rural areas when market access and diet diversity is good. A multi-country World Food Programme analysis

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Table 6. Classification of household food security based on the five indicators for urban region

Food security indicators	International classification	Number of households (*n*, %)
HDDS	high (≥ 6)	133 (53.6)
	medium (4–5)	93 (37.5)
	low (≤ 3)	22 (8.8)
FCS	acceptable (> 35)	233 (93.9)
	borderline (21.5–35)	13 (5.2)
	poor (0–21)	2 (0.8)
MAHFP	very high (10–12)	225 (90.7)
	high (7–9)	21 (8.4)
	medium (4–6)	2 (0.8)
	low (0–3)	0 (0.0)
HFIAS	food secure	172 (69.4)
	mildly food insecure	59 (23.7)
	moderately food insecure	14 (5.6)
	severely food insecure	3 (1.2)
CSI	low (0–2)	136 (54.8)
	mild (3–12)	76 (30.6)
	high (> 12)	36 (14.5)
Composite food security status	food secure	96 (38.7)
	food insecure	152 (61.2)

CSI – coping strategy index; FCS – food consumption score; HDDS – household dietary diversity score; HFIAS – household food insecurity access scale score; MAHFP – month of adequate food provisioning
Source: Authors' own elaboration

found in 17 low-and middle-income countries that the mean acceptable FCS was 92% in urban and 88% in rural areas, explaining slight differences between urban and rural areas by similar staple consumption but better dietary diversity in cities (Akakpo et al. 2014). Likewise, 95% of urban and 89% of rural households in Liberia produced acceptable FCS scores showing how context enabling good food supply chains can lead to high dietary diversity (Maxwell and Caldwell 2008). This international pattern, from which we find 94% urban and 90% rural households with acceptable FCS, is corroborated in the available literature.

Regarding the MAHFP, 90.7% of urban families and 88.8% of rural households possessed between 10- and 12-months' worth of appropriate provisions, indicating a high level of food security. Our MAHFP results support known food security measurement trends observed in developing countries with the same protocol. Evidence from Kenya shows that urban populations who achieve 10–12 months of adequate food provisioning in a year are considered food-secure, and about 85–90% of these stable households maintain the status in non-crisis periods (Frayne and McCordic 2015). Additional research also supports the reliability of MAHFP as a proxy of 'household's ability to have an adequate food supply throughout all year, (that is why) household members can access sufficient quantity and quality food' and reported similarities across different African cities when basic food systems are working properly (Frayne and McCordic 2015). There are also documented validation studies in international literature that confirm our result of comparable food security rate between urban (90.7%) and rural dwellers (88.8%).

According to the CSI, just 45.2% of rural families and 54.8% of households in cities had sufficient food supplies. This result is in accordance with documented CSI patterns from agricultural food security studies conducted among different interfering cultures, through CSI methodology. Studies in South Africa using the CSI show that urban areas generally reach higher food security levels, for example 60–65% of households in a stable urban context compared to 40–50% in rural

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Table 7. Classification of household food security based on the five indicators for rural region

Food security indicators	International classification	Number of households (*n*, %)
HDDS	high (≥ 6)	137 (54.8)
	medium (4–5)	66 (26.4)
	low (≤ 3)	47 (18.8)
FCS	acceptable (> 35)	225 (90)
	borderline (21.5–35)	21 (8.4)
	poor (0–21)	4 (1.6)
MAHFP	very high (10–12)	222 (88.8)
	high (7–9)	19 (7.6)
	medium (4–6)	7 (2.8)
	low (0–3)	2 (0.8)
HFIAS	food secure	155 (62.0)
	mildly food insecure	70 (28.0)
	moderately food insecure	22 (8.8)
	severely food insecure	3 (1.2)
CSI	low (0–2)	113 (45.2)
	mild (3–12)	81 (32.4)
	high (>12)	56 (22.4)
Composite food security status	food secure	82 (32.8)
	food insecure	168 (67.2)

CSI – coping strategy index; FCS – food consumption score; HDDS – household dietary diversity score; HFIAS – household food insecurity access scale score; MAHFP – month of adequate food provisioning

Source: Authors' own elaboration

(Grobler 2014). According to the results of the HFIAS, 69.4% and 62% of the households were food secured. This result is consistent with reported HFIAS patterns from extensive international validation studies based on the same measurement procedures. Research conducted in Ethiopia has found that urban populations have food security rates ranging from 62–70% when measured by HFIAS, which is very similar to our cut-off of 69.4%, while rural populations had a pattern similar to our findings but with seasonal variance related to agricultural patterns (Hadley et al. 2008).

Following Mutea et al. (2019), to determine which households could meet all food security dimensions, we found that in urban areas 38.7% of households were food secure across all food security indicators as opposed to 32.8% in rural areas, which parallels the well documented urban–rural gap in household food security (Ehebhamen et al. 2017; Roberts et al. 2019; FAO et al. 2020; Fatimah et al. 2025), whereas 61.2% and 67.2% were not and were thus classified as food insecure. A total of 178 (35.74%) families were food-secured in the urban and rural regions jointly.

Results of the binary logistic regression

Table 8 depicts the result of the binary logistic model. We found that the pseudo R^2 value is 0.43. This means that the independent variables may explain the model's dependent variable to the extent of 43%. In addition, according to the Chi-square estimates, the total logistic model was significant ($P < 0.01$), which suggests that the explanatory variables are important in influencing the level of household food security in the region.

Resilience index. The significant positive association between the resilience index and food security shown in this study is consistent with a wealth of evidence on the role of household-level climate resilience capacity as a major factor in determining access to and stability of food supply. The Resilience Index Measurement and Analysis (RIMA) programme has demonstrated that for each unit of increase in resilience

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Table 8. Possibilities of food insecurity in individual households and the factors that affect them

Food security	Marginal effects	Odds ratio	*P*-value
Resilience index	0.009 752 1**	1.086 594	0.027
Annual income	0.000 189 7***	1.001 616	0.000
Off farm activities	0.100 201 7***	2.347 413	0.002
Farm size	0.043 597 9*	1.449 586	0.076
Number of crops grown	0.022 202 9**	1.208 136	0.013
Family size	0.006 163 4	1.053 889	0.529
Number of livestock owned	0.011 644 5*	1.104 248	0.087
Irrigation	–0.028 071 6	0.787 370	0.514
Educational level	0.082 188 5***	2.013 579	0.000
Pseudo R^2: 0.43			

***, ** and *significance levels at 0.01, 0.05 and 0.1, respectively

Source: Authors' own elaboration

capacity, there are observable changes in food expenditure patterns, leading to a reduction of vulnerability to food insecurity. Recent applications of the RIMA-II approach in developing countries confirm that resilient households have a greater ability to protect food consumption adequacy even when they face the strong climatic and economic shocks (Egamberdiev 2024; Tasnim et al. 2025).

There are several pathways through which resilience to food security works. Households with greater resilience capacity have more diversified asset portfolios, better adaptive strategies and enhanced access to the social safety net that allows them to maintain dietary quality and quantity in critical situations. Agricultural systems resilient to climate reduce variability in food production, while adaptive capacity allows more diverse livelihoods that can ameliorate the severity of shock-induced food shortages. The empirical findings across a range of developing country contexts show that resilience capacity is highly effective in attenuating the adverse effects on food security outcomes of weather shocks (Ansah et al. 2023; Omay et al. 2025).

Annual per capita income. The significant positive association between annual *per capita* income and food security mirrors a well-established association in the literature across developing nations. Household access to food is primarily determined by income via direct purchasing power effects and the indirect effect of agricultural input investments. The little marginal effect that one Euro increase in the family income will increase food security probability by 0.019% shows how crucial income growth is to the welfare of a farming household (Ruslan and Prasetyo 2023; Bai et al. 2024; Bogmans et al. 2024; Niazi et al. 2025; Omay et al. 2025).

Cross-country evidence clearly demonstrates that a high *per capita* income level will lead to a lower prevalence of undernourishment, and more stable food expenditure patterns. The relationship works through several mechanisms: higher purchasing power allows to access diverse, nutrient-dense foods and increased incomes makes it affordable to invest in food storage, processing technologies and market participation. This research highlights income generation as a crucial path to sustainable improvements in food security in rural agricultural-based communities (Jyoti et al. 2005; Masa and Chowa 2021; Omay et al. 2025).

Engagement in off-farm activities. The positive relationship between off-farm activity participation and food security attests the importance of diversification of livelihoods to welfare of rural households. Households engaging in two or more income-generating activities ensures diversified sources of incomes, decreasing consumption variability and improving access to diet. The 10% increase in the food security likelihood for off-farm working households indicates a large welfare gain from diversifying income sources (Babatunde and Qaim 2010; Akosikumah et al. 2025).

Multiple surveys from developing countries have shown that participation in off-farm employment has a positive association with the income and food security status of households. Non-farm activities represent important sources of extra seasonal work and income for smallholder households with limited resources. These networks allow households to efficiently shift labour between on farm and non-farm work according to seasonality and the incidence of shock, leading

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to important coping strategies in response to agricultural downturns (Duong et al. 2021; Bai et al. 2024).

Farm size. A positive association of farm size with food security probability mirrors economies of scale in agricultural production and net welfare. Bigger farms allow households to reach high output levels, introduce crop diversification and gain easier access to better inputs and credit markets. The impact on food security probability, which increased by 4% points as farm size increased, indicates that access to land for agriculture remains crucial for rural household welfare (Del Prete et al. 2019; Abay et al. 2020; Ruslan and Prasetyo 2023).

However, empirical evidence indicates that farm size and food security are related subtler than simple linear association. Small farmers mitigate the limitation on land resources by intensively using the lands, accessing input and output markets for cash transactions and working off-farm. The welfare impacts of farm size are critically conditioned on complementary investments in land-neutral improvements of agricultural productivity and rural infrastructure (Abay et al. 2020).

Number of different types of crops grown. Positive and significant association between number of crops grown and household food security indicate that crop diversification is a critical element of risk management for smallholder farmers. Polyculture cropping system spreads production risks over different species by ensuring that foods are always available despite seasonal variations and makes communities less vulnerable in the face of climate-related crop failure. The 2.2% increase in food security per additional crop variety emphasises the sizable contribution of agricultural diversification (Mango et al. 2018; Appiah-Twumasi and Asale 2024; Mihrete and Mihretu 2025).

Diversification of crops promotes greater food security due to several factors: spreading risk across different crops decreases the likelihood that production will fail entirely, and with diverse systems come a variety of nutritional sources and income. Diversified farms are also more adaptable to weather variability and market price changes. The benefits are especially substantial in climate-vulnerable areas where monoculture systems suffer large production risks (Mango et al. 2018; Adesiyan and Kehinde 2024; Mihrete and Mihretu 2025).

Number of livestock held. The significant favourable association between ownership of livestock and food security may suggest the potential benefit associated with owning cattle in local livelihoods. Livestock offer regular sources of protein-rich food, income in the form of sales of animal products and wealth they represent as stores which can be liquidated during times of shortage. The 1.2% increase in the probability of food security due to a one livestock additional unit represents the marginal welfare gain at different levels of livestock holding (FAO 2009, Taruvinga et al. 2022; Raholiarimanana et al. 2023; Danso-Abbeam et al. 2024). Having livestock contributes to food security stability because of the role they play as a cushion in cases of crop failure and as a commodity that households can sell and/or consume during crises. Among livestock species, the contribution to food security differs, the smaller (ruminant) animals providing more immediate benefits for food insecure households as their management requires far fewer resource inputs and are relatively liquid. The mixed crop-livestock systems also create beneficial synergies for nutrients cycling and agricultural intensification (FAO 2009; Taruvinga et al. 2022; Raholiarimanana et al. 2023; Bwalya et al. 2024).

Educational level. The significant positive effect of household head education on food security of 8% for an additional unit increase in education justified the multi-dimensional gains associated with the investment in human capital. Education increases food security by raising nutritional knowledge, adopting more modern agricultural techniques and gaining access to off-farm employment. More educated households are better able to optimise their production and consumption decisions based on information, have better access to formal credit and extension services (Jyoti et al. 2005; Masa and Chowa 2021; Prasetyo et al. 2023; Monroe-Lord et al. 2024).

The intervention of education with food security can be direct as well as indirect. Direct impacts were in terms of better nutrition knowledge and food preparation practices, while the indirect effect include income generation opportunities and agricultural yields. Maternal education in particular is strongly correlated with child nutrition status and household food security levels, illustrating the intergenerational returns on investment into education (Burchi and De Muro 2006).

Infrastructure and demographic considerations. The insignificant influence of irrigation and household size on food security in this study should be cautiously interpreted in a policy framework of agriculture development. Although irrigation generally tends to boost crop production and food security, the lack of impact in this case might indicate poor management of water resources, high cost of infrastructure or erratic mechanism for providing irrigation services under study. These results imply that irrigation investments need complementary support systems if they are to deliver their full potential of food security gain (Dabour 2002; Zhang et al. 2023; Wang et al. 2025).

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Effects of family size on food security reveal a mixed relationship which differs depending on household settings. On the other hand, with more individuals being available for work and as sources of income in larger families it would, however, result in higher food needs, which could stretch household resources. The absence of significant association could indicate such counter-balancing between these two forces in the study group (Ruslan and Prasetyo 2023).

CONCLUSION

This work contributes to understanding of the nexus between climate change resilience and food security at the household level, focusing on indicator-based research techniques including principal component analysis. The study enriches theoretical understanding by showing that climate resilience serves as a moderator in the relationship from climate vulnerability to household food security results, and that it varies significantly with space and socioeconomic factors. The logistic regression model reveals key drivers: income, off-farm employment and education all contribute to household food security in a combined way accounting for a lot of the variation. Based on the situated case of Bangladesh, these findings reflect broader trends in high climate vulnerable regions globally and make up a replicable model for other similar LDCs under increasing pressure from climate risks.

Authorities need to put into place cohesive governance frameworks that link climate adaptation with agricultural development and social protection policies. A spatially differentiated policy framework is needed due to the fragmented climate resilience across populations. For rural regions, where vulnerability is more rampant, strong investment in climate-resilient infrastructure and diversified livelihood options must be made. On the other hand, cities need robust food distribution channels to ensure fair access to supplies. Furthermore, the robust association between non-farm employment and food security indicates that strategies to stimulate climate-resilient economic diversification that prioritises support for rural industries and the generation of climate-smart value chains are necessary.

There is a need for policymakers to concentrate on building strong systems for monitoring climate resilience and food security, employing standardised indicators to support adaptive management. These monitoring systems need to be built in the national and local capacity to monitor and adapt policies on a real time basis. In addition, international collaboration will continue to be key given that the climate resilience challenge is global in scope. The developed nations should extend vital support in terms of technology transfer, climate finance and knowledge sharing programmes for developing local capacities. Funds should be directed in a well-planned manner to families and territories displaying the most serious lack of resources. This also ensures that support is provided to those who need it most and strengthens underlying strong systems.

Although the current examination provides useful knowledge about what is driving food security and climate vulnerabilities in northwestern Bangladesh, its generalisability within, but more importantly outside the northwest should be cautiously examined. Demographics, institutional capacity and infrastructure vary between regions and provide them with different profiles of resilience and resource constraints. Therefore, the trends witnessed here may not entirely represent the dynamics related to socioeconomic drivers, investment levels and climate-induced pressures present elsewhere. To increase the inferential strength of these findings, researchers in the future could include multi-regional or nationally representative data considering multi agro-ecological zones and government structures. This broadened mandate would allow it to hone policy recommendations and guarantee that strategic advice is sensitive to the specific competitions faced elsewhere.

Drawing upon the policy implications and in light of our regional emphasis, a crucial next step will be to investigate how urban–rural variation in climate preparedness and food security is characterised across the world's diverse agro-ecological zones – from the flood-prone delta to saline-affected coast and hilly uplands – and to pinpoint which context-appropriate interventions (such as community rainwater harvesting in uplands or saline-tolerant rice varieties in coastal zones) are most effective in levelling these disparities, thus guiding place-specific policies that fortify responsiveness and nutritional outcomes at the international scale.

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