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An Assessment of Long-term Meteorological Variability and Farmer's Perception towards the Impact of Climate Change in Coastal Bangladesh: Evidence from Khulna and Pirojpur (1989–2019)

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An Assessment of Long-term Meteorological Variability and Farmer's Perception towards the Impact of Climate Change in Coastal Bangladesh: Evidence from Khulna and Pirojpur (1989–2019)

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Abstract

Coastal farming systems in Bangladesh are exposed to interacting climatic, hydrological, and salinity-related stresses, yet long-term station records and farmers' experiences do not always show identical patterns. This study integrated a 31-year record of annual minimum and maximum temperature, total rainfall, and mean relative humidity (1989–2019) with a 2019 survey of 421 farmers in Bayerbhanga and 6 No. Koyra villages of Khulna District and Faloibuniya village of Pirojpur District. Meteorological trends were assessed using the Mann–Kendall test and Sen's slope, while household responses were summarized using descriptive statistics and interpreted with evidence from focus group discussions and key-informant interviews. Khulna showed a significant increase in annual minimum temperature (Sen's slope = 0.078 °C year^{-1}, $p = 0.008$), whereas its annual maximum temperature, rainfall, and mean relative humidity showed no significant monotonic trends. Pirojpur showed no significant temperature or rainfall trend, but annual mean relative humidity declined significantly (Sen's slope = −0.060 percentage points year^{-1}, $p = 0.016$). Across the three villages, 92.4–99.2% of respondents perceived increasing temperature and 89.7–91.5% perceived increasing heat stress. Rainfall perceptions differed substantially by location; with decreasing rainfall most frequently reported in 6 No. Koyra. Farmers described cyclones, flooding, waterlogging, riverbank erosion, salinity, and freshwater scarcity as interacting hazards. Agricultural production was the most frequently reported household impact, affecting 91.0–95.2% of respondents, while drinking-water scarcity was particularly acute in 6 No. Koyra. The findings demonstrate that station-based annual indicators and farmer observations provide complementary evidence and should be combined in location-specific coastal climate-risk assessment and planning.

Keywords: coastal agriculture; climate variability; farmer perception; extreme events; salinity; household impacts; Bangladesh

1. Introduction

Bangladesh's coastal zone supports a large rural population whose food security and income depend on climate-sensitive agriculture, fisheries, livestock, and natural resources. The region is exposed to tropical cyclones, storm surges, tidal and riverine flooding, drainage congestion, riverbank erosion, salinity intrusion, and seasonal freshwater scarcity. These hazards interact with high population density, small farm

holdings, limited savings, and uneven access to public services, making coastal livelihoods especially sensitive to climatic variability and extreme events [1, 2].

Salinity is a particularly important constraint in southwest and south-central coastal Bangladesh. During the dry season, limited freshwater flow and saline surface water or groundwater can restrict irrigation, reduce crop choice, and lower land-use intensity. Salt stress may also interact with poor soil fertility, waterlogging, tidal inundation, and embankment failure, producing compound effects on crop growth, household water security, and income [3, 4]. The severity of these effects varies over short distances because exposure depends on local elevation, river connectivity, drainage, embankment condition, and access to freshwater sources. Farmers' perceptions are important for understanding these impacts because agricultural decisions are based on experienced conditions, expected risks, and observed consequences at particular crop stages.

Instrumental records commonly summarize annual or seasonal climate variables, whereas farmers may respond to rainfall timing, short dry spells, heat during field work, saline-water entry, crop damage, or the coincidence of several hazards. Studies in coastal Bangladesh have therefore emphasized the value of combining meteorological evidence with locally grounded observations rather than treating either source as sufficient on its own [5–7].

The present manuscript uses meteorological and survey material that has appeared in two previous publications. Ara and Sattar [8] presented 1989–2019 climate observations and farmer-perception findings for the same study villages. Ara et al. [9] subsequently published an article in the STFT Journal (June 2026) under the same title as this manuscript, reporting the same 421-farmer survey and overlapping meteorological analyses, tables and figures. Both publications are acknowledged here to make the shared data and results explicit. The novelty and eligibility of the current submission require editorial assessment.

The study addressed two questions: (1) What long-term trends are evident in annual temperature extremes, rainfall, and relative humidity in Khulna and Pirojpur? and (2) How do farmers in Bayerbhanga, 6 No. Koyra, and Faloibuniya perceive changes in climatic conditions, extreme events, salinity, and associated agricultural and household impacts?

2. Study Area and Methodology

2.1 Study area at a glance

The study was conducted in three coastal villages: Bayerbhanga in Gangarampur Union, Batiaghata Upazila, Khulna District; 6 No. Koyra in 6 No. Koyra Union, Koyra Upazila, Khulna District; and Faloibuniya in Shialkathi Union, Kawkhali Upazila, Pirojpur District (Fig. 1). The villages represent contrasting coastal settings. Bayerbhanga is relatively inland and elevated compared with 6 No. Koyra, although farmers reported salinity and dry-season water constraints. 6 No. Koyra is located close to tidal rivers and is highly exposed to cyclones, embankment failure, coastal flooding, salinity, and freshwater scarcity. Faloibuniya is less saline but is influenced by riverine flooding, erosion, rainfall variability, and seasonal waterlogging. Administrative information and the farmer-household population of each village are presented in Table 1.

Table 1. Administrative location and farmer-household population of the three study villages (Source: Department of Agricultural Extension, 2019, unpublished administrative records; previously published by Ara et al. [9]).

District	Upazila	Union	Village	Total farmer households
Khulna	Batiaghata	Gangarampur	Bayerbhanga	506
Khulna	Koyra	6 No. Koyra	6 No. Koyra	284
Pirojpur	Kawkhali	Shialkathi	Faloibuniya	435
Total				1,225

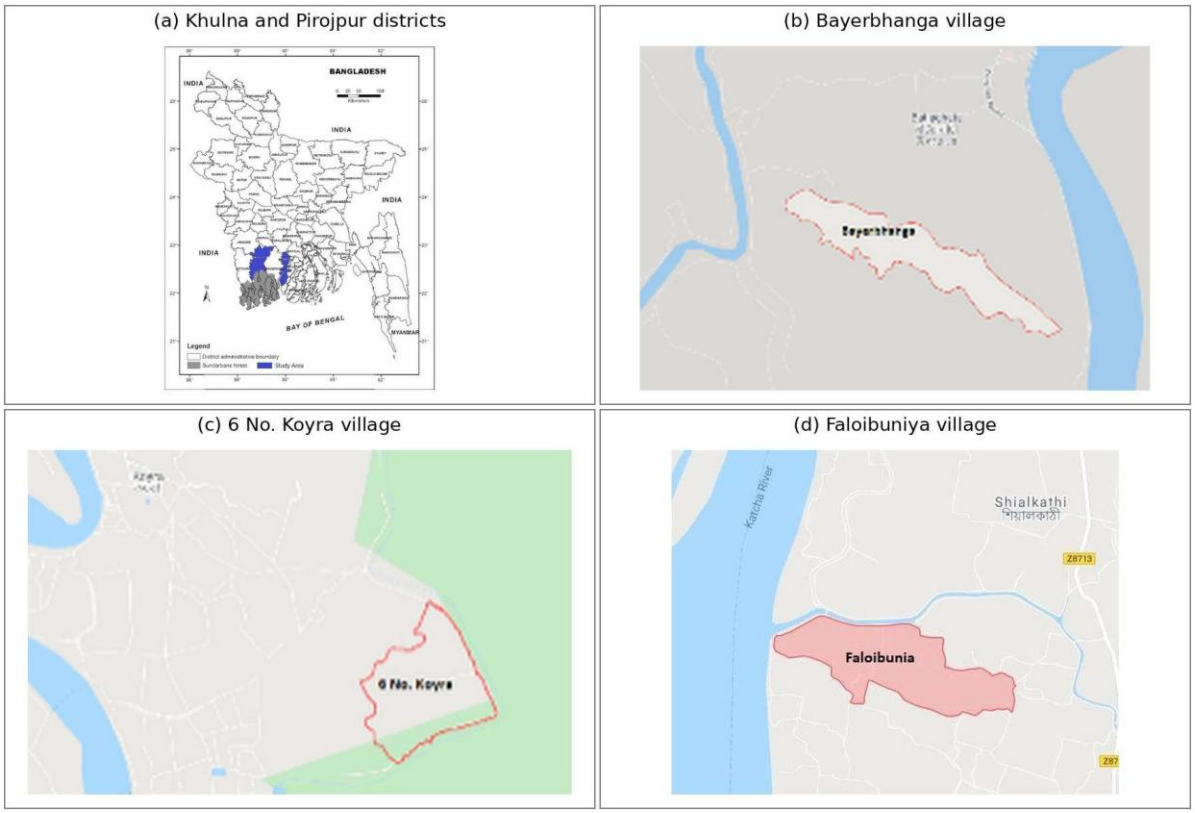

Fig. 1 Location of the study districts and three survey villages (Source: previously published by Ara et al. [9])

2.2 Household sampling and data collection

The household sample was designed using the finite-population formula as follows:

$$n = \frac{z^2 pqN}{e^2(N-1) + z^2 pq}$$

where N is the farmer-household population, n is the required sample size, z is the standard normal value, p is the assumed population proportion, q = 1 − p, and e is the allowable error [10]. The design used z = 2.5758 for a 99% confidence level, p = 0.10, q = 0.90, and e = 0.05. This produced target samples of 162 households in Bayerbhanga, 130 in 6 No. Koyra, and 154 in Faloibuniya. Following completeness and consistency

checks, 421 interviews were retained for analysis: 145 from Bayerbhanga, 130 from 6 No. Koyra, and 146 from Faloibuniya.

A structured questionnaire was administered to farmers during the 2019 field campaign. It collected information on demographic and farm characteristics, knowledge of climate variability and change, perceived changes in temperature, rainfall, humidity, and heat stress, experience of extreme climatic events, salinity conditions, and agricultural and household impacts. Questions concerning change over time referred to respondents' experience over approximately three decades and are therefore interpreted as retrospective perceptions rather than instrumental measurements.

Three focus group discussions and three key-informant interviews were conducted to interpret the household-survey patterns. Key informants included experienced farmers, local community representatives, and other knowledgeable residents. The qualitative enquiry focused on locally important hazards, changes in their frequency or intensity, salinity and freshwater conditions, agricultural damage, and wider household consequences. The qualitative evidence was used to explain spatial differences and was not treated as a separate statistically representative sample.

2.3 Meteorological and survey data analysis

Annual meteorological data for Khulna and Pirojpur were obtained from the Bangladesh Meteorological Department (BMD) for 1989–2019 [11]. The variables comprised annual minimum temperature, annual maximum temperature, total annual rainfall, and annual mean relative humidity. The temperature series represent annual extremes rather than annual mean temperature and were therefore interpreted as indicators of low- and high-temperature extremes.

Trend significance was assessed using the two-sided Mann–Kendall test with correction for tied values, which is suitable for detecting monotonic change in environmental time series without requiring normally distributed data [12, 13]. The magnitude of change was estimated using Sen's median slope [14], and statistical significance was evaluated at $\alpha = 0.05$. Household data were summarized using frequencies and percentages for the complete sample and by village. Qualitative findings were reviewed thematically and used to support interpretation of the quantitative patterns. Because the household survey was cross-sectional and retrospective, the analysis describes reported experience and association and does not establish causal attribution.

3. Results and Discussion

3.1 Assessment of long-term meteorological data

3.1.1 Annual temperature extremes

The annual minimum-temperature series in Khulna increased significantly over 1989–2019 (Kendall $\tau = 0.338$; Sen's slope = 0.078 °C year^{-1}; $p = 0.008$). This result indicates an upward shift in the annual low-temperature extreme, although considerable year-to-year variability remained. The annual maximum-temperature series in Khulna also had a positive Sen slope (0.035 °C year^{-1}), but the trend was not statistically significant ($p = 0.152$). In Pirojpur, neither annual minimum temperature ($p = 0.759$) nor annual maximum temperature ($p = 0.225$) showed a significant monotonic trend. The unusual combination

of a high annual minimum and a low annual maximum in 2019 occurred in both districts, but the full-series results demonstrate that individual endpoint years should not be used to infer long-term change.

The significant increase in Khulna's annual minimum temperature suggests that the lowest temperature reached during the year became progressively higher over the study period. Such a change may influence cool-season crop development, pest survival, and the duration of conditions suitable for winter production. However, the absence of significant trends in the remaining temperature series shows that the climate signal was not uniform across variables or districts. Agricultural interpretation therefore requires attention to local exposure, crop calendars, and the timing of temperature extremes rather than reliance on a single annual indicator.

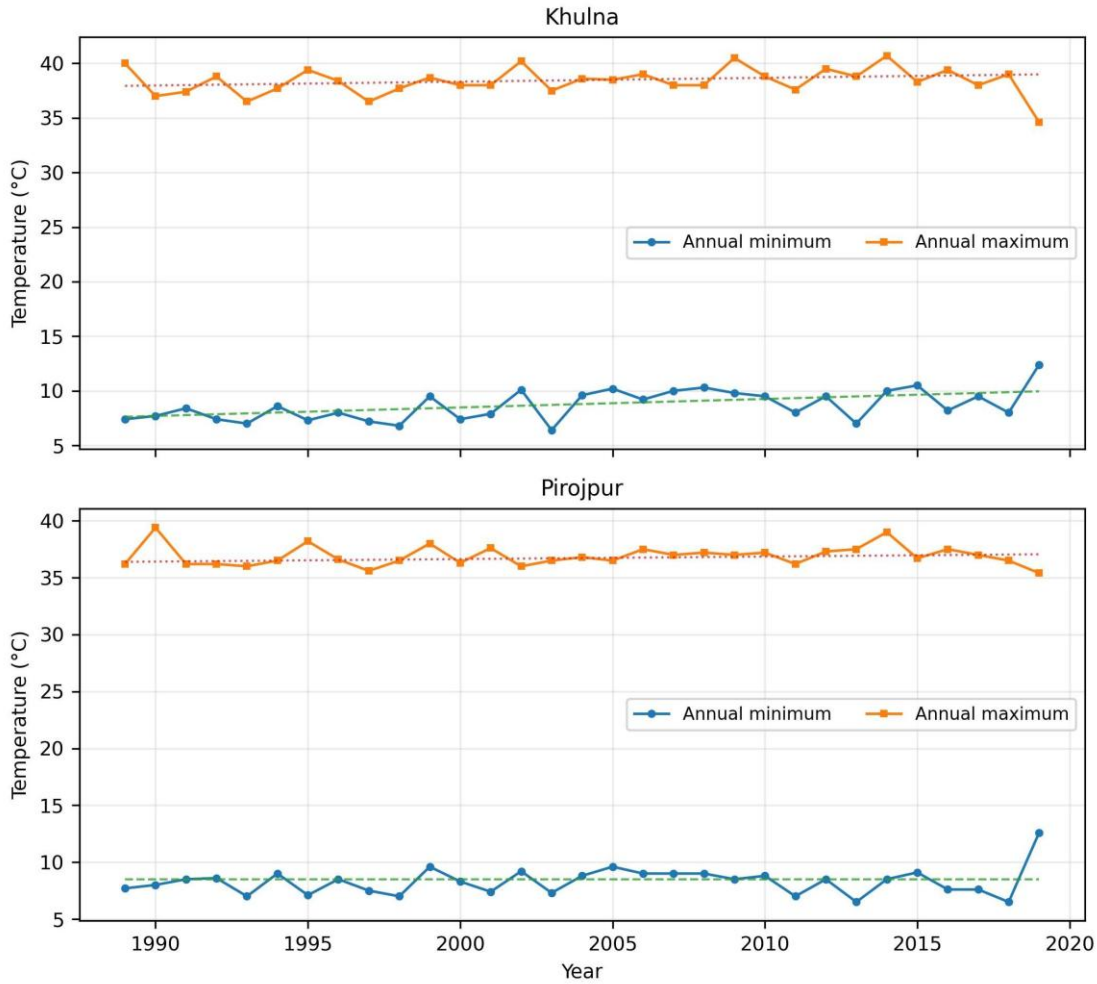

Fig. 2 Annual minimum and maximum temperatures in Khulna and Pirojpur, 1989–2019. Dashed and dotted lines indicate Sen-slope trends (Source: BMD [11]; previously published by Ara et al. [9])

3.1.2 Annual rainfall and relative humidity

Annual rainfall varied markedly in both districts. Khulna ranged from 1,073 mm in 2018 to 2,594 mm in 2002, while Pirojpur ranged from 1,418 mm in 2018 to 2,858 mm in 1998. Despite pronounced wet and dry years, no significant monotonic rainfall trend was detected in Khulna (Sen's slope = 9.86 mm year^{-1}; $p = 0.264$) or Pirojpur (Sen's slope = −3.83 mm year^{-1}; $p = 0.613$). The sharp reduction between 2017 and 2018 was therefore

a short-term fluctuation within a highly variable series rather than evidence of a statistically established long-term decline.

Annual mean relative humidity showed no significant monotonic change in Khulna (Sen's slope = −0.007 percentage points year^{-1}; p = 0.695), but it declined significantly in Pirojpur (Sen's slope = −0.060 percentage points year^{-1}; p = 0.016). Humidity nonetheless fluctuated substantially between years, and annual means may conceal short periods of high humidity during crop-sensitive seasons. This distinction is important because farmers may experience greater heat discomfort or crop-disease pressure during particular periods even when the annual mean is stable or declining.

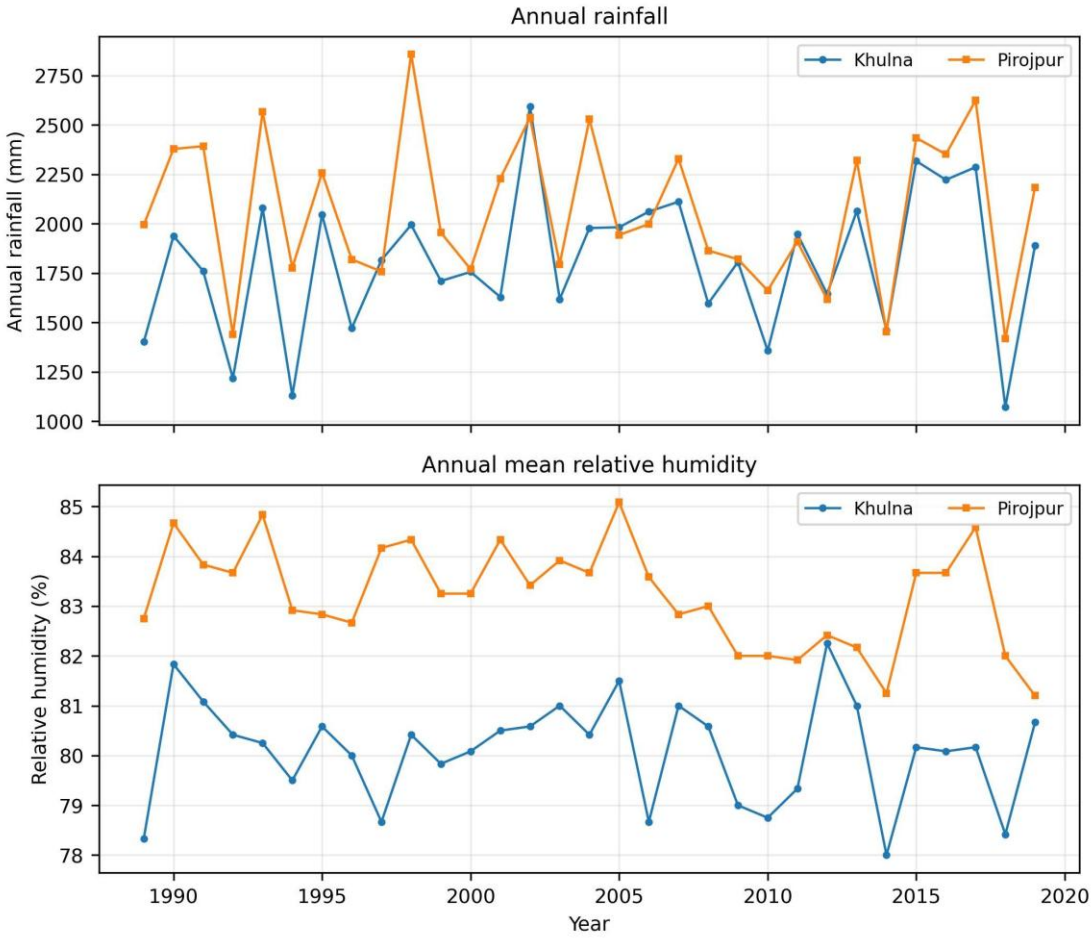

Fig. 3 Total annual rainfall and annual mean relative humidity in Khulna and Pirojpur, 1989–2019 (Source: BMD [11]; previously published by Ara et al. [9])

Table 2. Mann–Kendall trend results for the 1989–2019 meteorological series (Source: analysis of BMD data [11]; previously published by Ara et al. [9]).

District	Variable	Kendall τ	Sen slope	p value	Interpretation
Khulna	Annual minimum temperature	0.338	0.078 °C yr^{-1}	0.008	Significant
Khulna	Annual maximum temperature	0.184	0.035 °C yr^{-1}	0.152	Not significant
Pirojpur	Annual minimum temperature	0.040	0.000 °C yr^{-1}	0.759	Not significant

District	Variable	Kendall τ	Sen slope	p value	Interpretation
Pirojpur	Annual maximum temperature	0.157	0.022 °C yr^{-1}	0.225	Not significant
Khulna	Annual rainfall	0.144	9.857 mm yr^{-1}	0.264	Not significant
Pirojpur	Annual rainfall	−0.067	−3.833 mm yr^{-1}	0.613	Not significant
Khulna	Annual mean relative humidity	−0.050	−0.007 percentage points yr^{-1}	0.695	Not significant
Pirojpur	Annual mean relative humidity	−0.307	−0.060 percentage points yr^{-1}	0.016	Significant

A two-sided p value below 0.05 was considered statistically significant.

3.2 Farmer perception of climate change and agricultural impacts

3.2.1 Farmer characteristics and climate-change knowledge

The sample was dominated by middle-aged and older farmers: 42.0% were 36–50 years old and 36.1% were at least 51 years old. Educational attainment was generally low to moderate; 48.9% had primary education and 39.9% had secondary education, while only 3.8% had completed higher-secondary or higher education. Small farms of 0.21–1.00 ha accounted for 67.9% of the sample, and 68.2% of households were in the lowest annual-income category. Most respondents had not received agricultural credit (70.3%). These characteristics indicate that farmer observations and risk responses were formed within conditions of limited land, income, and formal education.

Knowledge of climate variability and change was also limited. On the study's knowledge scale, 60.3% of farmers were classified as having poor knowledge, 38.5% had medium knowledge, and only 1.2% had high knowledge. The pattern differed substantially by site: medium knowledge was most common in 6 No. Koyra, whereas 82.9% of respondents in Faloibuniya were classified as having poor knowledge. These differences provide important context for interpreting how farmers described climatic changes and their causes.

Table 3. Selected characteristics of surveyed farmers (N = 421; Source: Field Survey, 2019; previously published by Ara et al. [9]).

Characteristic	Category	Respondents (%)
Age	≤35 years	21.9
	36–50 years	42.0
	≥51 years	36.1
Education	No schooling	7.4
	Primary	48.9

Characteristic	Category	Respondents (%)
	Secondary	39.9
	Higher secondary or above	3.8
Farm size	Landless/marginal (≤0.20 ha)	8.3
	Small (0.21–1.00 ha)	67.9
	Medium/large (>1.00 ha)	23.7
Annual family income	Low (≤BDT 80,000)	68.2
	Medium (BDT 81,000–175,000)	20.7
	High (>BDT 175,000)	11.2
Climate-change knowledge	Poor	60.3
	Medium	38.5
	High	1.2

Percentages may differ slightly from 100 because of rounding.

3.2.2 Perceived changes in climatic conditions

Farmers reported a clear and geographically consistent perception of warming. The proportion reporting increased temperature was 92.4% in Bayerbhanga, 99.2% in 6 No. Koyra, and 96.6% in Faloibuniya. Perceived heat stress was similarly widespread, ranging from 89.7% to 91.5%. These responses are consistent with the significant rise in Khulna's annual minimum temperature, but the near-universal perception across all three villages suggests that respondents were also reacting to seasonal daytime heat, humid conditions, and direct occupational exposure during agricultural work. The perception percentages reported here were also presented in the earlier study by Ara and Sattar [8], based on the same underlying household evidence; they are therefore included as part of an expanded analysis rather than as independent new observations.

Rainfall perceptions were more heterogeneous. In Bayerbhanga, 53.8% of respondents perceived an increase, whereas 68.5% of farmers in 6 No. Koyra perceived a decrease. Faloibuniya was divided almost equally between increasing and decreasing rainfall. This mixed pattern is consistent with the meteorological evidence of strong interannual variability and no significant trend in annual totals. Farmers may have been responding to changes in rainfall onset, dry-spell duration, heavy-rainfall intensity, or rainfall during planting and harvesting periods rather than to total annual accumulation.

Most farmers perceived increased humidity, particularly in Faloibuniya, where 78.8% reported an increase. This contrasts with the significant decline in Pirojpur's annual mean relative humidity. The difference does not necessarily invalidate either source: perceived humidity is shaped by hot, stagnant conditions and short periods of high atmospheric moisture, whereas the station series represents an annual meaning. The comparison illustrates why farmer observations should be interpreted as impact-oriented evidence that complements, rather than replaces, meteorological measurement.

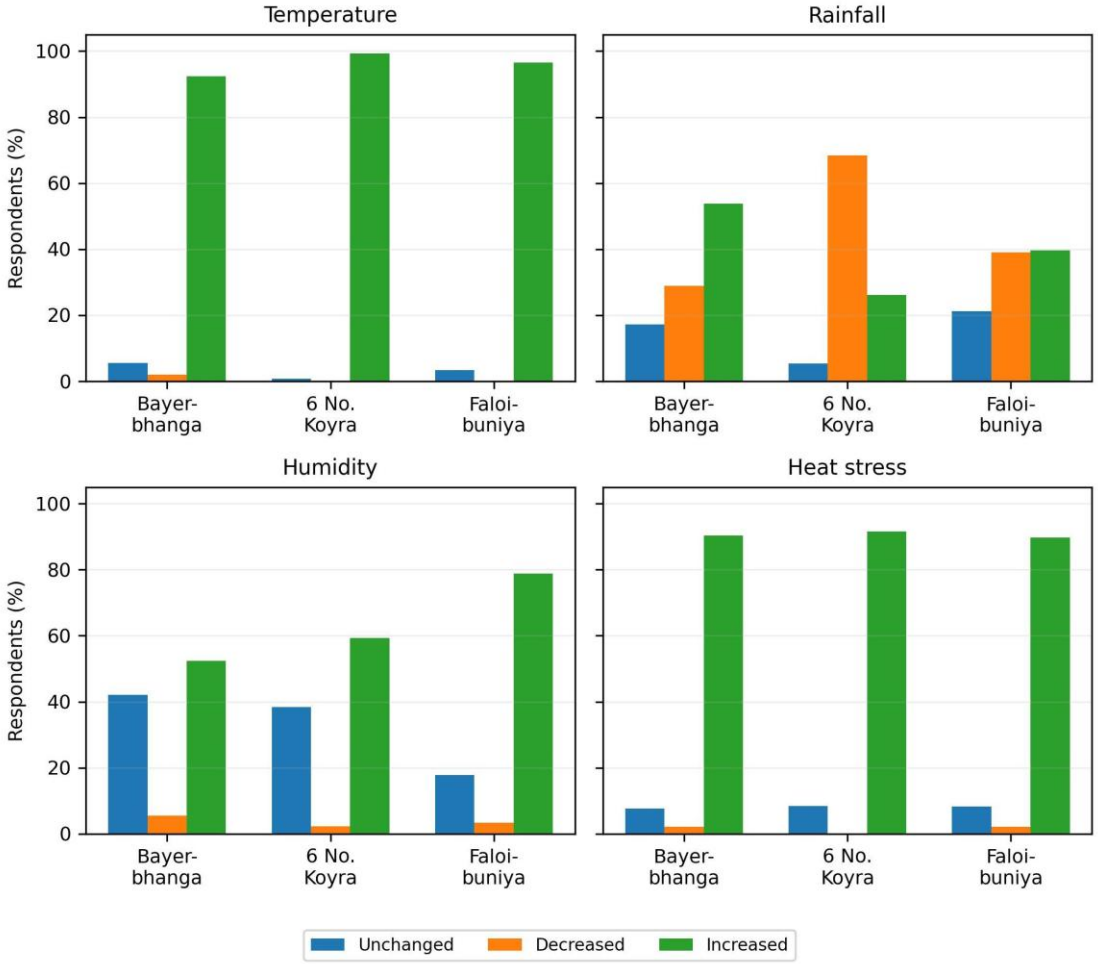

Fig. 4 Farmer perceptions of changes in temperature, rainfall, humidity and heat stress by village (Source: Field Survey, 2019; previously published by Ara et al. [9])

Table 4. Perceived direction of climatic change by village (Source: Field Survey, 2019; related findings in Ara and Sattar [8] and table previously published by Ara et al. [9]).

Climatic factor	Village	Unchanged (%)	Decreased (%)	Increased (%)
Temperature	Bayerbhanga	5.5	2.1	92.4
	6 No. Koyra	0.8	0.0	99.2
	Faloibuniya	3.4	0.0	96.6
Rainfall	Bayerbhanga	17.2	29.0	53.8
	6 No. Koyra	5.4	68.5	26.2
	Faloibuniya	21.2	39.0	39.7
Humidity	Bayerbhanga	42.1	5.5	52.4
	6 No. Koyra	38.5	2.3	59.2
	Faloibuniya	17.8	3.4	78.8
Heat stress	Bayerbhanga	7.6	2.1	90.3

Climatic factor	Village	Unchanged (%)	Decreased (%)	Increased (%)
	6 No. Koyra	8.5	0.0	91.5
	Faloibuniya	8.2	2.1	89.7

3.2.3 Extreme events, salinity and household impacts

Survey narratives and group discussions showed that climatic risk was experienced through compound and location-specific hazards. Farmers across the three villages described cyclones as more frequent or intense than in the past. Coastal flooding and salinity were especially prominent in 6 No. Koyra, where proximity to tidal rivers, embankment weakness, and saline-water entry affected cropland and drinking-water sources. Faloibuniya farmers emphasized riverine or coastal flooding and temporary waterlogging, while Bayerbhanga farmers reported salinity and dry-season water constraints despite the village's relatively inland setting. Riverbank erosion was most strongly associated with 6 No. Koyra.

Farmers' assessments of climatic impacts on crop production were predominantly unfavorable. Strongly unfavorable responses were reported by 45% of Bayerbhanga farmers, 51% of 6 No. Koyra farmers, and 39% of Faloibuniya farmers. Perceptions of salinity were most severe in 6 No. Koyra, where 69% reported a strongly unfavorable effect on soil and water conditions, compared with 49% in Bayerbhanga and 27% in Faloibuniya. Farmers linked salinity with reduced dry-season cultivation, limited availability of suitable irrigation water, poor germination and crop growth, and declining crop productivity. These observations are consistent with documented effects of soil and water salinity on coastal agriculture [3, 4].

Agricultural production was the most frequently reported household impact in every village, affecting 91.0% of respondents in Bayerbhanga, 93.1% in 6 No. Koyra, and 95.2% in Faloibuniya. Homestead damage and loss of income sources were also common, and respondents reported losses of trees and home gardens, domestic animals, and adverse health effects. Drinking-water scarcity showed the strongest spatial concentration: it was reported by 52.3% of farmers in 6 No. Koyra, compared with 3.4% in Bayerbhanga and none in Faloibuniya. This pattern indicates that similar regional hazards can generate quite different household consequences depending on local hydrology, embankment condition, freshwater infrastructure, and proximity to tidal channels.

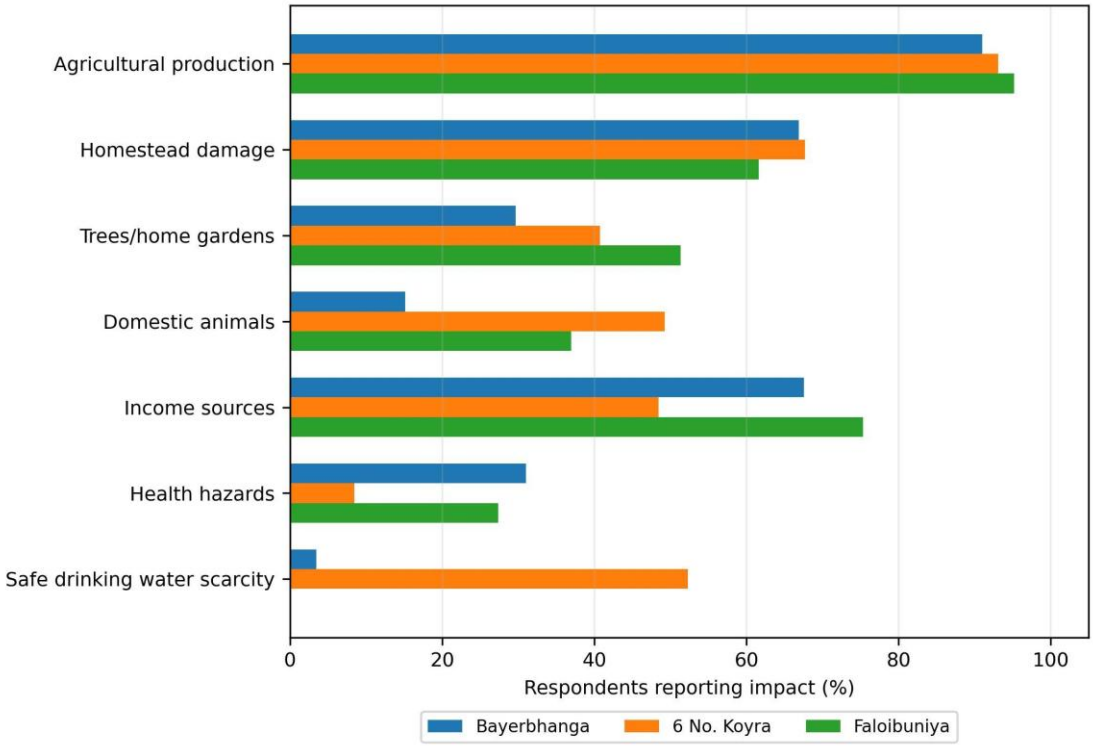

Fig. 5 Household impacts of climatic and extreme events reported by farmers
(Source: Field Survey, 2019; previously published by Ara et al. [9])

When asked about the principal causes of climatic events, 61.1% of respondents attributed them mainly to natural factors, 38.2% identified human influence, and 0.7% were unable to identify a cause. The result indicates broad recognition that environmental change has both natural and human dimensions, while also showing the need for locally accessible climate information that distinguishes long-term change from seasonal variability and connects observed hazards with practical risk-reduction decisions.

4. Conclusion

This study integrated a 31-year meteorological record with the experiences of 421 farmers in three coastal villages of Khulna and Pirojpur. Khulna showed a significant increase in annual minimum temperature, while Pirojpur showed a significant decline in annual mean relative humidity. Annual rainfall and the remaining temperature and humidity indicators were highly variable but did not exhibit significant monotonic trends. These results show that long-term change in the study region was variable-specific and spatially uneven.

Farmer perceptions added an important impact-based perspective. Respondents across all villages overwhelmingly reported increasing temperature and heat stress, but their rainfall perceptions differed by location. Cyclones, flooding, waterlogging, riverbank erosion, salinity, and freshwater scarcity were experienced as interacting hazards. Agricultural production was the most widely reported household impact, while the concentration of drinking-water scarcity in 6 No. Koyra demonstrated the importance of local hydrology, embankments, and freshwater infrastructure.

Coastal climate-risk assessment should therefore combine station-based monitoring with systematic documentation of farmer observations. Location-specific priorities include monitoring of seasonal heat, rainfall timing, salinity, and freshwater availability; maintenance of drainage and embankment systems; protection of drinking-water sources;

and clear communication of climate and hazard information. The findings should be interpreted in light of three limitations: district-level station data may not capture village microclimates, annual indicators do not represent seasonal timing or short-duration extremes, and retrospective survey responses may be affected by recall and attribution bias. Future work should use village-level environmental monitoring and repeated household surveys to examine these relationships more precisely.

Declarations

Author contributions

Shifat Ara: conceptualization, methodology, investigation, data curation, formal analysis and writing – original draft.

Mohammad Bashir Ahmed: conceptualization, methodology, supervision, validation and writing – review and editing.

Md. Bariul Musabbir: data curation, formal analysis, visualization, and writing – review and editing.

All authors reviewed and approved the final manuscript.

Data availability

The meteorological series analyzed in this study were obtained from the Bangladesh Meteorological Department and are subject to the agency's data-sharing conditions. Anonymized household-survey summaries and the derived analytical outputs are available from the corresponding author upon reasonable request, subject to participant confidentiality and applicable institutional requirements.

Ethics approval and consent to participate

Ethics approval: The study was reviewed by the Institutional Ethical Committee for Experimentations on Human, Animal, Microbes, Agriculture, Environment, and Living Natural Sources, Gopalganj Science and Technology University (GSTU), Gopalganj-8105, Bangladesh. The Committee reviewed the research objectives, methodology, informed consent procedures, and potential ethical implications. The ethical review is documented in the Ethical Compliance Confirmation (Memo No.: Chairman/AGR/Phd/18AGR003/2026/20/370(02), dated 05 March 2026). The Committee confirmed that the reported research procedures were consistent with standard ethical practices for non-clinical research involving human participants. The ethical review was conducted subsequent to the 2019 field campaign.

Ethical Guidelines and Compliance: The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. The research procedures ensured voluntary participation, informed consent, confidentiality, anonymity, and respect for participants' rights. Before data collection, the objectives and purpose of the study were explained to the participating farmers. Respondents were free to decline participation or withdraw at any stage without any adverse consequences. All collected information was treated confidentially, anonymized during analysis, and used exclusively for academic and scientific research purposes.

Consent to participate: Verbal informed consent was obtained from all participating farmers before data collection during the 2019 field campaign. Participants were informed about the objectives and purpose of the study, the voluntary nature of their participation, and their right to decline participation or withdraw at any time without consequences. All responses were treated confidentially and anonymized during data analysis.

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Competing interests: The authors declare that they have no competing interests.

Consent for publication: Not applicable; the manuscript presents aggregated results without identifying individual participants.

Related prior publications: Data, results, tables and figures in this manuscript overlap substantially with Ara and Sattar (2021) [8] and with Ara, Ahmed and Musabbir (2026) [9], published in the STFT Journal under the same title. Eligibility for publication as a distinct article is subject to the journal's editorial decision.

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