



Decadal Performance and Adoption of High-Yielding Rice Varieties for Climate-Resilient Agriculture in Patuakhali District, Bangladesh

Papri Hazra¹, Md. Fuad Hasan^{2*}, Rana Ghosh³, Marzia Sultana Shefa⁴, Nafisa Mehzabin⁵, Sanjida Hossain Setu⁶, Israt Zahan Oyshi⁷, Rashidul Islam⁸ and Md Shamsuzzoha⁹

¹Associate Professor, Dept. of Environmental Science, Patuakhali Science and Technology University, Dumki, Patuakhali- 6802, Bangladesh, Email: ph7bau@gmail.com

²Lecturer, Dept. of Environmental Science and Technology, German University Bangladesh, Email: fuad.dm.pstu@gmail.com

³Student, Faculty of Environmental Science and Disaster Management, Patuakhali Science and Technology University, Dumki, Patuakhali- 8660, Bangladesh, Email: rana1706022@gmail.com

⁴Student, Dept. of Disaster Risk Management, Patuakhali Science and Technology University, Dumki, Patuakhali- 8660, Bangladesh, Email: shefa7390@pgs.pstu.ac.bd

⁵Student, Institute of Environmental Science and Disaster Management, Bangladesh Agricultural University, Mymensingh, Bangladesh, Email: mehzabinnafisa28@gmail.com

⁶Student, Dept. of Emergency Management, Patuakhali Science and Technology University, Dumki, Patuakhali- 8660, Bangladesh, Email: sanjidasetu17@gmail.com

⁷Student, Dept. of Emergency Management, Patuakhali Science and Technology University, Dumki, Patuakhali- 8660, Bangladesh, Email: isratzahan6383@gmail.com

⁸Student, Faculty of Environmental Science and Disaster Management, Patuakhali Science and Technology University, Dumki, Patuakhali- 8660, Bangladesh, Email: psturashed@gmail.com

⁹Professor, Dept. of Emergency Management, Patuakhali Science and Technology University, Dumki, Patuakhali- 8660, Bangladesh, Email: zohageo@pstu.ac.bd

*Correspondence: fuad.dm.pstu@gmail.com, Tel: +880 01765865603

Received: 13/07/2026

Accepted: 30/09/2026

Available online: 02/10/2026



Copyright: ©2026 by the author(s).

This work is licensed under a Creative Commons Attribution 4.0 License.

<https://creativecommons.org/licenses/by/4.0/>

Abstract: Rice (*Oryza sativa* L.) production in coastal Patuakhali District is exposed to erratic rainfall, rising temperature, salinity and tidal flooding, yet evidence on how improved rice types have performed there over time remains limited. This study evaluated a ten-year (2015–16 to 2024–25) district-level series of area, yield and production for local, high-yielding variety (HYV) and hybrid rice in the Aus, Aman and Boro seasons, compiled from eight issues of the Yearbook of Agricultural Statistics of Bangladesh, together with Patuakhali station rainfall and temperature records and a household survey of 50 farmers. Paired t-tests, coefficients of variation (CV), Mann–Kendall trend tests with Sen’s slope and correlation analysis were applied. HYVs yielded on average 2.62, 2.70 and 3.33 t/ha in Aus, Aman and Boro, respectively, compared with 1.35, 1.39 and 1.72 t/ha for local varieties, an advantage of about 94% in every season ($p < 0.001$). HYV yields were also more stable than local yields (CV 4.8% vs 19.9% in Aman; 9.7% vs 15.9% in Aus), and none of the HYV yield series was significantly correlated with annual rainfall or temperature. HYV yields increased significantly in Aman (0.030 t/ha/yr) and Boro (0.127 t/ha/yr), and the HYV share of Aman area rose from 22% to 55%. Boro area expanded almost tenfold, with hybrid Boro yielding 4.59 t/ha in 2024–25, whereas Aus area declined significantly. Farmers’ awareness of climate change was low although familiarity with HYVs was comparatively high. As a general recommendation for farmers, extension services and policymakers, low-yielding local cultivars should be progressively replaced with locally adapted, stress-tolerant HYVs and hybrids in all seasons, supported by quality seed, extension and sustainable irrigation, to raise and stabilise rice output in Patuakhali and other climate-vulnerable rice-growing areas of Bangladesh.

Keywords: High-yielding varieties; Yield gap; Yield stability; Climate resilience; Coastal Bangladesh.

INTRODUCTION

Rice (*Oryza sativa* L.) dominates both the diet and the farming system of Bangladesh, occupying roughly three-quarters of the cropped area and supplying most of the country's cereal output (BBS 2024a). Its role in household food security and rural employment is therefore difficult to overstate, particularly for the smallholders who make up the majority of producers (Bala and Hossain 2010; Binte Mostafiz et al. 2021). The southern coastal districts contribute substantially to this production, but they farm under conditions that are becoming progressively harder: low elevation, tidal flooding, cyclones, dry-season salinity and increasingly irregular monsoon rainfall (IPCC 2023; Khatun and Saadat 2021).

These stresses act on rice through several pathways. Salinity and waterlogging restrict the length of the growing season and the choice of crop, erratic rainfall disturbs transplanting and flowering, and extreme events can destroy standing crops within days (Dasgupta et al. 2018; Islam et al. 2022; Shamsuzzoha et al. 2022). Earlier modelling work had already shown that the dry-season Boro crop in Bangladesh is sensitive to changes in temperature and water availability (Mahmood and Hayes 1995), and households in coastal areas have had to adjust their livelihoods accordingly (Momtaz and Shameem 2016a). Patuakhali District, bordered by tidal rivers that open directly into the Bay of Bengal, sits in the middle of this exposure.

A central adaptation response has been varietal. The Bangladesh Rice Research Institute (BRRI) and the Bangladesh Institute of Nuclear Agriculture (BINA) have released high-yielding varieties (HYVs) with tolerance to salinity, submergence, drought and short growing windows, and private-sector hybrids have entered the market more recently (IRRI 2020). Whether these technologies are delivering higher and steadier yields under real farm conditions in a particular coastal district, however, is a separate empirical question. Satellite and statistical studies have documented rice yield variability and losses after extreme events in Bangladesh (Alam et al. 2019; Myint Htun et al. 2023; Shamsuzzoha et al. 2022), but few studies have examined, over a continuous period, how local, HYV and hybrid rice have performed side by side in Patuakhali, how their adoption has changed, and whether their yields respond differently to year-to-year climate variability.

An earlier version of this work (Ghosh et al. 2026) compared rice varieties in Patuakhali using a short secondary dataset. The present study substantially extends and revises that analysis by (i) compiling an official, verifiable ten-year series (2015–16 to 2024–25) for all three rice seasons from the Yearbook of Agricultural Statistics of Bangladesh; (ii) testing the HYV–local yield gap statistically; (iii) assessing yield stability and long-term trends in yield and adoption; (iv) relating yields to station rainfall and temperature; and (v) interpreting the results alongside farmers' awareness of climate change and HYVs. The objective is to provide district-specific evidence on the contribution of improved

rice types to climate-resilient rice production in coastal Bangladesh.

MATERIALS AND METHODS

Study area

Patuakhali District lies in the south-central coastal zone of Bangladesh within Barishal Division (Figure 1). It covers about 3,221 km² and had a population of about 1.73 million in the 2022 census (BBS 2023a). The district comprises eight upazilas (Patuakhali Sadar, Dumki, Mirzaganj, Bauphal, Galachipa, Dashmina, Rangabali and Kalapara) and is intersected by tidal rivers, including the Lohalia and Laukathi, that connect to the Bay of Bengal (GoB 2025). Its soils belong mainly to the Ganges Tidal Floodplain and Young Meghna Estuarine Floodplain agro-ecological zones, where dry-season salinity and tidal inundation strongly shape the rice calendar (BBS 2024b).

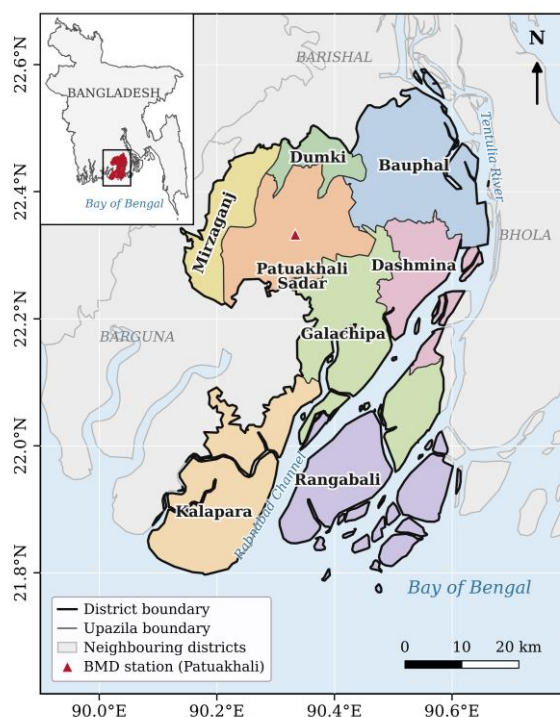


Figure 1. Study area: Patuakhali District and its eight upazilas, with the location of the district in Bangladesh (inset) and the BMD station at Patuakhali (boundary data: geoBoundaries, Runfola et al. 2020; the extent of Rangabali Upazila is approximate)

Data sources

Rice statistics. District estimates of area (ha), yield (t/ha of clean rice) and production (t) for Patuakhali were transcribed from the district tables of eight consecutive issues of the Yearbook of Agricultural Statistics published by the Bangladesh Bureau of Statistics (BBS 2018, 2019, 2020, 2021, 2022, 2023b, 2024b, 2026). Each issue reports two fiscal years, so the issues together provide an uninterrupted series from 2015–16 to 2024–25. Separate tables are published for local and HYV Aus; broadcast, local

transplanted and HYV Aman (with hybrid Aman from 2023–24); and local, HYV and hybrid Boro. Where a fiscal year appeared in two issues, the value from the later issue was used; in practice all overlapping values were identical. BBS estimates rice yields objectively through stratified two-stage crop-cutting surveys, with about fifty crop cuts per district and season (BBS 2024b). BBS includes Pajam rice in the HYV category, and it notes that data were collected on revised forms from 2017–18 onward.

Climate data. Annual rainfall (2008–2024) and annual mean temperature (2015–2024) for the Bangladesh Meteorological Department station at Patuakhali (Figure 1) were taken from the meteorology chapter of the same yearbooks. The 2023 annual mean temperature was not reported because October–December records were missing, so that year was excluded from temperature analyses.

Farmer survey. A structured household survey of 50 rice farmers in Patuakhali District recorded farmers' awareness of climate change and their familiarity with HYV rice, using closed and open-ended questions (Dubey and Kothari 2022; Momtaz and Shameem 2016b).

The complete dataset, with the issue and page number of every transcribed value, is provided as supplementary material (Excel workbook).

Data analysis

Yield statistics (mean, standard deviation, range) were computed for local and HYV rice in each season. The HYV–local yield gap was tested with two-tailed paired t-tests using years as pairs ($n = 10$), with the Wilcoxon signed-rank test as a non-parametric check and Cohen's d_z as the effect size. Yield stability was evaluated with the coefficient of variation (CV), a widely used static stability measure (Francis and Kannenberg 1978). Monotonic trends in yield, total area and the share of area under HYV and hybrid rice were tested with the Mann–Kendall test (Mann 1945; Kendall 1975), and trend magnitude was estimated with Sen's slope (Sen 1968). Associations between yields and climate were examined with Pearson correlation (confirmed with Spearman's rank correlation). Aus and Aman yields of fiscal year t –($t+1$) were matched with climate in calendar year t , and Boro yields with calendar year $t+1$, following the cropping calendar. Statistical significance was assessed at $\alpha = 0.05$. Analyses were performed in Python using SciPy (Virtanen *et al.* 2020), and figures were produced with Matplotlib; the study area map (Figure 1) was drawn with GeoPandas from open administrative boundary data (geoBoundaries; Runfola *et al.* 2020).

RESULTS

Yield performance of local and HYV rice

HYV rice out-yielded local rice in every season and in every one of the ten years (Figure 2; Table 1). Mean HYV yields were 2.62 t/ha in Aus, 2.70 t/ha in Aman and 3.33 t/ha in Boro, against 1.35, 1.39 and 1.72 t/ha for local rice. Boro produced the highest HYV yields, reaching 4.31 t/ha in 2024–25, which reflects the irrigated, high-radiation conditions of the dry season.

Table 1. Yield statistics of local and HYV rice in Patuakhali District, 2015–16 to 2024–25 (t/ha)

Season	Type	Mean	SD	Range	CV (%)
Aus	Local	1.35	0.21	1.09–1.71	15.9
	HYV	2.62	0.25	2.29–3.00	9.7
Aman	Local	1.39	0.28	1.10–1.80	19.9
	HYV	2.70	0.13	2.46–2.91	4.8
Boro	Local	1.72	0.33	1.03–2.14	19.2
	HYV	3.33	0.50	2.50–4.31	14.9

Source: compiled from BBS Yearbooks of Agricultural Statistics (2017–2025 issues). CV = coefficient of variation.

The yield gap between HYV and local rice was large and highly significant in all seasons (Table 2). HYVs produced on average 1.27 t/ha more than local varieties in Aus, 1.31 t/ha more in Aman and 1.60 t/ha more in Boro, roughly doubling yield (mean HYV/local ratios of 1.98–2.01). The effect sizes ($d_z = 3.3$ – 3.7) were very large, and the Wilcoxon test gave the same conclusion ($p = 0.002$ in each season, the minimum attainable with ten pairs).

Table 2. Yield gap between HYV and local rice and paired comparison tests

Season	Gap (t/ha), mean $\pm$ SD	HYV/Local ratio	t (df = 9)	p	Cohen's d_z
Aus	1.27 $\pm$ 0.34	1.98	11.65	< 0.001	3.68
Aman	1.31 $\pm$ 0.35	2.01	11.67	< 0.001	3.69
Boro	1.60 $\pm$ 0.48	1.99	10.58	< 0.001	3.35

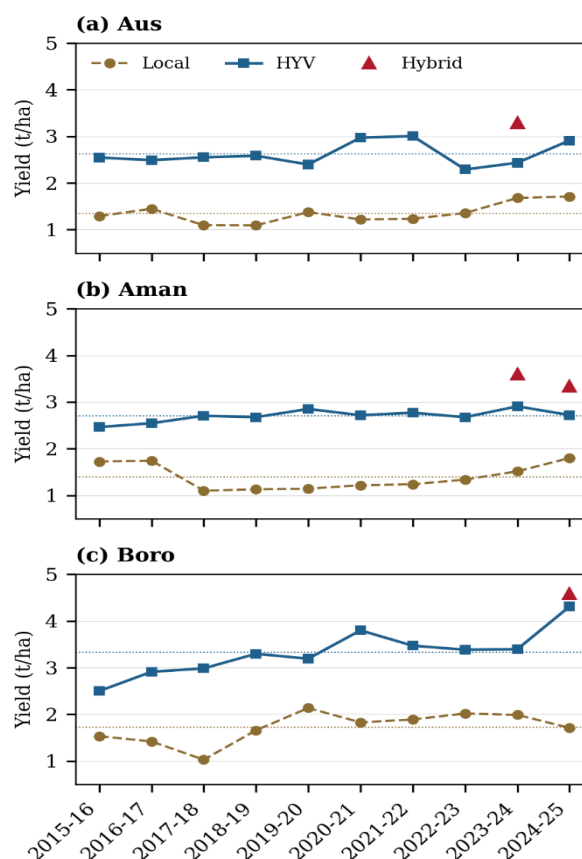


Figure 2. Yield of local, HYV and hybrid rice in (a) Aus, (b) Aman and (c) Boro seasons in Patuakhali District, 2015–16 to 2024–25 (dotted lines show ten-year means; source: BBS)

Yield stability

HYV yields fluctuated less from year to year than local yields (Table 1). The contrast was sharpest in Aman, the district's main rice season, where the CV of HYV yield (4.8%) was about one-quarter of that of local transplanted Aman (19.9%). In Aus the corresponding values were 9.7% and 15.9%, and in Boro 14.9% and 19.2%. Local Aman yield fell abruptly from 1.74 t/ha in 2016–17 to 1.10 t/ha in 2017–18 and recovered only gradually thereafter, whereas HYV Aman stayed within a narrow band of 2.46–2.91 t/ha throughout the decade.

Trends in yield and adoption

Mann–Kendall tests (Table 3) showed significant upward trends in HYV yield in Aman (Sen's slope 0.030 t/ha per year, $p = 0.049$) and especially in Boro (0.127 t/ha per year, $p = 0.004$), while local yields showed no significant trend in any season. The all-type Aman yield also increased significantly (0.040 t/ha per year, $p = 0.012$).

Adoption patterns differed by season (Figure 3). In Aman, the share of area under HYV and hybrid rice rose significantly from 22.0% in 2015–16 to 55.3% in 2024–25 (1.96 percentage points per year, $p = 0.007$) while total Aman area remained broadly stable at 170,000–205,000 ha. Part of the step change between 2016–17 and 2017–18 coincides with BBS's revised data-collection forms and should be interpreted with that caveat. Total Aus area declined significantly, from 43,079 ha to 18,639 ha ($p = 0.012$), although HYVs continued to occupy about three-quarters of the remaining Aus area. Boro, historically marginal in the district, expanded significantly from about 1,000–1,600 ha before 2022–23 to 15,060 ha in 2024–25 ($p = 0.032$). In 2024–25 almost all Boro land was sown to HYV (11,286 ha) or hybrid rice (3,659 ha), and hybrid Boro recorded the highest yield in the series (4.59 t/ha). Hybrid Aman appeared on small areas in 2023–24 and 2024–25 with yields of 3.60 and 3.33 t/ha.

Table 3. Mann–Kendall trend test and Sen's slope for yield and area indicators, 2015–16 to 2024–25

Season	Indicator	Z	p	Sen's slope (per year)
Aus	Local yield (t/ha)	1.43	0.152	0.047
	HYV yield (t/ha)	0.36	0.721	0.013
	HYV + hybrid share (%)	1.61	0.107	2.15
	Total area (ha)	-2.50*	0.012	-1956
Aman	Local yield (t/ha)	1.43	0.152	0.037
	HYV yield (t/ha)	1.97*	0.049	0.030
	HYV + hybrid share (%)	2.68**	0.007	1.96
	Total area (ha)	-0.36	0.721	-862
Boro	Local yield (t/ha)	1.61	0.107	0.062
	HYV yield (t/ha)	2.86**	0.004	0.127
	HYV + hybrid share (%)	0.00	1.000	-0.27
	Total area (ha)	2.15*	0.032	506

* significant at $p < 0.05$; ** significant at $p < 0.01$. Share = HYV + hybrid area as a percentage of total seasonal area.

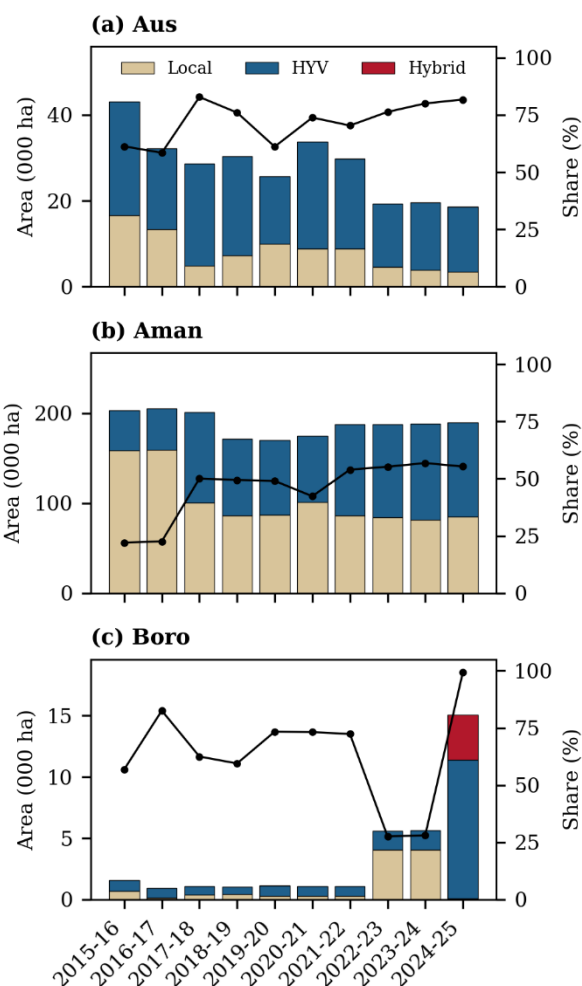


Figure 3. Area under local, HYV and hybrid rice (bars) and the HYV + hybrid share of area (line) in (a) Aus, (b) Aman and (c) Boro seasons, Patuakhali District (source: BBS)

Climate variability and rice yield

Annual rainfall at Patuakhali averaged 2,437 mm during 2008–2024 but varied widely between years (CV 17.9%), from 1,765 mm in 2022 to 3,303 mm in 2024 (Figure 4). No significant monotonic trend was detected in annual rainfall (Mann–Kendall $Z = 0.54$, $p = 0.59$). Annual mean temperature ranged from 26.6 to 27.4 °C during 2015–2024, with the highest value in 2024; the short temperature record showed no significant trend ($Z = 0.94$, $p = 0.35$).

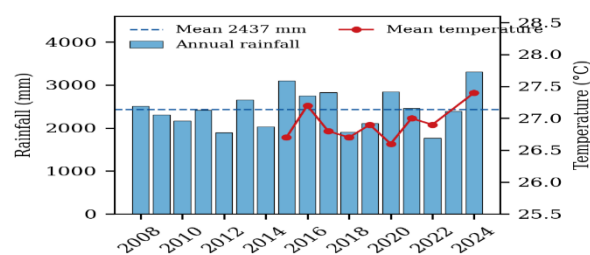


Figure 4. Annual rainfall (2008–2024) and annual mean temperature (2015–2024) at Patuakhali station (source: BMD, reported in BBS Yearbooks)

None of the HYV yield series was significantly correlated with annual rainfall or mean temperature (Table 4), indicating that HYV yields were largely insensitive to the interannual climate variability observed during the decade. Local yields showed stronger associations: local Aus yield was positively correlated with mean temperature ($r = 0.84$, $p = 0.005$), and local Aman yield showed weak positive associations with both rainfall and temperature that were not significant at the 5% level ($r = 0.59$, $p = 0.074$; $r = 0.61$, $p = 0.082$). Given the short record, these correlations are exploratory, and the local Aus association may partly reflect the coincidence of higher yields and warmer years at the end of the series.

Table 4. Pearson correlation between rice yield and annual climate variables at Patuakhali

Yield series	r with rainfall (p)	r with mean temperature (p)
Aus local	0.26 (0.465)	0.84** (0.005)
Aus HYV	0.52 (0.119)	0.12 (0.750)
Aman local	0.59 (0.074)	0.61 (0.082)
Aman HYV	-0.35 (0.319)	0.08 (0.830)
Boro local	0.35 (0.359)	0.22 (0.601)
Boro HYV	-0.18 (0.644)	0.03 (0.939)

Aus and Aman matched to the calendar year of cultivation; Boro to the calendar year of harvest. $n = 10$ (Aus, Aman) and 9 (Boro) for rainfall; $n = 9$ (Aus, Aman) and 8 (Boro) for temperature. ** $p < 0.01$.

Farmers' perceptions

The household survey showed that awareness of climate change as a concept was low among farmers, particularly older respondents, whereas familiarity with HYV rice was considerably higher (Table 5). Among farmers aged 60 years and above, 2% were aware of climate change but 60% knew about HYVs; among those aged 35–45 years, the figures were 10% and 70%, respectively. Farmers therefore appear to be adopting improved varieties for their practical benefits, such as yield and duration, rather than as a conscious response to climate change.

Table 5. Farmers' awareness of climate change and knowledge of HYV rice by age group ($n = 50$)

Age group (years)	Aware of climate change (%)	Know about HYV rice (%)
60 and above	2	60
35–45	10	70

DISCUSSION

The most consistent finding of this study is the size and persistence of the HYV advantage. In each season and each year, HYVs yielded roughly twice as much as local varieties, and the gap of 1.3–1.6 t/ha is large relative to the district's all-type yields of 2.0–2.8 t/ha. This agrees with national evidence that the replacement of traditional cultivars by modern varieties has been a major source of rice productivity growth in Bangladesh (Hossain et al. 2006; Kabir et al. 2015; Al Mamun et al. 2021), and with participatory trials in the southern coastal wetlands, where improved salt-tolerant lines yielded more than 1 t/ha above the standard varieties (Salam et al. 2010). Rice yields in Patuakhali remain well below the national level; in 2022–23, for example, the all-

type Aman yield in the district was 2.08 t/ha compared with a national average of about 2.69 t/ha (BBS 2024b). The results suggest that the district's low average yield is less a limitation of what can be grown there than a consequence of the still large area under local cultivars: in 2024–25 nearly 85,000 ha of Aman, about 45% of the Aman area, remained under local varieties yielding 1.8 t/ha against 2.7 t/ha for HYVs. Yield gaps of a similar order, close to half of the potential yield, have been estimated for rice across Bangladesh (Timsina et al. 2018), so the scope for improvement seen in Patuakhali is not exceptional.

The stability results are directly relevant to climate resilience. Resilience implies not only a higher mean yield but also a smaller loss in unfavourable years. HYV Aman combined the higher mean with a CV of under 5%, whereas local Aman showed a sharp and prolonged decline after 2016–17. HYV yields were also not significantly associated with interannual variation in rainfall or temperature, even though annual rainfall varied by nearly 1,500 mm across the period. These patterns are consistent with the intended purpose of stress-tolerant and short-duration varieties (IRRI 2020), although salinity remains a binding constraint on HYV productivity in parts of the coast (Dasgupta et al. 2018). Evidence from comparable stress-prone environments supports this interpretation: submergence-tolerant rice lowered yield variability while raising expected yield in flood-prone eastern India (Dar et al. 2013), and farmers who adopted it in Bangladesh obtained higher yields, profits and household rice consumption than non-adopters (Bairagi et al. 2021). Among local varieties, the positive association between Aus yield and temperature is in line with national time-series results showing a positive effect of maximum temperature on Aus and Aman yields (Sarker et al. 2012). The stability patterns should nevertheless be interpreted cautiously, because HYV plots also tend to receive more fertiliser, better water management and more timely transplanting, so the stability advantage reflects the whole HYV management package rather than genetics alone. Stress-tolerant varieties have indeed been shown to crowd in fertiliser, more labour-intensive planting and other modern inputs (Emerick et al. 2016).

The adoption trends indicate a district in transition. The rise of HYVs in Aman from about one-fifth to more than half of the area, and the almost tenfold expansion of Boro after 2022–23, point to intensification of the rice system. Both changes mirror the national picture, in which Boro has gained and Aus has lost importance in total rice output while HYV adoption has risen (Al Mamun et al. 2021). Because Boro depends on dry-season irrigation, its expansion in a salinity-affected district implies improved access to fresh surface water or other irrigation sources, and the very high hybrid and HYV Boro yields recorded in 2024–25 (4.59 and 4.31 t/ha) show the potential gains where water is available. Geospatial analysis has likewise identified large areas of fallow and low-intensity rainfed land in south-western Bangladesh that could be intensified with surface-water irrigation, while noting that salinity limits groundwater use (Krupnik et al. 2017). Conversely, the steady decline in Aus area suggests that farmers are shifting away from the rain-

dependent early monsoon crop, a pattern consistent with reports of Aus being displaced by more profitable or less risky alternatives (BBS 2024b). Sustaining the Boro expansion will require attention to salinity monitoring, freshwater management and the cost of irrigation.

Several BRRI varieties are specifically targeted to coastal constraints, including salt-tolerant varieties (e.g., BRRI dhan47, BRRI dhan53, BRRI dhan54, BRRI dhan55, BRRI dhan61 and BINA dhan8 and dhan10), submergence-tolerant varieties (e.g., BRRI dhan51, BRRI dhan52 and BINA dhan11 and dhan12) and drought-tolerant varieties (e.g., BRRI dhan56 and BRRI dhan57) (BRRI 2024). Work combining farmers' perceptions with crop modelling on the south-western coast places the salinity tolerance threshold at about 8–10 dS/m for salt-tolerant varieties, against 4–5 dS/m for traditional ones (Islam *et al.* 2021), and salt-tolerant varieties such as Binadhan-8 and Binadhan-10 have been found profitable in coastal areas even though most growers do not yet apply the recommended inputs and agronomic practices (Haque *et al.* 2019). The district statistics used here do not distinguish individual varieties, so they cannot show which of these cultivars account for the HYV gains. Variety-level data from on-farm trials or Department of Agricultural Extension records would be needed to guide seed-system decisions more precisely.

The survey results show a gap between practice and understanding: most farmers knew about HYVs, but very few recognised climate change as a driver of the conditions they face. This suggests that adoption has been driven mainly by yield and duration advantages communicated through extension services and peer networks. Framing extension messages around familiar risks, such as salinity, early floods and late rains, may be a more effective route to promoting stress-tolerant varieties than abstract messages about climate change. Research on the south-western coast similarly shows that farmers hold detailed, experience-based knowledge of how salinity affects rice, which can be brought into variety targeting and policy (Islam *et al.* 2021).

Limitations

This study has several limitations. First, the BBS series is aggregated by rice type rather than by variety, and it cannot separate genetic effects from management differences between HYV and local plots. Second, the revision of BBS data-collection forms in 2017–18 may have introduced a structural break, particularly in the Aman local/HYV split. Third, ten years is a short period for trend detection and climate–yield correlation, and annual climate indicators do not capture within-season events such as cyclones, dry spells or salinity peaks. Fourth, the farmer survey was small ($n = 50$) and covered two age groups only. Future work should combine longer series with upazila-level or variety-level data, seasonal climate indices and salinity measurements.

Policy implications

The findings support four priorities for Patuakhali and similar coastal districts. First, expanding HYV and hybrid coverage on the roughly 85,000 ha still under local Aman

offers the largest single opportunity to raise district rice output, provided suitable stress-tolerant varieties are matched to land types. This is in line with the national strategy of closing yield gaps and shortening the adoption lag of new varieties (Kabir *et al.* 2015). Second, the recent Boro expansion should be supported with freshwater conservation, canal re-excavation and salinity monitoring so that it remains sustainable. Third, the seed system, including quality seed of salt- and submergence-tolerant varieties, needs to reach remote char and island areas. Fourth, extension programmes should link varietal recommendations to farmers' own experience of local hazards and include training on climate-smart practices such as adjusted planting dates and efficient irrigation.

CONCLUSION

Using a verifiable ten-year district series from official statistics, this study shows that HYV rice in Patuakhali District consistently yielded about twice as much as local rice in all three seasons (2.62–3.33 t/ha against 1.35–1.72 t/ha), with a statistically significant gap of 1.27–1.60 t/ha. HYV yields were also more stable, particularly in Aman (CV 4.8% vs 19.9%), and were not significantly affected by interannual rainfall and temperature variability. HYV yields increased significantly in Aman and Boro, HYV adoption in Aman more than doubled, and Boro cultivation expanded almost tenfold with hybrid yields of 4.59 t/ha, while Aus area declined. Farmers were familiar with HYVs but had limited awareness of climate change. As a general recommendation, low-yielding local cultivars should be progressively replaced with locally adapted, stress-tolerant HYVs and hybrids in all seasons, with priority given to the large area still under local Aman. This replacement needs to be backed by a reliable supply of quality seed, extension messages built around the hazards farmers already recognise, and sustainable dry-season irrigation. Together, these measures can substantially strengthen rice productivity, food security and climate resilience in Patuakhali and in other climate-vulnerable rice-growing areas of Bangladesh.

Acknowledgement

The authors thank the farmers of Patuakhali District who participated in the survey. An earlier version of this study was presented at the 8th International Conference on Civil Engineering for Sustainable Development (ICCESD 2026), KUET, Khulna, Bangladesh (Ghosh *et al.* 2026). The present manuscript is a substantially revised and extended version based on a new ten-year dataset and new analyses.

Data Availability

All rice and climate data used in this study are publicly available in the cited BBS Yearbooks of Agricultural Statistics. The compiled dataset, including issue and page references for every value, is provided as supplementary material.

Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

- Alam, M.S., Kalpoma, K., Karim, M.S., Al Sefat, A. and Kudoh, J. 2019. Boro rice yield estimation model using MODIS NDVI data for Bangladesh. In: Proc. IGARSS 2019 – 2019 IEEE International Geoscience and Remote Sensing Symposium, pp. 7330-7333. <https://doi.org/10.1109/IGARSS.2019.8899084>
- Al Mamun, M.A., Nihad, S.A.I., Sarkar, M.A.R., Aziz, M.A., Qayum, M.A., Ahmed, R., Rahman, N.M.F., Hossain, M.I. and Kabir, M.S. 2021. Growth and trend analysis of area, production and yield of rice: A scenario of rice security in Bangladesh. PLOS ONE, 16 (12): e0261128. <https://doi.org/10.1371/journal.pone.0261128>
- Bairagi, S., Bhandari, H., Das, S.K. and Mohanty, S. 2021. Flood-tolerant rice improves climate resilience, profitability, and household consumption in Bangladesh. Food Policy, 105: 102183. <https://doi.org/10.1016/j.foodpol.2021.102183>
- Bala, B.K. and Hossain, M.A. 2010. Modeling of food security and ecological footprint of coastal zone of Bangladesh. Environment, Development and Sustainability, 12 (4): 511-529. <https://doi.org/10.1007/s10668-009-9208-1>
- BBS. 2018. Yearbook of Agricultural Statistics-2017 (28th series). Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Dhaka.
- BBS. 2019. Yearbook of Agricultural Statistics-2018 (30th series). Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Dhaka.
- BBS. 2020. Yearbook of Agricultural Statistics-2019 (31st series). Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Dhaka.
- BBS. 2021. Yearbook of Agricultural Statistics-2020 (32nd series). Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Dhaka.
- BBS. 2022. Yearbook of Agricultural Statistics-2021 (33rd series). Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Dhaka.
- BBS. 2023a. Population and Housing Census 2022: National Report (Volume I). Bangladesh Bureau of Statistics, Dhaka.
- BBS. 2023b. Yearbook of Agricultural Statistics-2022 (34th series). Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Dhaka.
- BBS. 2024a. Statistical Yearbook Bangladesh 2023. Bangladesh Bureau of Statistics, Dhaka. Available at: http://nsds.bbs.gov.bd/storage/files/1/Stat_Yearbook-23.pdf
- BBS. 2024b. Yearbook of Agricultural Statistics-2023 (35th series). Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Dhaka.
- BBS. 2026. Yearbook of Agricultural Statistics-2025 (37th series). Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Dhaka.
- Binte Mostafiz, R., Noguchi, R. and Ahamed, T. 2021. Calorie-based seasonal multicrop land suitability analysis for regional food nutrition security in Bangladesh. Asia-Pacific Journal of Regional Science, 5 (3): 757-795. <https://doi.org/10.1007/s41685-021-00197-5>
- BRRI. 2024. Modern rice varieties. Bangladesh Rice Knowledge Bank, Bangladesh Rice Research Institute, Gazipur. Available at: <http://knowledgebank-brri.org>
- Dar, M.H., de Janvry, A., Emerick, K., Raitzer, D. and Sadoulet, E. 2013. Flood-tolerant rice reduces yield variability and raises expected yield, differentially benefitting socially disadvantaged groups. Scientific Reports, 3: 3315. <https://doi.org/10.1038/srep03315>
- Dasgupta, S., Hossain, M.M., Huq, M. and Wheeler, D. 2018. Climate change, salinization and high-yield rice production in coastal Bangladesh. Agricultural and Resource Economics Review, 47 (1): 66-89. <https://doi.org/10.1017/age.2017.14>
- Dubey, U.K.B. and Kothari, D.P. 2022. Research Methodology. Chapman and Hall/CRC. <https://doi.org/10.1201/9781315167138>
- Emerick, K., de Janvry, A., Sadoulet, E. and Dar, M.H. 2016. Technological innovations, downside risk, and the modernization of agriculture. American Economic Review, 106 (6): 1537-1561. <https://doi.org/10.1257/aer.20150474>
- Francis, T.R. and Kannenberg, L.W. 1978. Yield stability studies in short-season maize. I. A descriptive method for grouping genotypes. Canadian Journal of Plant Science, 58 (4): 1029-1034. <https://doi.org/10.4141/cjps78-157>
- Ghosh, R., Hazra, P., Shefa, M.S., Mehzaibin, N., Setu, S.H., Hasan, M.F. and Shamsuzzoha, M. 2026. Investigating the potential high-yield rice varieties for climate-resilient agriculture in Patuakhali District. In: Proc. 8th International Conference on Civil Engineering for Sustainable Development (ICCESD 2026), KUET, Khulna, Bangladesh (Paper ID ICCESD_2026_1184).
- GoB. 2025. Patuakhali District: Geographical introduction. Patuakhali District Portal, Government of the People's Republic of Bangladesh. Available at: <https://www.patuakhali.gov.bd>
- Haque, M.R., Sultana, R., Rahman, H., Islam, S. and Hasan, A.K. 2019. Impact of adopting salt tolerant rice varieties in the coastal areas of Bangladesh. Fundamental and Applied Agriculture, 4 (2): 823-828. <https://doi.org/10.5455/faa.19122>
- Hossain, M., Bose, M.L. and Mustafi, B.A.A. 2006. Adoption and productivity impact of modern rice varieties in Bangladesh. The Developing Economies, 44 (2): 149-166. <https://doi.org/10.1111/j.1746-1049.2006.00011.x>

- IPCC. 2023. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. <https://doi.org/10.1017/9781009325844>
- IRRI. 2020. Rice profile in Bangladesh. International Rice Research Institute. Available at: http://books.irri.org/Bangladesh_IRRI_brochure.pdf
- Islam, M.A., Shelia, V., Ludwig, F., Lobry de Bruyn, L., Rahman, M.H. and Hoogenboom, G. 2021. Bringing farmers' perceptions into science and policy: Understanding salinity tolerance of rice in southwestern Bangladesh under climate change. *Land Use Policy*, 101: 105159. <https://doi.org/10.1016/j.landusepol.2020.105159>
- Islam, M.S., Samreth, S., Islam, A.H.M.S. and Sato, M. 2022. Climate change, climatic extremes, and households' food consumption in Bangladesh: A longitudinal data analysis. *Environmental Challenges*, 7: 100495. <https://doi.org/10.1016/j.envc.2022.100495>
- Kabir, M.S., Salam, M.U., Chowdhury, A. et al. 2015. Rice vision for Bangladesh: 2050 and beyond. *Bangladesh Rice Journal*, 19 (2): 1-18. <https://doi.org/10.3329/brj.v19i2.28160>
- Kendall, M.G. 1975. Rank Correlation Methods, 4th edn. Charles Griffin, London.
- Khatun, F. and Saadat, S.Y. 2021. Climate change in Bangladesh: A sustainable development perspective. United Nations. Available at: https://www.un.org/ldc5/sites/www.un.org/ldc5/files/revised_climate_change_in_bangladesh_a_sustainable_development_perspective-22_september_2021.pdf
- Krupnik, T.J., Schulthess, U., Ahmed, Z.U. and McDonald, A.J. 2017. Sustainable crop intensification through surface water irrigation in Bangladesh? A geospatial assessment of landscape-scale production potential. *Land Use Policy*, 60: 206-222. <https://doi.org/10.1016/j.landusepol.2016.10.001>
- Mahmood, R. and Hayes, J.T. 1995. A model-based assessment of impacts of climate change on Boro rice yield in Bangladesh. *Physical Geography*, 16 (6): 463-486. <https://doi.org/10.1080/02723646.1995.10642566>
- Mann, H.B. 1945. Nonparametric tests against trend. *Econometrica*, 13 (3): 245-259. <https://doi.org/10.2307/1907187>
- Momtaz, S. and Shameem, M.I.M. 2016a. Livelihood adaptation to climate change. In: *Experiencing Climate Change in Bangladesh*. Elsevier, pp. 123-139. <https://doi.org/10.1016/b978-0-12-803404-0.00008-9>
- Momtaz, S. and Shameem, M.I.M. 2016b. The research setting. In: *Experiencing Climate Change in Bangladesh*. Elsevier, pp. 41-68. <https://doi.org/10.1016/b978-0-12-803404-0.00004-1>
- Myint Htun, A., Shamsuzzoha, M. and Ahamed, T. 2023. Rice yield prediction model using normalized vegetation and water indices from Sentinel-2A satellite imagery datasets. *Asia-Pacific Journal of Regional Science*, 7: 491-519. <https://doi.org/10.1007/s41685-023-00299-2>
- Runfola, D., Anderson, A., Baier, H. et al. 2020. geoBoundaries: A global database of political administrative boundaries. *PLOS ONE*, 15 (4): e0231866. <https://doi.org/10.1371/journal.pone.0231866>
- Salam, M.A., Islam, M.R., Rahman, M.S. et al. 2010. Rice varieties and cultural management practices for high and sustained productivity in the coastal wetlands of southern Bangladesh. In: *Tropical Deltas and Coastal Zones: Food Production, Communities and Environment at the Land and Water Interface*. CABI, pp. 183-198. <https://doi.org/10.1079/9781845936181.0183>
- Sarker, M.A.R., Alam, K. and Gow, J. 2012. Exploring the relationship between climate change and rice yield in Bangladesh: An analysis of time series data. *Agricultural Systems*, 112: 11-16. <https://doi.org/10.1016/j.agry.2012.06.004>
- Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, 63 (324): 1379-1389. <https://doi.org/10.1080/01621459.1968.10480934>
- Shamsuzzoha, M., Noguchi, R. and Ahamed, T. 2022. Rice yield loss area assessment from satellite-derived NDVI after extreme climatic events using a fuzzy approach. *Agricultural Information Research*, 31 (1): 32-46. <https://doi.org/10.3173/air.31.32>
- Timsina, J., Wolf, J., Guilpart, N. et al. 2018. Can Bangladesh produce enough cereals to meet future demand? *Agricultural Systems*, 163: 36-44. <https://doi.org/10.1016/j.agry.2016.11.003>
- Virtanen, P., Gommers, R., Oliphant, T.E. et al. 2020. SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nature Methods*, 17: 261-272. <https://doi.org/10.1038/s41592-019-0686-2>

